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Root system development of European beech (*Fagus sylvatica* L.) after different site preparation in the air-polluted area of the Krušné hory Mts.

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Abstract: Mauer, O., Palátová, E. 2011: Root system development of European beech (*Fagus sylvatica* L.) after different site preparation in the air-polluted area of the Krušné hory Mts. – *Beskydy*, 4 (2): 147–160

The paper analyzes the development and health condition of root system in European beech aged 8–10 years, planted in the Krušné hory Mts. within the framework of reconstructions on plots prepared by various technologies before the establishment of substitute tree species stands. Root systems from natural regeneration in the Krušné hory Mts. and beech trees planted in the Bohemian-Moravian Upland served as controls. Only a third of trees from the natural regeneration developed a taproot. Planted between non-spread mounds, all beech trees developed a superficial root system. In other stands, a half of the trees had a root system with substitute taproots and a half of the trees had a superficial root system. No material differences were found in the development of the root system between beech trees in the Krušné hory Mts. and those in the Bohemian-Moravian Upland. Even in the Krušné hory Mts., the beech can be regenerated on screened localities sized up to 0.50 ha.

Keywords: European beech, root system, Ore Mts., reconstruction of substitute tree species stands, natural regeneration

Introduction and Objectives

European beech did not belong in the last century to tree species of high representation in the Krušné hory Mts. According to Kubelka (1992), its share in 1955 was only 8.8 %. In spite of the fact that some authors (Pashutová 1985; Kubelka 1992) considered the species relatively resistant to air pollution (which can be corroborated by individual older trees, which had survived air-pollution calamity and showed decreased fructification only), it could not be used for regeneration at the time of culminating air-pollution calamity. European beech represents a climax species unsuitable for the forestation of open areas and is severely damaged by browsing (game) and nipping (rodents). Regarding the specific climatic and air pollution conditions in the Krušné hory Mts., nearly all clear-cut areas induced by air pollution had been forested with substitute tree species stands that were capable of facing the high concentrations of air pollutants and the harsh climatic conditions. The situation changed in the 1990s. The emissions of harmful substances decreased (Lomský et al. 2007) and according to Mauer et al. (2005a), the current emission and climatic situation makes it possible to switch in the upper parts of the Krušné hory Mts. to the standard forest management of higher mountain elevations. However, the late 1990s had also witnessed a gradual worsening of the health condition of the substitute tree species stands (Mauer et al. 2005b; Balcar et al. 2008), which further urged a need of their reconstruction.

The choice of tree species for reconstruction in the forest altitudinal vegetation zone 7 is not wide. For the broadleaved species, the beech takes up the highest share and can be found in all stand and site situations occurring in the concerned area. It is used for planting under all substitute tree species stands as well as under currently surviving Norway spruce stands with no regard to site preparation method before the establishment of those stands – soil preparation by dozer, dredger, plough or soil surface scarification (spot treatment). The success of beech plantations may highly differ (Hobza, Mauer 2007; Pop et al. 2007; Kubík, Mauer 2007). Although the screening of plantations by adjacent stands against abiotic and wildlife impacts appears a dominant factor of success at the moment, no data are available on how the foundation of tree – root system – develops. This is of particular importance because the plantations are implemented on plots where humus horizons had been removed or overlay due to the use of different site preparation technologies and liming had changed soil chemical properties, which might modify the development of root systems and subsequently affect both nutrition and mechanical stability of the established stands of this species. Therefore, the goal of our work was to find out how the root systems of beech trees planted on sites that had been prepared for regeneration with substitute tree species by different methods – planting in spread mounds, planting in the intermediate strip between two non-spread mounds, planting onto the furrow bottom after ploughing, planting after scarification (spot treatment) before planting the species of substitute stands with at least partial levelling of soil surface prior to planting beech and planting into soils without any mechanical preparation.

Material and Methods

Basic methodological approach

Analyzed were root systems of beech trees with identical shoot length occurring in nine stand situations (in Tables of results Stands 1–9). With respect to the fact that the root systems did not differ too much visually, a summative assessment was made for all root systems in these nine stand situations, too (1–9 in the Table of results). Controls were two localities, viz. the "Kindhaidské bučiny" beech stands that had been regenerating naturally even at the time of the culminating air pollution disaster (Stand 10 in the Table of results), and beech trees from the non-polluted Bohemian-Moravian Upland, growing in similar site conditions (Stand 11 in the Table of results). Detailed characteristics of the analyzed stands and stand situation are presented in Tab. 1. Stands marked as LMCH-KH are owned by Lesy města Chomutov (Forests of the town of Chomutov), stands marked as LČR-KH are situated on lands operated by the Forest District LČR Litvínov, and the stand marked as ČMV is in the territory under management of Forest District LČR Nové Město na Moravě.

