Root system development and health condition of sycamore maple (*Acer pseudoplatanus* L.) in the air-polluted region of Krušné hory Mts.

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ABSTRACT: The paper presents results from a study of sycamore maple development, health condition and growth in forest altitudinal vegetation zones (FAVZ) 6 and 7 occurring in pollution damage zones A and B in the air-polluted region of Krušné hory Mts. as compared with the trees of identical height in FAVZ 4 and 5 occurring in pollution damage zone D in the Bohemian-Moravian Upland. Sycamore maple develops a fully diversified root system. On spread mounds it creates only a superficial root system and its growth is retarded. The growth of sycamore maple is limited by the layer of humus horizons. If the layer thickness is over 20 cm, the sycamore roots would grow into mineral horizons.

Keywords: sycamore maple; root system; humus; afforestation; mounds

Sycamore maple is one of the noble broadleaved species. Its representation in the existing species composition of forest stands being rather low, the study of the species and mainly of its root system has been paid little attention so far. Available data which are however of rather general character can be found mostly in dendrological works. Svoboda (1955) described the sycamore maple rooting as sturdy. Good anchorage with large-diameter roots reaching to a depth in the boulder terrain was described also by Amann (1967), Kavka (1995) and Úradníček et al. (2001). Köstler et al. (1968) judged the sycamore maple root system as poorly organized, usually intensively branching and irregular. The authors' opinions about the root system type vary. The sycamore maple root system is described either as a flat and heart-shaped anchor with distinct horizontal roots (Köstler et al. 1968) or as a heart-shaped anchor (Biebelriether 1966; Polomski, Kuhn 1998), sometimes only as a heart-shaped formation (Úradníček et al. 2001).

Fine roots are important for the uptake of nutrients and water. However, there are hardly any data available in literature related to that part of the sycamore maple root system. Only Köstler et al. (1968) recorded different intensities of fine roots in sycamore maples growing on comparable sites. The authors claimed however that the rooting intensity of fine roots was high but mainly confined to the upper soil.

Fine roots of most forest tree species are modified by the presence of mycorrhizae. Members of the *Acer* genus typically exhibit the occurrence of endomycorrhiza or more precisely arbuscular endomycorrhiza (Levisohn et al. in Lyr et al. 1967; Kozlowski, Pallardy 1997; Polomski, Kuhn 1998). Endomycorrhiza is considered by Meyer (1991) to be a regular type of symbiosis and the same author admits also an incidence of ectomycorrhiza.

With respect to its specific site requirements the sycamore maple is normally grown at mid- and high altitudes on sites with a good supply of humus and nutrients. In the air-polluted region of Krušné hory Mts. the species is however planted out on acidic sites in forest altitudinal vegetation zones 6 and 7 in areas most threatened with air pollution – in damage zones A and B. In these localities, sycamore maple is planted out especially into longitudinally spread

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648902.

mounds and to a smaller extent the species is also used for underplanting the stands of substitute tree species or the existing Norway spruce stands.

There is neither any experience with sycamore maple on these sites nor the species occurred in this region in the past (i.e. before the air pollution disaster). The quality of current plantations varies with sycamore maple doing relatively well at some places and poorly at others. The hitherto research shows that the condition of the root system as a tree foundation in the broadest sense of the word is a useful parameter not only indicating the tree health condition and general vitality but also providing – unlike the response of the aboveground tree part – an early warning about the increasing incidence of negative stressors.

The objective of the present paper is to analyze the sycamore maple root system development, health condition and the species growth in the air-polluted region of Krušné hory Mts., and to contribute with these new findings to the decision whether sycamore maple is an appropriate tree species for the ecotopes in question.

METHODS

Principal methodological approaches

The project solution is based on the following three methodological approaches (solution of three partial tasks):

(1) To make a mutual comparison of the root system development and health condition between the trees of identical height from natural regeneration (self-seeding) in pollution damage zones A and B in the region of Krušné hory Mts. and those growing in pollution damage zone D in the region of the Bohemian-Moravian Upland. Goal: to establish possible deviations in root system development and health condition in the air-polluted region of Krušné hory Mts.

(2) To make a mutual comparison between the regions of Krušné hory Mts. and Bohemian-Moravian Upland as to the root system development and health condition of trees of the same height originating from artificial regeneration (planting) and natural regeneration (self-seeding). Goal: to establish possible deviations in root system development induced by the method of planting.

(3) To make a mutual comparison within the region of Krušné hory Mts. between the root system development and health condition in the trees of identical height growing on sites with different thickness of humus horizons. Goal: to establish the influence of humus horizon thickness on the root system development and growth of sycamore maple in the region of Krušné hory Mts.

