JOURNAL OF FOREST SCIENCE, *63*, 2017 (6): 263–274

doi: 10.17221/11/2017-JFS

Results of Czech ash provenance experiment

Václav BURIÁNEK, Petr NOVOTNÝ, Jaroslav DOSTÁL*

Department of Forest Tree Species Biology and Breeding, Forestry and Game Management Research Institute, Strnady, Czech Republic

**Corresponding author: burianek@vulhm.cz*

Abstract

Buriánek V., Novotný P., Dostál J. (2017): Results of Czech ash provenance experiment. J. For. Sci., 63: 263–274.

This study is focused on testing progenies of common and narrow-leaved ash based on the measurement of provenance trial plots established in various forest regions under different site conditions within the Czech Republic in the spring of 1999. Height and diameter growth of 35 provenances was measured and evaluated at the stand age of 10–14 years. The main goal of this research is to analyse and compare differences in growth between progenies originating from alluvial versus scree habitats as well as between the two evaluated ash species. Moreover, the influence of localities on growth was tested using standard provenances planted on all plots. The results of the last measurement were compared with those from the first survey in 2000 at the age of 4–5 years (1 year after planting). With the exception of DBH on the Koněprusy plot, statistically significant differences in height and diameter growth between provenances were verified. The results confirmed a very strong site influence on growth. The main conclusions indicate significant differences in growth parameters between provenances, faster growth of alluvial versus scree provenances on most lowland plots, and generally faster growth of narrow-leaved ash as compared to common ash.

Keywords: alluvial ecotype; common ash; height and diameter growth; narrow-leaved ash; progeny testing; scree ecotype

Two economically important ash species are naturally distributed in the territory of the Czech Republic: common ash (*Fraxinus excelsior* Linnaeus) and narrow-leaved ash (*Fraxinus angustifolia* Vahl). The current combined share of the two ash species constitutes only about 1.41% of the country's forestland area. The overall proportion of narrow-leaved ash is small, while this species was not separately distinguished until recently. Today, it is reported as covering 0.11% of forestland area (Ministry of Agriculture of the Czech Republic 2016). The largest area and the highest proportion of ash are situated especially in the natural forest regions (NFRs) of South Moravian Valley Basins (Židlochovice Forest District (FD), Strážnice FD), Upper Moravian Valley Basin (Prostějov FD), Elbe River Basin (Nymburk FD, Mělník FD), and Bohemian Central Uplands (Litoměřice FD).

The main European ash species, common ash, grows nearly throughout Europe, with the exception of the northernmost and southernmost parts of the continent (Pliūra, Heuertz 2003). It naturally occupies a wide range of site types, including dry calcareous sites (Dobrowolska et al. 2008). The core of its autochthonous distribution is located mainly in the floodplain forests of the first forest vegetation zone. Ash in mixture with oak species and admixture of other floodplain trees is an edificator in a series of hardwood floodplain forest types. It also rises to higher altitudes along streams, where it is an important component of maple-ash forests. In addition to the floodplain ecotype, it is also a typical tree species of scree and ravine forests, where it grows from the oak to beech-spruce forest vegetation zone in mountain regions. The maximum elevation of its occurrence

Supported by the Ministry of Agriculture of the Czech Republic, Resolution RO0117 (reference number 6779/2017-MZE-14151).

in the Czech Republic is situated in the Krkonoše ("Giant") Mountains at an altitude of 980 m a.s.l. (Koblížek 1997).

Narrow-leaved ash is found throughout southern and southeastern Europe and extends partly northwards up to Slovakia and southern Moravia (FRAXIGEN 2005). It was discovered in the Czech territory as late as in 1956, and its occurrence on the margin of the distribution area is regionally restricted to the Moravian valley basins, where it occurs in the floodplain forests of the Morava and Dyje basins (NFR 34 – Upper Morava Valley Basin and 35 – South Morava Valley Basins). The maximum elevation of occurrence in the Czech Republic (Koblížek 1997) is at just 220 m a.s.l. (Upper Morava Basin, Grygov near Olomouc). Reliable distinguishing traits are its brown buds, unlike the black ones of common ash.

The conservation and reproduction of ash genetic resources are currently provided (Forest Management Institute Brandýs nad Labem 2016) by 667 certified seed stands (2,581.41 ha) of common ash and 3 certified seed stands (196.55 ha) of narrow-leaved ash. Totally, 121 ortets, 4 parents of the family, and 30 seed trees of common ash are currently in the register. Moreover 7 genetic conservation units for common ash have been established.

Ash fructifies regularly and abundantly and regenerates easily and naturally. At many sites, massive ash expansion and spreading to new ecotopes have occurred in recent years (Buriánek 2001). Until recently ash did not suffer from diseases and pests, but since 2009 severe ash dieback caused by the invasion of the fungal disease *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz, Hosoya has occurred widespread (Havrdová et al. 2016), especially in wet site conditions. Thus, the health condition of ash stands in some countries has deteriorated significantly in recent years. The development of ash dieback symptoms has been also observed in the Lithuanian and German ash provenance trials (Pliūra et al. 2011; Metzler et al. 2012; Enderle et al. 2013).

Attention has been devoted to the ash intraspecific variability already in the past. Variability of ash in the Carpathian part of Moravia was studied in the 1980s by Prudič (1984). Phenotypic variability at 18 Czech localities was studied by Utinek (1987) and later by Radosta (1995). Matovič and Simančík (1968) described morphological and ecological characteristics, including wood properties, of both domestic species. An outline of measures for the conservation and reproduction of genetic resources and a conception of breeding programmes for some previously neglected deciduous trees, including ash, were suggested in the Czech Republic in the early 1990s (Šindelář 1991). These were later adopted by the Forests of the Czech Republic, State Enterprise (Kotrla et al. 2000; Svoboda et al. 2010).