In addition, two identical stand situations were compared in the Krušné hory Mts. and in the Bohemian-Moravian Upland – screened clear-cut areas sized up to 0.50 ha – Stands 2 and 11.

All analyzed stands were situated on tablelands and soils did not contain skeleton. The analyses included co-dominant, vital, significantly not damaged by game, non-marginal trees. All root systems were lifted manually by using the archaeological method and there were 9–10 trees analyzed in each stand situation at all times.

Measured parameters and traits

– Biometrical parameters of aboveground part. Each analyzed tree was measured for the length of aboveground part (from the ground surface up to the tip of terminal shoot) and for the root collar diameter at 10 cm above the ground surface.
– Root system type. Root systems were assessed in each tree and classified as:
- root system with the taproot (clearly dominant taproot)
- root system with substitute taproots (one or more substitute taproots shooting from the stem base and growing in positive geotropic direction; taproot is missing)
- superficial root system (one or more horizontally growing horizontal roots shoot from the stem base, substitute taproots growing in positive geotropic direction or missing taproot).

– Horizontal skeletal roots are the roots growing horizontally with the ground surface whose diameter is over 3 mm. Their number and diameter at a distance of 10 cm from the stem was measured. Horizontal skeletal roots were considered also as roots shooting from taproots or substitute taproots growing in plagiotropic direction. Taproot diameter was measured at half of its length.
– Substitute taproots are roots shooting from the stem base and growing in positive geotropic direction, whose diameter is over 3 mm. Their number and diameter at 2 cm from their setting point was measured.

Tab. 1: Characteristics of analyzed forest stands

Stand designa-tion	Owner	Stand number	Stands property+	Air-pollution danger zone	Forest type	Age of beech (years)
1	LMCH	521A6/1b	Beech is planted under Norway spruce; the 65-year old Norway spruce is gradually being removed.	A	7K3	10
2	LMCH	521A6/1b	Beech planted on the screened clear-cut area under a 65-year old Norway spruce stand sized 0.42 ha.	A	7K3	10
3	LMCH	514A3a/1a	Beech planted under birch after scarification – 24-year old birch stand, crop density 0.7.	A	7K3	8
4	LMCH	514A3a/1a	Beech planted under blue spruce after scarification – 24-year old blue spruce, crop density 0.4.	A	7K3	8
5	LMCH	516C/3/2/1a	Beech planted under sycamore maple after scarification – 21-year old sycamore maple, crop density 0.7	A	7K3	10
6	LMCH	5353a/1a	Beech planted into a spread mound - width 18 m, length 100 m	B	7K3	8
7	LČR KH	16G02a	Beech planted under birch after site preparation by ploughing – 19-year old birch, crop density 0.3 (planting onto the furrow bottom).	A	7K3	8
8	LČR KH	12F03a	Beech planted under larch with no previous site preparation – crop density 0.4	B	7K3	8
9	LČR KH	12C03	Beech planted under blue spruce into the non-spread mound – 22-year old blue spruce,crop density 0.3	A	7K3	9
10	LČR KH	4F15/02/01	Natural regeneration "Kindhaidská bučina" beech	B	6K1	
11	LČR ČMV	463A11	Beech planted on a screened clearcut sized 0.54 ha in a 110-year old Norway spruce stand	C	6K3	8

Note: +Presented is the situation of underplanted stands at the time of measurement. Stock density had not been changed from the planting to the time of measurement except for Stand 1.

– Mean rooting depth was measured as a perpendicular distance from the ground surface down to the tip of horizontal skeletal roots, substitute taproots or taproot.
– Maximum angle between two mutually most distant horizontal skeletal roots characterizes regularity of the distribution of horizontal skeletal roots within the circular root pattern.
– Non-skeletal roots are the roots shooting from the stem base, the diameter of which is below 3 mm. Their number was measured.
– Index p (Ip) characterizes the relation between root system size and size of aboveground part of trees. It was calculated as a ratio of the cross-section areas of all horizontal skeletal roots, substitute roots and taproot (in mm^2) to the tree height (in cm). The higher is the Ip value, the larger is the tree's root system.
– Health condition. Each root was cut lengthwise to detect possible incidence of rots. The occurrence of honey fungus and other biotic agents was inspected visually.
– Biomass of fine roots (diameter < 2 mm) was established in selected stands. In each analyzed stand situation, thirty soil cores of 5 cm in diameter were lifted from a soil pit. These were divided into the following parts: all humus horizons (in the Table of results marked as Humus) and mineral soil from the lower face of humus horizons to a depth of 10 cm (in the Table of results marked as Mineral). Individual horizons were homogenized in the laboratory, washed in water and fine roots were manually picked, their weight in g/100 ml of loose homogenate was determined after drying out to constant mass.
– Vitality of the fine roots was established by using the method of 2,3,5 triphenyltetrazolium-chloride reduction (Joslin, Henderson 1984).
– Mycorrhizal infection of the fine roots was assessed by using the method of the quantitative establishment of glucosamine (basic construction element of chitin) (Vignon et al. 1986) following the acid hydrolysis of chitin (Plassard et al. 1982).
– The Tables of results present arithmetic means and their standard errors. Significance of results was tested by t-test at a significance level of $\alpha = 0.05$. Test results are marked as follows: + (significant difference), - (insignificant difference). The graphical sign in front of the arithmetic mean is to express a difference compared with the control stand 10 (natural regeneration "Kindhaidská bučina" beech stand) while the graphical sign behind the standard error is to express a difference compared with the control stand 11 (Bohemian-Moravian Upland).

Results

– **Root system type.** The occurrence of the root system with the taproot was found only in a third of trees lifted from the stand established by natural regeneration (stand 10). All other analyzed stands (including the control stand on ČMV – stand 11) exhibited only the occurrence of superficial root systems and root systems with substitute taproots with the incidence of root systems with the substitute taproots was only slightly higher than the incidence of superficial root systems. Exception was the stand 9 (planting into the intermediate strip between non-spread mounds) where only the superficial root system was recorded (tab. 2).
– **Number of horizontal skeletal roots in trees with the superficial root system.** As compared with the control stand 10 (natural regeneration), it can be stated that the analyzed trees developed an identical or even significantly higher number of horizontal skeletal roots. Compared with the control stand 11 (ČMV), no significant differences were found. Differences between the stands 2 and 11 were insignificant (tab. 2).
– **Number of horizontal skeletal roots in trees with the root system with substitute taproots.** No significant differences were found in the number of horizontal skeletal roots between the control stand 10 (natural regeneration) and other stands. The same conclusion holds for the comparison with the control stand 11 (ČMV). Differences between the planting on the clear-cut areas in the Krušné hory Mts. And ČMV (stands 2 and 11) were insignificant (tab. 2).
– **Average diameter of horizontal skeletal roots, horizontal skeletal root with the highest diameter.** As compared with the control stands 10 (natural regeneration) and 11 (ČMV), no significant differences were found either in trees with the superficial root system or in trees with the root system with substitute taproots (tab. 2). Neither were significant differences found between the stands 2 (planting on the clear-cut areas

in the Krušné hory Mts.) and 11 (ČMV – Bohemian-Moravian Upland). As to absolute values, the worst parameters were detected in the stand 7 (planting onto the furrow bottom after site preparation by ploughing).

- **Number of substitute taproots, diameter of substitute taproots and substitute taproot with the highest diameter.** No significant differences were found in these parameters between the analyzed stands and the control stands 10 (natural regeneration) and 11 (ČMV). Neither were any significant differences found between the stands 2 (planting on the clear-cut areas in the Krušné hory Mts.) and 11 (ČMV). Exception was the stand 7 (planting onto the furrow bottom after site preparation by ploughing), which showed not only a significantly lower average diameter but also a significantly lower diameter of the substitute taproot with the largest diameter (tab. 2).
- **Average rooting depth of horizontal skeletal roots.** As compared with the control stands 10 and 11, no significant differences were found in trees with the superficial root system and in trees with the root system with substitute taproots. Neither were significant differences found between the stands 2 and 11 (tab. 2).
- **Average rooting depth of substitute taproots and taproot.** Neither trees with the superficial root system nor trees with the root system with substitute taproots showed significant differences in rooting depth as compared with the control stands 10 (natural regeneration) and 11 (ČMV). Exception was the stand 7 (planting onto the furrow bottom after site preparation by ploughing), which exhibited generally the smallest rooting depth and showed significant differences as compared with the control stand 11. No significant differences were found between the stands 2 and 11. An interesting finding was that the greatest rooting depth (in absolute figure by up to 20 cm) reached taproots in root systems with the taproot (tab. 2).
- **Maximum angle between horizontal skeletal roots.** As compared with the control stands 10 and 11, no significant differences were found either in the trees with a superficial root system or in trees with a root system with the substitute taproots. Neither were any significant differences found between the stands 2 and 11. Worth noting was that irregular and nearly identical pattern (large angles) of horizontal skeletal roots was observed both in the trees with the superficial root system and trees with the root system of substitute taproots (tab. 2).
- **Number of non-skeletal roots.** As compared with the control stands 10 and 11, no significant differences were found in the trees with the superficial root system and the trees with the root system of substitute taproots. Neither were found any significant differences between the stands 2 and 11 (tab. 2).
- **Index Ip.** With an exception of stand 7, trees with the superficial root system did not show any significant differences in the Ip value of the whole root system as compared with the control stands 10 and 11 and no significant differences in this type of the root system were found between the stands 2 and 11. Trees with the superficial root system showed in most stands a significantly lower Ip value for the whole root system as compared with the control stand 10 while no significant differences were found as compared with the control stand 11 with the exception of stand 7. Differences between the stands 2 and 11 were not observed. With the exception of stand 7, no significant differences were found in the Ip values of horizontal skeletal roots as compared with the control stands 10 and 11 and between the stands 2 and 11 (tab. 2).
- **Root system damage.** Damage to roots or stem base by rots, honey fungus or other biotic agents was not found in any of the analyzed trees.
- **Analyses of fine roots and mycorrhiza.** Due to laboriousness, the analyses included only four stands (1, 2, 3 and 6) in stand situations most frequently occurring at regeneration by beech in the concerned region, and the control stands 10 and 11. The analyses revealed that no material differences in biomass and in the studied stratigraphy of fine roots were found between the analyzed and the control stands (as well as between the control stands themselves). Neither were found any essential differences in the mycorrhizal infection (tab. 3).
- Vitality of fine roots is higher in sheltered trees (underplanting, natural regeneration) as compared with the clear-cut area. No significant differences were found in the vitality of fine roots between the stands 2 and 11 (tab. 3).