The European Forest Genetic Resources Programme (EUFORGEN), coordinated by today's Bioversity International in Rome, has devoted attention to ash in the working groups Noble Hardwoods and Scattered Broadleaves. A long-term European strategy of the conservation of genetic resources for ash was developed in 1998 (Pliūra 1998), wherein the current state of genetic knowledge was assessed and the aims and conservation methods of genetic resources for ash were defined. Furthermore, within the framework of EUFORGEN activities, technical guidelines for the protection and utilization of ash genetic resources were published (Pliūra, Heuertz 2003). These guidelines were intended especially for practical forest managers and state administrative workers. Another valuable source of information about ash from abroad is the Polish monograph by Bugała (1995). The variability of American ash species *Fraxinus americana* Linnaeus and *Fraxinus pennsylvanica* Marshall has been studied, for example, by Wright (1944) and Clausen et al. (1981). More recently, in the framework of the international project (FRAXIGEN 2005) and the projects REGECON and CYTOFOR, studies of ash genetic structure, diversity, and gene flow have been carried out using modern methods (Heuertz et al. 2004a, b, 2006).

This paper is focused on provenance research of common and narrow-leaved ash based on the measurement and evaluation of provenance trial plots established in various forest regions under different site conditions within the Czech Republic during the spring of 1999. The main goal of the presented research is to analyse and compare the differences in growth parameters between progenies originating from alluvial and scree ecotypes and also between the two evaluated ash species at the age of 10–14 years. The influence of localities on growth was also tested using five standard provenances planted on all plots.

MATERIAL AND METHODS

The planting stock was grown from seeds collected in 1995 and 1996 and sown next spring after collection. Pre-sowing preparation was carried out in a two-phase stratification at a Seed Unit Plant in Týniště nad Orlicí according to established methodologies (Suzska et al. 1994). The warm (15–20°C) and subsequent cold (3°C) phases lasted 16 weeks each. 3-year-old (provenances No. 1–11) and 2-year-old (provenances No. 12–35) seedlings were planted in the spring of 1999. Differences between the seedlings were negligible, and therefore they were not taken into consideration.

The investigated ash provenance trial originally consisted of 11 plots (Table 1). The plots were located in 11 different NFRs from the first to the sixth forest vegetation zone. Priority was given to regions and locations where ash occurs and grows at least on a small scale or where seeds had been collected for the trial. The plot areas were about 0.5 ha each, and the number of tested provenances in each plot ranged from 10 to 24. Fifty plants of each tested provenance were planted in three replications on 10 × 10 m quadrates at a spacing of 2 × 1 m. The first mortality evaluation and measurement were conducted two vegetation seasons after planting, in the autumn of 2000 (Buriánek 2000). In the final years, five plots had to be excluded due to high tree mortality resulting mostly from game damage, fungal disease, or disruption of stabilization. Thus, the second evaluation was carried out only on the six remaining plots (Koněprusy, Veltruby, Kroměříž, Tvrdonice, Bůrová, and Deštná).

Locations of research plots and provenance origin are documented in Fig. 1, a list of provenance origin is given in Table 2.

Thirty-three provenances of common ash and two provenances of narrow-leaved ash of different origins (according to NFR, altitude, and habitat) collected from across the Czech Republic were used (Fig. 1, Table 2). Altitudes ranged from 160 to 870 m a.s.l. Most provenances (5) came from Elbe River Basin (NFR 17) and Šumava and Novohradské hory Mts. Foothills (NFR 12). The Central Bohemian Highlands (NFR 10), Central Moravian Carpathians (NFR 36), Šumava Mountains (NFR 13), and Lower Beskids Highlands (NFR 39) are each represented by more than one provenance. Both narrow-leaved ash provenances came from the South Moravian Valley Basins (NFR 35). It can be stated that all types of habitats where ash has a significant incidence were appropriately represented. Common ash provenances came from various habitats. Alluvial habitats are represented 11 times, alluvial-highland 5 times, scree 17 times, and limestone scree 2 times. Five provenances (15, 19, 24, 25, and 26) were planted as standards on all six evaluated plots.

Table 1. Characteristics of the provenance plots

No.	Locality	Forest district	District, locality	Stand No.	Forest region	Vegetation zone	Altitude (m a.s.l.)	Forest type	Habitat
179	Užín	Litvínov	Unčín	748 BOV	2b – Most Basin	1	180	1V	reclaimed spoil ground
180	Křepkovice	Teplá	Klášter	379 C10	3 – Karlovy Vary Highlands	6	710	6K1	scree
181	Koněprusy	Nižbor	Koněprusy	203 D12	8b – Bohemian Karst	2	350	2B	limestone scree
182	Bujanov	Kaplice	Rychnov	former nursery	12b – Novohradské Mts. Foothills	5	680	5O1	former nursery
183	Veltruby	Nymburk	Kolín	526 H12	17 – Elbe River Basin	1	190	1L	alluvial
184	Kroměříž	Bystřice pod Hostýnem	Zámeček	630 A8	34 – Upper Moravian Valley Basin	1	190	1L0	alluvial
185	Tvrdonice	Židlochovice	Tvrdonice	917 A9	35 – South Moravian Valley Basins	1	155	1L	alluvial
186	Bůrová	Strážnice	Javorník	510 A9	38a – White Carpathians	3	490	3B1	scree
187	Bělotín	Frenštát	Jindřichov	620 B50	29 – Low Jeseník Mountains	4	360	4F1	alluvial highland
188	Vysoká	Spálené Poříčí	Bohutín	823 B13	7 – Brdy Highlands	3	625	3K3	unambiguous
189	Deštná	Česká Lípa	Dubá	meadow	18a – Northern Bohemian Sandstone Plateau	1	250	–	alluvial highland