Tab. 2: Results of root system analyses

Stand designation	Types of root systems	Number of analyzed trees (pcs)	Above-ground part length (cm)	Diameter of root colar (mm)	Horizontal skeletal roots			Substitute taproots		
					Number (pcs)	Average diameter (mm)	Diameter of the largest one (mm)	Number (pcs)	Average diameter (mm)	Diameter of the largest one (mm)
1	superficial	4	284±40	41.7±0.9	+8.7±1.7-	-9.8±3.1-	-14.3±2.8-	-	-	-
Under Norway spruce	with substitute taproots	6	272±27	37.5±0.2	-7.7±1.9-	-8.6±3.3-	-13.5±2.2-	-3.6±1.8-	-9.6±2.9-	12.0±2.5-
	with the taproot	-	-	-	-	-	-	-	-	-
2	superficial	4	316±52	41.8±7.1	+9.2±2.2-	-10.0±3.1-	-14.7±2.5-	-	-	-
Clear-cut area 0.42 ha	with substitute taproots	5	295±46	37.8±2.9	-7.8±3.0-	-8.6±2.9-	-13.6±3.0-	-2.2±1.3-	-13.1±5.4	-16.6±5.4-
	with the taproot	-	-	-	-	-	-	-	-	-
3	superficial	4	261±35	37.5±7.5	+9.2±0.5-	-9.2±3.6-	-14.7±2.9-	-	-	-
Under birch after scarification	with substitute taproots	5	231±25	39.4±3.1	-6.6±0.6	-8.9±3.2-	-14.2±1.3-	-3.0±0.7-	-9.9±2.8-	-12.4±3.3-
	with the taproot	-	-	-	-	-	-	-	-	-
4	superficial	3	287±38	35.7±5.5	-6.3±0.6-	-9.6±3.7-	-14.3±2.9-	-	-	-
Under blue spruce after scarification	with substitute taproots	6	257±25	40.5±4.5	-7.3±1.9-	-8.8±3.4-	-13.8±4.4-	-4.0±0.6-	-10.0±2.7-	-12.8±2.1-
	with the taproot	-	-	-	-	-	-	-	-	-
5	superficial	4	226±32	33.5±2.0	-6.5±2.1-	-8.6±3.2-	-13.5±3.0-	-	-	-
Under mountain ash	with substitute taproots	5	244±35	39.0±2.9	-5.6±1.1	-9.5±4.4-	-15.6±4.3-	-2.8±0.8-	-13.4±4.1-	-17.6±2.5-
	with the taproot	-	-	-	-	-	-	-	-	-
6	superficial	3	223±25	33.0±2.6	+10.3±1.5-	-7.6±1.8-	+11.3±1.2-	-	-	-
Into a spread mound	with substitute taproots	7	237±26	30.7±4.3	-5.1±2.1	-8.2±2.6-	+11.3±1.8+	-3.1±1.1-	-10.8±3.9-	-13.0±3.0-
	with the taproot	-	-	-	-	-	-	-	-	-