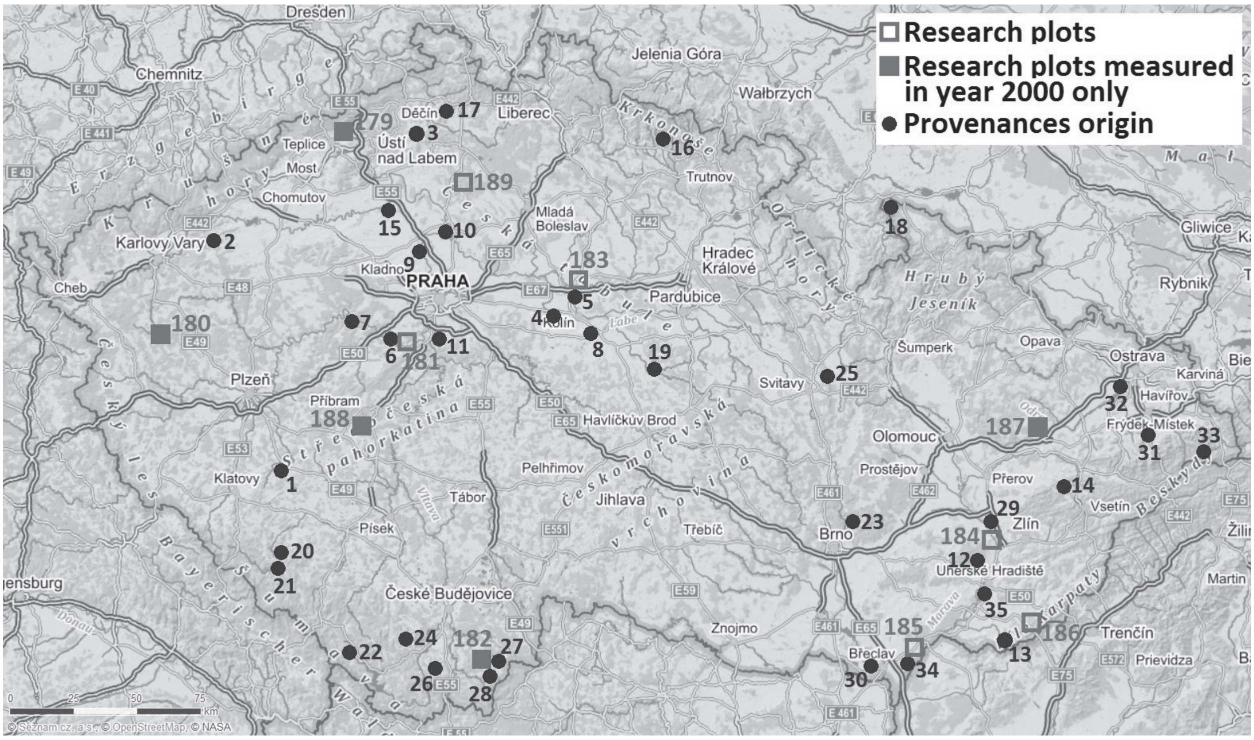

Fig. 1. Locations of research plots and provenance origin

The heights of trees were first measured on all plots in autumn 2000 at the age of 4–5 years (1 year after planting) (Buriánek 2000, 2009). The second measurement was carried out between autumn 2006 and autumn 2009 (Deštná plot in autumn 2006, at the age of 10–11 years; Bůrová and Tvrdonice in autumn 2007, 11–12 years; Veltruby in spring 2008, 11–12 years; Koněprusy and Kroměříž in autumn 2009, 13–14 years). In addition to height, DBH was also measured, except on the Deštná plot.

The acquired measurement data were statistically processed using common statistical methods (Meloun, Militký 2012). The basic data testing was performed in the QC.Expert software (Version 3.1), whereby non-normality in the data set was found. Significance of differences was assessed by means of Kruskal-Wallis one-way ANOVA in the NCSS program (Version 10.0.6, 2015), wherein the impact of provenance on measured parameters was tested. In case of statistically significant differences between provenances, a Kruskal-Wallis multiple comparison test (Dunn's test) was used, by means of which the evaluated provenances were sorted into homogeneous groups.

The differences between all provenances on each plot were statistically examined. First, the differences between groups of common ash provenances originated from all four habitats (alluvial, alluvial-highland, scree, and limestone scree) were compared. Next, for purposes of simplification, the differences were tested only between provenances originated from two basic habitats (alluvial and scree). The differences between the two planted ash species were also tested. Regarding the differences between plots (the site impact), testing was done only between those plots measured at the same time. So-called standards (i.e. provenances planted on all the plots) were then used. The results were compared with those from a previous survey in 2000 at the age of 4–5 years (Buriánek 2009).

RESULTS

Summary results of heights and DBH are given in Tables 3 and 4. Statistical processing confirmed significant differences in height and diameter growth between provenances. The provenance influence on DBH was not significant only on the Koněprusy plot. The comparison of standards showed the best growth in provenances 19 – Běstvina and 26 – Silniční domky, which were above average on all plots.

Plot No. 181, Koněprusy

The mean heights of provenances ranged from 1.88 to 2.59 m, and the overall mean was 2.14 m. The differences were statistically significant. The tallest mean height was recorded for the provenance from a scree habitat in the Šumava Moun-

Table 2. List of provenance origin

Provenance No.	Locality of origin	Stand No.	Altitude (m a.s.l.)	Natural forest region	Habitat
1	FD Spálené Poříčí – Polánka	551 A9	535	12 – Šumava and Novohradské Mts. Foothills	scree
2	MFF Velichov	32 H	620	4 – Doupovské Hills	scree
3	FD Děčín – Benešov nad Ploučnicí	632 C9	350	5 – Bohemian Central Mountains	scree
4	SFE Kostelec nad Černými lesy – Svojšice	55 F11	265	10 – Central Bohemian highlands	alluvial
5	FD Nymburk – Libice	2 H6	190	17 – Elbe River Basin	alluvial
6	FD Nižbor – Karlštejn	18 A4	320	8b – Bohemian Karst	limestone scree
7	FD Křivoklát – Pustá Seč	9 F3	340	8a – Křivoklát region	scree
8	FD Nymburk – revír Kolín, Kačina	125 D3	210	17 – Elbe River Basin	alluvial
9	MF Veltrusy	3 K	170	17 – Elbe River Basin	alluvial
10	Mělník (Lobkowiczké lesy) – Úpor	24 D	160	17 – Elbe River Basin	alluvial
11	FE Zbraslav – Dol. Břežany	23 B7	205	10 – Central Bohemian Highlands	alluvial-highland
12	FD Buchlovice – Jankovice	608 D9	340	36 – Central Moravian Carpathians	alluvial-highland
13	FD Strážnice – Javorník	564 C5	380	38 – White Carpathians and Vizovice Hills	alluvial-highland
14	FD Bystřice pod Hostýnem – Rajnochovice	107 C5	580	41 – Hostýn-Vsetín Upland and Javorníky Mountains	scree
15**	FD Litoměřice – Budyně nad Ohří	316 C7	180	17 – Elbe River Basin	alluvial
16	FE Horní Maršov – LS Rýchory FE Vrchlabí – LS Volský Důl	142 B13/5 346 F9	750 750	22 – Krkonoše ("Giant") Mountains	scree
17	FD Česká Lípa – Prysk	363 D2	500	18a – Northern Bohemian Sandstone Plateau	scree
18	FD Javorník – Bílá Voda	606, 602	450	28 – Hrubý Jeseník Mts. Foothills	scree
19**	FD Ronov nad Doubravou – Běstvina	547 A12	320	10 – Central Bohemian Highlands	scree
20	FD Kašperské Hory	551 A9	530	12 – Šumava and Novohradské Mts. Foothills	alluvial-highland
21	FD Kašperské Hory – Rejštejn	257 A12	800	13 – Šumava Mountains	scree
22	MFF Horní Planá – Jelení vrchy	43 C	870	13 – Šumava Mountains	scree
23	SFE Křtiny – Bílovice nad Svitavou	311 A11	500	30 – Drahanská vysočina Highlands	limestone scree
24**	FD Český Krumlov – Chvalšiny	439 H	720	12 – Šumava and Novohradské Mts. Foothills	scree
25**	FD Svitavy – Nová Ves	103 B11	560	31 – Bohemian-Moravian Foothills	scree
26**	FD Kaplice – Silniční domky	731 C, E	800	12 – Šumava and Novohradské Mts. Foothills	scree
27	FD Nové Hrady – Horní Stropnice	F3, 4	557	12 – Šumava and Novohradské Mts. Foothills	alluvial-highland
28	FD Nové Hrady – Hojná Voda	424 C	800	14 – Novohradské hory Mts.	scree
29	FD Bystřice pod Hostýnem – Kroměříž	640 D11/6	200	34 – Upper Moravian Valley Basin	alluvial
30	FE Židlochovice – LS Horní les	230 E	160	35 – South Moravian Valley Basin	alluvial
31	FD Frenštát pod Radhoštěm – Palkovské hůrky	541 E60	430	39 – Low Beskids Mts.	scree
32	FD Šenov – Polanecký les	319 D14	200	39 – Low Beskids Mts.	alluvial
33	FD Jablunkov – Mionší	405 B6	720	40 – Moravian-Silesian Beskids Mts.	scree
34*	FE Židlochovice – Tvrdonice	933 B11 929 A9	160	35 – South Moravian Valley Basins	alluvial
35*	FD Strážnice – Nedakonice	324 C10	175	35 – South Moravian Valley Basins	alluvial

*provenances of *Fraxinus angustifolia* Vahl, **standards, FD – Forest District, MFF – Military Forests and Farms, SFE – School Forest Enterprise, MF – Municipal Forests, FE – Forest Enterprise