Stand designation	Types of root systems	Number of analyzed trees (pcs)	Above-ground part length (cm)	Diameter of root colar (mm)	Horizontal skeletal roots			Substitute taproots		
					Number (pcs)	Average diameter (mm)	Diameter of the largest one (mm)	Number (pcs)	Average diameter (mm)	Diameter of the largest one (mm)
7	superficial	5	183±33	25.6±2.7	-5.8±1.5-	+6.5±2.2+	+9.8±1.6+	-	-	-
Under birch after site preparation by ploughing	with substitute taproots	5	204±25	27.6±4.4	-5.0±2.6	+7.5±2.1-	+9.6±2.3+	-2.4±0.5-	+8.8±1.8+	-9.8±2.6-
	with the taproot	-	-	-	-	-	-	-	-	-
8	superficial	2	247±11	38.5±0.7	+10.5±3.5-	-8.0±2.4-	-12.5±2.1-	-	-	-
Under larch with no previous site preparation	with substitute taproots	8	264±26	35.8±4.2	-5.6±1.9-	-10.9±4.5-	-16.8±3.9-	-3.1±1.1-	-11.0±3.5-	-14.4±2.9-
	with the taproot	-	-	-	-	-	-	-	-	-
9	superficial	10	248±43	35.6±3.8	-8.8±2.6-	-8.2±3.1-	-13.5±3.5-	-	-	-
Under blue spru-ce into the non--spread mound	with substitute taproots	-	-	-	-	-	-	-	-	-
	with the taproot	-	-	-	-	-	-	-	-	-
10	superficial	3	241±32	35.0±2.0	6.0±1.0-	9.8±4.0-	16.3±3.7-	-	-	-
Natural regeneration	with substitute taproots	4	235±36	39.0±3.3	5.5±1.3	11.0±5.3-	17.7±6.9-	2.7±0.5-	12.6±5.3-	16.8±4.2-
	with the taproot	3	220±27	34.3±3.2	10.0±2.6	8.6±3.2	15.0±2.6	-	-	-
11	superficial	5	308±45	42.6±6.1	+9.5±2.1	-9.8±2.9	-15.4±2.1	-	-	-
ČMV -screened clear-cut 0.52 ha	with substitute taproots	5	301±47	38.2±1.9	-8.1±2.6	-9.2±2.2	-14.2±3.1	-2.8±1.7	-11.5±1.9	-14.6±2.4
	with the taproot	-	-	-	-	-	-	-	-	-
1-9	superficial	39	250±51	35.5±6.2	-8.3±2.4-	-8.6±3.1-	-14.8±3.7-	-	-	-
	with substitute taproots	47	250±35	35.9±5.7	-6.3±2.1-	-9.0±3.5-	-15.8±3.3	-3.1±1.1	10.7±3.6-	-17.2±4.4-
	with the taproot	-	-	-	-	-	-	-	-	-

Tab. 2: Results of root system analyses–cont.

Stand designation	Types of root systems	Average rooting depth (cm)			Max. angle between horiz. skeletal roots (degrees)	Number of non-skeletal roots (pcs)	Ip Whole root system	Ip Horizontal skeletal roots	Damage to trees (numbers) by:		
		Horizontal skeletal roots	Substitute taproots	Taproot					honey fungus	root rots	wildlife
1	superficial	-19.5±2.1-	-	-	-190±66-	-5.3±1.7-	-2.68±0.35-	-2.68±0.35-	-	-	-
Under Norway spruce	with substitute taproots	-20.0±2.3-	-59.6±9.2-	-	-131±52-	-7.3±2.1-	+3.05±0.86-	-1.99±0.57-	-	-	1
	with the taproot	-	-	-	-	-	-	-	-	-	-
2	superficial	-19.0±1.6-	-	-	-132±86-	-5.0±3.3-	-2.76±1.40-	-2.76±1.4-	-	-	1
Clear-cut area 0.42 ha	with substitute taproots	-17.4±2.9-	-56.8±4.7-	-	-140±37-	-4.8±2.3-	+3.10±0.89-	-1.87±0.59-	-	-	2
	with the taproot	-	-	-	-	-	-	-	-	-	-
3	superficial	-18.5±1.0-	-	-	-125±19	-5.2±2.2-	-2.94±1.30-	-2.94±1.30-	-	-	4
Under birch after scarification	with substitute taproots	-17.8±0.8-	-50.0±8.8-	-	-124±37-	-4.6±0.5-	+3.32±0.54-	-2.14±0.27-	-	-	4
	with the taproot	-	-	-	-	-	-	-	-	-	-
4	superficial	-19.0±3.0-	-	-	-143±37-	-5.0±1.0-	-1.95±0.72-	-1.95±0.72-	-	-	3
Under blue spruce after scarification	with substitute taproots	-18.2±3.3-	-63.7±8.2-	-	-180±61-	-4.3±2.1-	-3.52±0.86-	-2.01±0.58-	-	-	5
	with the taproot	-	-	-	-	-	-	-	-	-	-
5	superficial	-18.5±3.8-	-	-	-197±102-	-5.1±1.4-	-2.09±0.67-	-2.09±0.67-	-	-	4
Under moun-tain ash	with substitute taproots	-17.6±0.6-	-58.4±4.9-	-	+192±49-	-4.4±2.3-	-4.11±1.57-	-2.17±0.88-	-	- 5	
	with the taproot	-	-	-	-	-	-	-	-	-	-
6	superficial	-22.3±4.5-	-	-	-140±60-	-7.0±2.6-	-2.40±0.64-	-2.40±0.64-	-	-	2
Into a spread mound	with substitute taproots	-15.9±2.1-	-57.2±4.9-	-	-198±86-	-4.3±1.8-	+2.76±0.97-	-1.41±0.60-	-	-	3
	with the taproot	-	-	-	-	-	-	-	-	-	-