Table 3. Summary results of heights (m) on particular plots

Provenance	181 – Koněprusy				183 – Veltruby				184 – Kroměříž				185 – Tvrdonice				186 – Bůrová				189 – Deštná			
	N	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ
2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	57	5.68	5.50	0.99	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	54	6.57	6.55	1.29	101	3.03	3.20	0.90
4	38	2.19	2.00	1.04	34	7.56	8.10	2.71	–	–	–	–	127	4.21	4.30	1.09	66	6.78	7.15	1.28	91	2.97	3.10	1.07
5	–	–	–	–	73	6.11	6.10	2.04	47	5.25	5.60	2.28	120	4.93	5.10	1.13	55	5.28	5.40	1.05	103	3.27	3.30	0.90
6	17	2.09	2.10	0.90	–	–	–	–	38	6.09	6.40	1.98	–	–	–	–	83	6.04	6.10	1.14	115	3.03	3.10	0.82
7	42	1.93	1.95	0.53	–	–	–	–	–	–	–	–	–	–	–	–	90	6.29	6.15	1.12	90	3.14	3.15	1.03
8	–	–	–	–	65	6.93	7.90	2.93	–	–	–	–	–	–	–	–	79	6.98	6.70	1.36	–	–	–	–
9	–	–	–	–	56	5.59	5.25	2.21	–	–	–	–	–	–	–	–	71	6.14	6.30	1.43	13	1.28	1.30	0.47
10	–	–	–	–	26	5.57	5.40	2.42	66	4.46	4.15	2.48	131	4.55	4.60	1.14	83	6.77	6.90	1.65	79	2.47	2.45	1.13
11	62	2.04	2.00	0.55	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	73	5.48	5.40	2.17	–	–	–	–	48	6.14	6.20	1.31	–	–	–	–
13	–	–	–	–	–	–	–	–	52	6.82	7.55	2.67	115	3.90	3.90	1.22	55	5.88	6.10	1.09	88	2.97	3.10	0.96
14	–	–	–	–	–	–	–	–	67	4.62	4.00	2.61	99	3.79	3.75	1.23	75	6.41	6.60	1.13	82	2.04	1.90	0.99
15	52	2.33	2.10	0.89	60	6.74	7.20	2.15	69	6.26	6.40	1.96	117	4.22	4.40	1.45	78	7.17	7.40	1.55	94	2.85	2.93	0.93
17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	89	2.76	2.80	0.86
19	27	1.96	1.80	0.55	35	6.54	6.80	2.24	40	5.34	5.40	1.76	129	4.44	4.50	1.19	68	6.35	6.15	1.52	120	3.19	3.25	0.88
22	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	58	5.60	5.65	1.25	–	–	–	–
23	43	2.17	2.00	0.76	–	–	–	–	90	4.63	4.30	1.55	–	–	–	–	68	6.03	6.05	1.03	–	–	–	–
24	31	2.29	2.30	0.66	72	7.18	7.55	2.20	39	6.49	6.50	1.54	110	4.23	4.25	1.51	60	5.62	5.60	1.28	64	2.57	2.60	0.79
25	59	1.88	1.80	0.49	59	6.17	6.40	2.05	90	5.81	5.85	1.75	130	4.58	4.70	1.32	93	7.05	7.30	1.96	99	2.32	2.35	0.81
26	41	2.59	2.20	1.21	53	7.50	8.40	2.61	75	5.57	5.60	1.44	109	4.22	4.30	1.13	53	6.41	6.30	1.46	104	3.04	3.18	0.80
29	–	–	–	–	–	–	–	–	75	6.03	6.20	1.56	–	–	–	–	92	6.59	6.80	1.32	70	2.83	3.00	0.94
30	–	–	–	–	–	–	–	–	–	–	–	–	129	4.27	4.40	1.30	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	53	5.51	5.50	1.82	131	3.90	4.00	1.19	46	5.80	5.95	1.16	104	2.92	3.15	0.92
32	–	–	–	–	97	6.46	6.30	2.13	34	5.06	4.80	1.89	136	4.07	3.95	1.31	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	79	5.05	4.70	2.03	105	2.50	2.30	0.86	42	5.30	5.15	1.57	76	2.82	2.80	1.05
34*	–	–	–	–	94	6.94	7.25	2.22	95	5.63	5.20	2.69	133	5.64	5.70	1.20	76	6.09	6.20	1.25	124	3.46	3.50	1.02
35*	–	–	–	–	–	–	–	–	79	7.69	7.60	2.26	138	6.06	6.15	1.12	101	7.12	7.20	1.34	–	–	–	–

**Fraxinus angustifolia* Vahl, *N* – number of trees, no data (–), σ – standard deviation

Table 4. Summary results of DBH (cm) on particular plots

Provenance	181 – Koněprusy				183 – Veltruby				184 – Kroměříž				185 – Tvrdonice				186 – Bůrová			
	N	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ	*N*	mean	median	σ
2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	57	5.11	5.00	1.46
3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	54	5.74	5.50	1.79
4	30	1.18	0.70	1.08	34	5.88	6.25	3.02	–	–	–	–	127	3.66	3.50	1.10	66	5.97	6.00	1.76
5	–	–	–	–	73	4.06	4.00	1.80	47	3.93	4.00	2.47	120	4.48	4.50	1.38	55	4.75	5.00	1.39
6	12	1.20	1.15	0.69	–	–	–	–	38	4.83	4.40	2.32	–	–	–	–	83	5.32	5.50	1.55
7	37	0.91	0.80	0.41	–	–	–	–	–	–	–	–	–	–	–	–	90	5.58	5.50	1.38
8	–	–	–	–	65	4.85	5.00	2.35	–	–	–	–	–	–	–	–	79	6.03	6.00	1.83
9	–	–	–	–	56	3.95	3.50	1.95	–	–	–	–	–	–	–	–	71	5.47	5.00	1.67
10	–	–	–	–	26	3.88	4.00	1.85	66	3.20	3.00	2.33	131	3.99	4.00	1.19	83	6.01	6.00	1.81
11	58	0.93	0.80	0.44	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	73	4.39	4.50	2.20	–	–	–	–	48	5.79	5.50	1.66
13	–	–	–	–	–	–	–	–	52	5.82	6.30	3.08	115	3.23	3.00	1.26	55	5.53	6.00	1.41
14	–	–	–	–	–	–	–	–	67	3.37	2.50	2.58	99	3.16	3.00	1.29	75	5.59	5.50	1.55
15	48	1.28	1.00	0.96	60	4.68	5.00	1.88	69	4.89	4.60	1.95	117	3.42	3.50	1.37	78	6.29	6.50	2.01
19	25	0.84	0.80	0.45	35	4.89	5.00	2.55	40	4.15	4.00	1.90	129	3.94	4.00	1.30	68	6.06	5.50	2.52
22	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	58	4.96	5.00	1.73
23	40	1.05	1.00	0.63	–	–	–	–	90	3.16	3.00	1.44	–	–	–	–	68	5.57	6.00	1.71
24	29	1.10	1.00	0.57	72	4.94	5.00	2.00	39	5.11	5.20	1.87	110	3.57	3.50	1.69	60	5.18	5.00	1.76
25	53	0.94	0.80	0.48	59	4.33	4.00	2.05	90	4.09	4.05	1.79	130	3.75	4.00	1.40	93	6.11	6.50	1.98
26	36	1.28	1.05	0.81	53	5.34	6.00	2.34	75	4.14	4.00	1.55	109	3.51	3.50	1.12	53	5.81	6.00	1.95
29	–	–	–	–	–	–	–	–	75	4.66	4.30	1.81	–	–	–	–	92	5.76	5.50	1.85
30	–	–	–	–	–	–	–	–	–	–	–	–	129	3.61	4.00	1.33	–	–	–	–
31	–	–	–	–	–	–	–	–	53	4.07	4.10	1.97	131	3.19	3.50	1.37	46	5.54	5.50	1.80
32	–	–	–	–	97	4.61	4.50	1.99	34	4.05	3.50	2.14	136	3.42	3.50	1.43	–	–	–	–
33	–	–	–	–	–	–	–	–	79	3.67	3.00	2.28	105	1.82	2.00	1.05	42	4.24	4.00	1.65
34*	–	–	–	–	94	5.55	5.50	2.48	95	4.26	3.50	3.30	133	4.82	5.00	1.66	76	6.12	6.00	2.12
35*	–	–	–	–	–	–	–	–	79	6.34	6.10	2.87	138	5.07	5.00	1.36	101	6.63	6.50	2.02