Stand designation	Types of root systems	Average rooting depth (cm)			Max. angle between horiz. skeletal roots (degrees)	Number of non-skeletal roots (pcs)	Ip Whole root system	Ip Horizontal skeletal roots	Damage to trees (numbers) by:		
		Horizontal skeletal roots	Substitute taproots	Taproot					honey fungus	root rots	wildlife
7	superficial	-19.0±0.7-	-	-	-154±31-	-5.6±2.1-	+1.36±0.17+	+1.36±0.17+	-	-	5
Under birch after site preparation by ploughing	with substitute taproots	-18.2±2.2-	-46.4±3.5+	-	-190±110-	-5.4±0.9-	+2.07±0.67+	+1.26±0.31+	-	-	5
	with the taproot	-	-	-	-	-	-	-	-	-	-
8	superficial	-19.0±0.6-	-	-	-145±27-	+4.5±0.7-	-2.48±0.09-	-2.48±0.09-	-	-	2
Under larch with no previous site preparation	with substitute taproots	-19.0±1.6-	-53.3±3.8-	-	-167±81-	-4.9±2.1-	-3.86±1.20-	-2.57±1.03-	-	-	7
	with the taproot	-	-	-	-	-	-	-	-	-	-
9	superficial	-20.5±2.9	-	-	-157±60-	-5.5±1.9	-2.44±0.64-	-2.44±0.64-	-	-	10
Under blue spruce into the non-spread mound	with substitute taproots	-	-	-	-	-	-	-	-	-	-
	with the taproot	-	-	-	-	-	-	-	-	-	-
10	superficial	20.0±1.7-	-	-	170±113-	5.8±2.3-	2.32±0.67-	2.32±0.67-	-	-	3
Natural regeneration	with substitute taproots	18.1±2.7-	51.7±6.7-	-	112±65-	6.3±3.3-	4.89±1.03+	3.00±1.03-	-	-	4
	with the taproot	18.3±3.5	-	71.1±7.8	130±61	6.7±2.5	5.06±1.00	3.22±0.76	-	-	3
11	superficial	-16.5±2.8	-	-	-138±52	-6.2±2.8	-2.84±1.21	-2.84±1.21	-	-	-
ČMV -screened clear-cut 0.52 ha	with substitute taproots	-16.9±2.1	-61.4±6.2	-	-152±41	-4.9±2.1	+3.26±0.92	-1.97±0.48	-	-	-
	with the taproot	-	-	-	-	-	-	-	-	-	-
1-9	superficial	-19.6±2.6-	-		-149±63-	-5.1±2.2-	-2.21±0.61-	-2.21±0.61-			31
	with substitute taproots	-18.2±2.4-	-54.4±8.3-		166±70-	-4.8±2.2-	-3.42±0.77-	-2.11±0.72-			32
	with the taproot	-	-	-	-	-	-	-	-	-	

Tab. 3: Biomass, vitality and mycorrhizal infection of fine roots

Stand designation	Biomass of fine roots (g.100 ml^{-1})			Mycorrhizal infection (µg.mg^{-1})	Vitality of fine roots+
	Humus	Mineral	Total		
1 Under Norway spruce	0.212±0.005	0.040±0.003	0.253±0.004	+10.46±0.33+	100
2 Clear-cut area 0.42 ha	0.214±0.008	0.028±0.003	0.242±0.006	+8.24±0.45-	103
3 Under birch after scarification	0.191±0.010	0.054±0.004	0.245±0.012	-15.13±0.62-	114
6 Into a spread mound	0.194±0.006	0.046±0.004	0.240±0.006	unidentified	unidentified
10 Natural regeneration	0.177±0.010	0.042±0.003	0.219±0.008	13.38±0.53+	90
11 Screened clear-cut ČMV	0.216±0.090	0.038±0.003	0.255±0.008	+7.16±0.18	92

Note: + Control 100 %, stand 1

Discussion

Beech seedlings develop as primary the taproot, which usually soon begins to branch or several heart-shaped roots would develop instead. Later main roots differentiate already in the first year and the primary root reaches an average depth of 32 cm (Hoffmann 1939 ex Köstler et al. 1968) while in the second and third year, the depth increment is only 8–14 cm. The taproot declines or dies with the increasing age although according some authors mentioned by Köstler et al. (1968), it may be preserved in some rare cases until the age of 50 years. During the continuous and uninterrupted growth, the beech would create usually a typical heart-shaped root system at 20–30 years of age, consisting of lateral roots set aslant, heart-shaped roots and anchors and their branches.

Taking into account that the subject of assessment included plantations and stand from natural regeneration aged 8–10 years, the occurrence of the typical heart-shaped root system could not be anticipated. This stage of growth would be corresponding, namely in the newly established stand, to the occurrence of the root system with the taproot. Such a root system was however detected only in a third of the analyzed trees. The situation is not extreme though. Similar results provide the analyses of oak root systems from natural regeneration or sowing, in which the taproot dominates at young age too. Köstler et al. (1968) for example observed in analyzing 13-year old oaks from sowing that only 25 of 38 evaluated trees developed the typical taproot, 8 trees exhibited the taproot foundation splitting from the beginning and 5 individuals had heart-shaped roots. Similarly, Jeník (1955) observed in analyzing ten 12-year old oak trees that only seven of them had a single distinct taproot. The author maintains that the development of a system of substitute vertical roots is a usual phenomenon even in natural regeneration. It is induced by damage to germs (mechanical, edaphon feeding), damage to the taproot or by contact of the growing taproot tip with a mechanical obstacle in the soil (soil skeleton, ortstein).

Trees from artificial regeneration should at this stage of growth show dominant root systems with substitute roots because the lifting of seedlings or the use of technologies with the mechanical treatment of the root system (transplanting, undercutting) results in damage or elimination of the growing taproot tip as well, which regenerates usually by developing usually more than one substitute taproot. The number and character of developed substitute roots depends on the time when the tip was removed (Riedacker, Poda 1977). According to Jeník (1955), the number of regenerated roots is also affected by the size of the cutting surface. Rather surprising was however to find out that nearly a half of the analyzed trees had created only the superficial root system.

Development of flat root systems in trees which would normally create anchoring or heart-shaped root system under favourable conditions is quite normal on water-affected sites in a majority of tree species including beech (Kreutzer 1961). However, the stands analyzed by us grew on acidic sites and thus the abovementioned cause to the development of superficial root system can be eliminated. Root system formation can be also modified by the availability of nutrients and by the presence of humus horizons. The highest (100%) occurrence of superficial root systems was recorded in the stand 9, which came to existence by planting between the non-spread mounds. In this case, the flat root systems may relate to the absence of the humus layer. Superficial root systems on such localities were developed also by species used in substitute tree species stands such as birch, European mountain ash and European larch (Mauer et al. 2004; Mauer et al. 2005b).

A certain share of superficial root systems in beech was observed not only in the Krušné hory Mts. (even in the stand 10 from natural regeneration) but also in the stand situated in the Bohemian-Moravian Upland (ČMV). This suggests that the reason of the formation of superficial root systems were apparently not chemical changes in the soil due to long-term acidic depositions in the Krušné hory Mts. but rather a factor or a combination of factors that might have occurred in all surveyed regions. Köstler et al. (1968) claim that beech does not show any distinctive tendency to anchor roots as deep in the soil as possible and moreover, it shows an extreme susceptibility to changes of soil conditions, namely to the presence of skeleton, impermeable layers, oxygen deficiency and responds also very strongly to soil compactness changes. Exactly the local soil compaction induced anthropogenically (e.g. during mechanical site preparation) or due to natural reasons could explain the mosaic occurrence of superficial root systems. The authors assume that already medium compaction of clay soils may result in the flattening of the beech root system. Comparative works demonstrated that under such conditions, beech develops an essentially shallower root system than pine, fir, larch, oak, alder and trembling aspen. Species with similar shallow root systems were only lime and sycamore maple. The last mentioned tree species are very sensitive also to oxygen deficiency (Polomski, Kuhn 1998) and this is why they would not penetrate into deeper soil layers. To find out which of the mentioned factors had induced the development of superficial root systems in some trees would require a follow-up research work.