**Fraxinus angustifolia* Vahl, *N* – number of trees, no data (–), σ – standard deviation tains (26 – Silniční domky) at an altitude of 800 m a.s.l., where a height of the tallest tree (5.8 m) was measured. The slowest-growing provenances were 25 – Nová Ves, 7 – Pustá Seč, and 19 – Běstvina. The differences in DBH were not statistically significant, and these values ranged from 0.84 to 1.28 cm.

Plot No. 183, Veltruby

The mean heights of common ash provenances ranged from 5.57 to 7.56 m, and the overall mean was 6.58 m. Mean DBH values varied from 3.88 to 5.88 cm. Provenance of narrow-leaved ash (34 – Tvrdovnice) had a mean height of 6.94 m. The absolute maximum height (12.1 m) was measured in provenance 10 – Úpor. The highest values were recorded in provenance 4 – Svojšice and the lowest values in provenances 10 – Úpor, 9 – Veltrusy, and 5 – Libice.

Plot No. 184, Kroměříž

The mean heights of common ash provenances ranged from 4.46 to 6.82 m, and the overall mean was 5.48 m. Provenances of narrow-leaved ash were significantly higher on average, with a mean height of 6.57 m. The height of the tallest tree in common ash was found for provenance 33 – Mionší (11.2 m), in narrow-leaved ash for provenance 34 – Tvrdonice (13.5 m). Besides the greatly above-average narrow-leaved ash for provenance 35 – Nedakonice, the fastest DBH and height growth were recorded in provenances 13 – Javorník and 24 – Chvalšiny. Provenances 10 – Úpor, 14 – Rajnochovice, and 23 – Bílovice nad Svitavou showed the slowest growth. Mean DBH values ranged from 3.16 to 5.82 cm among common ash trees and from 4.26 to 6.34 cm among narrow-leaved ash trees.

Plot No. 185, Tvrdonice

The mean heights of common ash provenances ranged from 2.50 to 4.93 m, and the overall mean was 4.15 m. The mean height of narrow-leaved ash provenances was 5.85 m. Differences between the two species were highly significant. The absolute maximum heights (7.70 and 7.90 m, respectively) were measured in common ash for provenance 32 – Polanecký les and in narrow-leaved ash for provenance 35 – Nedakonice. In addition to the two narrow-leaved ash provenances, provenance 5 – Libice reported the fastest DBH and height growth. The slowest-growing provenance was 33 – Mionší. Mean DBH values among common ash trees ranged from 1.82 to 4.48 cm and among narrow-leaved ash trees from 4.82 to 5.07 cm.

Plot No. 186, Bůrová

The mean heights of common ash provenances ranged from 5.28 to 7.17 m, and the overall mean was 6.30 m. Provenances of narrow-leaved ash reached a mean height of 6.61 m. The absolute maximum heights (11.00 and 10.10 m, respectively) were measured in common ash for provenance 25 – Nová Ves and in narrow-leaved ash for provenance 35 – Nedakonice. The results significantly indicate the fastest height and DBH growth in narrow-leaved ash for provenance 35 – Nedakonice. The fastest growing among common ash provenances were 15 – Budyně, 25 – Nová Ves, and 8 – Kačina. Provenances 5 – Libice and 33 – Mionší were identified as the slowest growing. Mean DBH values ranged from 4.24 to 6.29 cm among common ashes and from 6.12 to 6.63 cm among narrow-leaved ashes.

Plot No. 189, Deštná

The mean heights of common ash provenances ranged from 1.28 to 3.27 m, and the overall mean was 2.84 m. Provenances of narrow-leaved ash reached a mean height of 3.46 m. In common ash, the absolute maximum height was measured in provenance 19 – Běstvina (5.10 m). In narrow-leaved ash, provenance 34 showed the height of the tallest tree (5.25 m). The fastest height growth among common ash trees was recorded in provenance 5 – Libice, while provenances 9 – Veltrusy, 14 – Rajnochovice, and 25 – Nová Ves showed the slowest growth.

Comparisons of growth differences between plots show that the highest growth was recorded on the Veltruby plot. The Bůrová plot exhibited the second-highest growth and the largest mean DBH. The lowest height and smallest DBH values for all provenances were recorded on the Koněprusy plot, although the measurement was carried out two vegetation seasons later than were those on the Veltruby, Tvrdonice, and Bůrová plots (Table 5).