The aim of our work was to find out whether and how different technologies of site preparation used before the establishment of substitute tree species stands reflect in the architecture of the root system of beech planted within the framework of reconstructions. No special plots had been established for the purpose; normal commercial stands were analyzed that represented a range of the used technologies and tree species used in substitute stands. Exact evaluation of losses was therefore not possible and was not our intention either. Yet we consider it is important to point out high losses in the stand 9, most likely induced by the absence of humus horizon (beech seedlings were planted into intermediate strip between non-spread mounds) and in the stand 7 in which the soil was prepared by ploughing prior to the planting of today 19-year old birch. The beeches were then planted onto the furrow bottom. The losses had been recorded until 3 years after planting, apparently due to water accumulation and oxygen deficiency. Souček and Bartoš (2007) recorded similar results planting beech under a pioneer birch stand into terrain depressions in the ridge part of the Krkonoše (Giant) Mts.

One of generally limiting factors for using beech in forestation is its high susceptibility to frost. This is why the species is used namely for planting under open stands of various tree species providing a sufficient ecological shelter (Balcar, Kacálek 2001; Kacálek, Balcar 2001). In addition to underplanting, we assessed also plantations on small-sized screened clear-cut areas and we can conclude that they exhibited the same frost damage as the underplanting.

The condition for a successful growth of planted and underplanted beech is consistent protection against wildlife. In spite of the fact that all plots had been fenced, the young plantations and stands exhibited severe damage by game – namely by hare. The reason was inappropriate quality of wire mesh used for the fencing. Another risk factor is rodents (mice), which may damage even grown-up plantations that have already survived the transplanting shock. During two years, three rodents in the stand had damaged 42% of trees of 1.5 m in height.

In spite of the fact that 9-10 trees were analyzed in all stand situations in order to assess the impact of different technologies of site mechanical preparation before planting the substitute tree species stands on the development of beech root system, the number of lifted trees was many a time much greater, sometimes even three times (with an exception of stand 10). The reason was that a great part of beech trees had the root system malformed into tangle, J or L due to incorrect planting, and some even exhibited combined deformations. Such trees could not be included into the analyses because the unnatural architecture of their root systems had not been induced by site or stand situations but rather by neglectful planting. Trees marked in the results as trees with the superficial root system did not show any root system malformation induced by planting. The high incidence of deformations is considered alarming. Although our experience (Mauer, Palátová 2004, 2009) as well as the experience of other authors (Nörr 2003, Nörr, Möβmer 2003) shows that deformations of root systems do not show any negative influence on the growth of aboveground part at early age (up to about 10 years in broadleaves), it is only a question of time when they manifest in the impaired vitality and mechanical stability of the trees.

Conclusions

The paper analyzes the development and health condition of the root system of European beech in nine basic stand situations occurring at the artificial regeneration of the species in the air polluted area of the Krušné hory Mts. (Ore Mts.). Controls were root systems of beech trees from natural regeneration in the Krušné hory Mts. and root systems of beech trees planted under similar site conditions on a clear-cut area in the non-polluted area of the Bohemian-Moravian Upland. Main conclusions from our study are as follows:

- No beech tree from artificial regeneration in the Krušné hory Mts. and in the Bohemian-Moravian Upland had developed a root system with the taproot. The root system with a taproot was developed by only a third of trees from natural regeneration.
- An exception being the planting into intermediate strip between two non-spread mounds where all trees had created a superficial root system, the beech trees in all other situations developed about a half of superficial root systems and a half of root system with substitute taproots. Nevertheless, in the given development phase, the root system type does not affect the length of aboveground part or the root collar diameter.
- The analyzed trees had developed a nearly identical root system within the respective root system types. Superficial root systems consisted of ca. 6-10 horizontal roots whose rooting depth was about 20 cm. Root systems with substitute taproots consisted of ca. 6–8 horizontal skeletal roots whose rooting depth was about 20 cm and featured 2–4 substitute taproots whose rooting depth reached to ca. 50-60 cm.
- No essential differences were detected in biomass, vitality and mycorrhizal infection between the stands in the respective stand situations and the control stands. None of the analyzed trees exhibited the incidence of root rots or the infestation of roots by other biotic agents.
- The superficial root systems are smaller and have a considerably smaller rooting depth than the root systems with substitute taproots. The root systems with taproots were largest in terms of size.
- We did not establish the reason for the development of superficial root systems and root systems with substitute taproots, which were detected at nearly identical proportions both in the air-polluted area of the Krušné hory Mts. and in the non-air-polluted area of the Bohemian-Moravian Upland.
- Taking into account that only a superficial root system develops upon beech having been planted into the intermediate strip between non-spread mounds and a very small root system develops upon beech having been planted onto the furrow bottom after site preparation by ploughing, the regeneration of beech on the mentioned sites preparation cannot be recommended.
- No material differences were detected in the development of the root system between the beech trees in the Krušné hory Mts. and in the Bohemian-Moravian Upland. Even in the Krušné hory Mts. the beech can be regenerated on screened localities sized up to 0.5 ha.

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