Statistical testing was carried out only among plots measured at the same age. The growth of all five standard provenances on the Koněprusy

Table 5. Mean tree height and DBH of common and narrow-leaved ash on provenance plots at measurement at the age of 10–14 years

Plot	Time of measurement	Common ash			Narrow-leaved ash		
		no. of trees	height (m)	DBH (cm)	no. of trees	height (m)	DBH (cm)
Koněprusy	autumn 2009	412	2.14	1.06	–	–	–
Veltruby	spring 2008	724	6.59	4.65	94	6.94	5.55
Kroměříž	autumn 2009	1,161	5.48	5.21	174	6.57	4.14
Tvrdonice	autumn 2007	1,959	4.15	3.51	271	5.85	4.94
Bůrová	autumn 2007	1,651	6.30	5.62	177	6.67	6.41
Deštná	autumn 2006	1,706	2.84	–	124	3.46	–

plot was significantly slower as compared to the Kroměříž plot measured at the same age. The results were then compared among the Bůrová, Tvrdonice, and Veltruby plots while using five standard provenances. Height and DBH growth of all standard provenances was slowest on the Tvrdonice plot. The differences from the Bůrová and Veltruby plots were statistically significant in all cases. Only the difference in DBH from the Veltruby plot was not significant. Regarding the comparison of Veltruby and Bůrová plots, the heights of provenances 15, 19, 24, and 26 were taller on the Veltruby plot, but this difference was statistically significant only in provenance 24. Provenance 25 was significantly taller on the Bůrová plot. On the other hand, the DBH values of all provenances were greater on the Bůrová plot, but the differences were statistically significant only for provenances 15, 19, and 25.

Faster height and diameter growth of provenances originating from alluvial habitats as compared to provenances from scree habitats was recorded on all plots with one exception – the Veltruby plot (Fig. 2a). On four plots (Kroměříž, Tvrdonice, Bůrová, and Deštná), the statistically significantly faster growth of alluvial provenances was confirmed. On the Koněprusy plot, the differences were not significant (Table 6).

By comparing the heights and DBH of the two assessed ash species (Table 5), it was revealed that the narrow-leaved ash grows significantly much faster than does the common ash (Fig. 2b). Only on the Veltruby plot was not the faster growth of narrow-leaved ash statistically significant (Table 6).

Table 6. Results of the Kruskal-Wallis test of differences in heights and DBH between alluvial and scree provenances of common ash and between common and narrow-leaved ash on particular plots

Plot	Alluvial × scree		Common × narrow-leaved ash	
	height	DBH	height	DBH
181, Koněprusy	NS	NS	–	–
183, Veltruby	+	+	NS	+
184, Kroměříž	+	+	+	+
185, Tvrdonice	+	+	+	+
186, Bůrová	+	+	+	+
189, Deštná	+	–	+	–

NS – not significant, significant (+), no data (–)

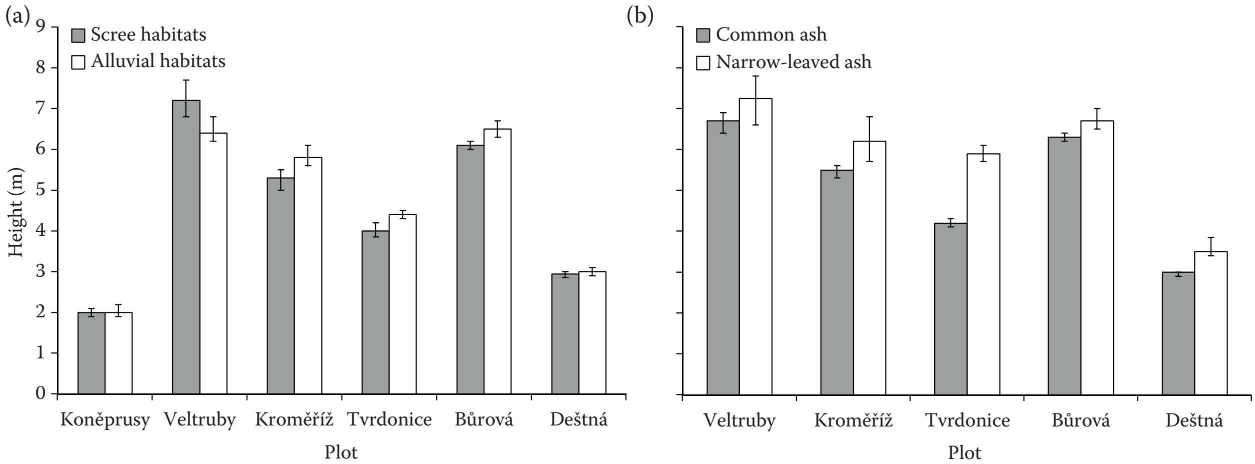

Fig. 2. Comparison of median heights in provenances originating from alluvial and scree habitats (a), common and narrow-leaved ash (b) on particular plots with confidence intervals

DISCUSSION

Mean mortality on plots upon the first assessment in 2000 in two vegetation seasons after planting was in the range of 6–28% (Buriánek 2000). Except for losses caused by game, the surviving plants prospered well until the invasion of *H. fraxineus*. Initially, the unknown symptoms of ash dieback were first observed in most provenance plots during 2007. The disease caused significant losses in the next years, especially on the Kroměříž, Tvrdonice, Deštná, and Veltruby plots.

Due to the low height values, the recorded differences between provenances during the first measurement in the second year after planting (2000) were mostly very small and statistically insignificant. The differences between plots resulting from site conditions, however, were significant (Buriánek 2000, 2009). When comparing the ranks of provenances on particular plots from the first measurement at 4–5 years of age versus the second measurement, considerable changes were registered. For example, provenance 5 – Libice on the Veltruby plot was ranked as the second-fastest growing in 2000 but it was among the slowest at 12 years of age. Provenance 19 – Běstvina was evaluated as slow-growing in the first measurement but was above average on all plots in the second measurement. Therefore, it was confirmed that the results at 4–5 years of age (2 years after planting) should be taken only as indicative and with low information value about the variability of the evaluated provenances and that it is not possible to formulate any preliminary conclusions from those results.

Regarding the provenance research, ash is the most frequently tested species among all noble hardwood species on a European level. Numerous provenance experiments have been established in many European countries. Differences between provenances have been investigated, for example, in Romania (Smintina 1993), Poland (Giertych 1995), Great Britain (Cundall et al. 2003), and Lithuania (Pliūra et al. 2011). The results of a German international experiment with ash conducted in the years 1986–1988 (Kleinschmit et al. 1996, 2002) are also available. The differences in growth between provenances at the age of 15 years were significant or even highly significant, but the influence of provenance explained only 4% of the total variability.

It is difficult to compare our trial consisting of Czech provenances with foreign trials due to different conditions and, especially, because of different provenances used. However, an indicative comparison of the acquired values for quantitative parameters with foreign data measured at similar age is possible (Kleinschmit et al. 2002). In this respect, it can be determined that in such a comparison the growth of Czech provenances is considerably below average relative to what would correspond to site conditions.

Slower growth was already recorded in the early years after planting at the first measurement in 2000. Apparently, this was due to the stress after planting and drought in the spring of 2000 (Buriánek 2000). In later years, the impact of natural competition from saplings which were not pruned on time was reflected in some cases.

The results confirmed a very strong influence of the site on growth. The highest values for height were recorded on the Veltruby plot located in a natural alluvial lowland habitat. The Bůrová plot exhibited the second highest growth and the largest mean DBH. The better diameter growth on the Bůrová plot was likely influenced favourably by its being a very rich fertile site with very good nutrient and water supply in the Carpathian region. On the other hand, the slowest growth, recorded on the Koněprusy plot, can easily be explained by the extremely dry xerothermic site conditions on the limestone bedrock in the Bohemian Karst. One of the reasons for the statistically insignificant differences in DBH on the Koněprusy plot could be the overall low values that were recorded.

One of the main goals of the present research was to test the differences between provenances originating from different habitat types (alluvial, alluvial-highland, scree, and limestone scree) in order to confirm or reject the hypothesis about ash growth being genetically conditioned by the habitat of origin.

Especially older references (Bovet 1958; von Schönborn 1967; Moulalis 1974) assume the existence of different ash ecotypes. Two main basic ecotypes are distinguished – alluvial or floodplain and scree. The alluvial ecotype can be divided into a lowland ecotype, widespread only in lowland floodplain forests, and a highland ecotype, which rises along small streams into higher forest vegetation zones up to the beech-spruce zone. In addition to the scree ecotype, a special limestone ecotype is also still considered, for which higher drought resistance is assumed. This ecotype occurs in the Bohemian and Moravian Karst areas and in some other smaller localities with the limestone bedrock. The distinction of the population according to different ecotypes is clearly manifested in the phenotype and is respected in forestry practice.

Some researchers, however, have questioned the existence of ecotypes. Leibundgut (1956), for example, found no statistically significant differences between ash trees originating from floodplain sites versus from limestone substrates. These results, however, stem from only a three-year experiment. The results of another German author are more conclusive. First on the basis of a container experiment and later also from results of evaluating a comparative plantation at ages of 10 and 33 years, he concluded that ash trees from dry ecotypes are not more resistant to drought and, likewise, populations from wetter ecotypes are not more resistant to flooding (Weiser 1965, 1974, 1995). Also, according to Pliūra and Heuertz (2003), the existence of different ecotypes has never been proved in the genotype by progeny studies.

Nevertheless, the recent results of our ash provenance trial confirm significant differences between provenances originating from alluvial and scree ecotypes. On four plots (three of them situated in an alluvial ecotype) the growth of alluvial provenances was better than that of scree provenances. It must be completed, however, that some scree provenances also showed above-average growth on some plots while floodplain provenances, on the contrary, were somewhere below average.

Statistical comparison of the two evaluated ash species indicates that narrow-leaved ash grows on average significantly better and faster than does common ash, and it does so not only in its typical site conditions such as lowland alluvial ecotype. Only on the Veltruby plot were the differences in height growth insignificant. Faster growth of narrow-leaved ash was recorded also on plots situated outside of its natural distribution area, like in the case of the Bůrová plot at an altitude over 600 m a.s.l. Moreover, recent trials in Czech provenances have shown the narrow-leaved ash to be significantly ($P < 0.01$) more resistant to the fungal disease caused by *H. fraxineus* (Havrdová et al. 2016). Nevertheless, the fact that there were found differences between the two tested narrow-leaved ash provenances should be taken into consideration. While provenance 35 – Nedakonice was the fastest growing practically on all plots, and for the most part very considerably so, the second narrow-leaved ash provenance (34 – Tvrdonice) was always poorer. On the Kroměříž and Bůrová plots it was rather average, especially in terms of the height. On the Veltruby plot the height growth of provenance 34 was only slightly above-average but provenance 35 was not represented there, which explains the statistically insignificant difference in heights of the two species on this plot.

CONCLUSIONS

The results confirmed a very strong site influence on the ash growth. The main conclusions indicate significant differences in growth parameters between provenances, faster growth of alluvial versus scree provenances on most lowland plots, and generally faster growth of narrow-leaved ash as compared to common ash. This applies not only to typical site conditions for narrow-leaved ash. Moreover, the provenances of the narrow-leaved ash have shown to be more resistant to the fungal disease caused by *H. fraxineus*.

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Received for publication January 18, 2017
Accepted after corrections April 25, 2017