A total of 14 forest stands were analyzed in the Krušné hory Mts. region (altitude 770–840 m above sea level, pollution damage zone A, B; all stands occurring in forest type 7K3). A total of 8 forest stands were analyzed in the Bohemian-Moravian Upland region (altitude 440–640 m a.s.l., pollution damage zone D, stands occurring in forest type 4S2 and 5S1). The respective stands are described for a better orientation by 4-digit codes in tables.

– The first digit in the code (letters) is to specify the studied region: KH – Krušné hory Mts., V – Bohemian-Moravian Upland.
– The second digit in the code (numerals) is to specify the shoot length of analyzed trees: 3 – 3 m, 7 – 7 m etc.
– The third digit in the code (letters) is to specify the method of stand establishment: S – planting, N – self-seeding.
– In the solution of tasks ad 1 and ad 2, the fourth digit in the code is to specify the observed root system deformations: Bez – no root system deformations, Def – serious root system malformations (tangle, missing taproot or substitute taproots).
– In the solution of task ad 3, the last (third) digit in the code is to specify the thickness of detected humus horizons in centimetres.

The analyses included forest stands aged 5 to 22 years and the analyzed trees were not injured by biotic agents. Older stands were not included in the analyses because they do not occur in the region of Krušné hory Mts. on the given sites.

In the region of Bohemian-Moravian Upland the analyses included forest stands whose trophic status nears as much as possible to the acidic sites.

Although the age of stands was respected in their selection, a decisive criterion for the solution of tasks ad 1 and ad 2 was the length of their aboveground part because its significance in the assessment of root system development and functionality is greater than that of age.

Forest stands included in the analyses were monocultures (pure plantation groups) with identical stocking that grew on the plain or on a mild slope (gradient up to 5%). Trees selected for partial analyses were only co-dominant non-marginal trees.

Analyses of root system architecture and health condition

All root systems were lifted by hand (archaeological method) and photographic documentation was made after their cleaning and measurement. The parameters measured and assessed in all trees were as follows: total length of the tree aboveground part; stem diameter at 10 cm above the soil surface (in trees with the aboveground part length up to 2 m) or at $d_{1.3}$ (in trees with the aboveground part length over 2 m); root system type – superficial, heart-shaped and fully diversified; number and diameter of horizontal roots; growing in the positive geotropic direction and aslant – roots considered to be aslant were those growing into mineral horizons and containing an angle with the soil surface of less than 45 degrees; rooting depth of horizontal roots and total rooting depth; length of horizontal skeleton roots; incidence of malformation. The measured values were used to calculate the index of surfaces (Index *p*, *Ip* in the tables of results). The index of surfaces is calculated as the ratio of the surface of cross sections of all horizontal skeleton roots growing in the positive geotropic direction and aslant at the gauging place (in mm^2) to the tree length (in cm). (The index of surfaces evaluates the relation between the root system development and the development of aboveground part. The higher the Index *p* value, the larger the root system.) Root rot incidence was determined on a longitudinal section of each root, bole rot incidence was determined on a cross-section of each stem.

Analyses of fine roots

The fine roots analyzed were those below 1 mm. Fine roots have a decisive role in the uptake of water and nutrients. The parameters measured and evaluated were as follows: biomass of fine roots; vitality of fine roots according to Joslin and Henderson (1984). Results obtained from the treatment of samples were subjected to a correlation analysis and the vitality was calculated in per cent. Mycorrhizal infection was determined according to Plassard et al. (1982) and Vignon et al. (1986) and by measuring the hyphal mantle thickness under microscope. The type of mycorrhiza was assessed anatomically and morphologically.

General methodological notes

– Rooting depth was monitored also in relation to the penetration into individual soil horizons.
– Roots and stems were subjected to special analyses to determine their possible infestation by parasitic fungi.
– Tree injury by biotic and abiotic agents was assessed visually.
– Tables of results contain arithmetic means of the respective parameters and their standard deviations.
– The root system analyses were done using methods of the Brno Rhizological School (detailed description see Mauer 1989).

RESULTS AND THEIR EVALUATION

The investigation included a total of 22 forest stands (forest stand groups) in which 175 trees were analyzed. Altogether 7 forest stand situations were studied (see the designation of forest stand situations in the tables of results):

(1) Mutual comparison of trees (height 1 m) from self-seeding with no root system deformations from the region of Krušné hory Mts. and from the region of Bohemian-Moravian Upland.
(2) Mutual comparison of trees (height 3 m) from planting with no root system deformations from the region of Krušné hory Mts. and from the region of Bohemian-Moravian Upland.
(3) Mutual comparison of trees (height 2–4 m) from self-seeding with no root system deformations from the region of Krušné hory Mts. and from the region of Bohemian-Moravian Upland.
(4) Mutual comparison of trees (height 6–8 m) from planting with no root system deformations from the region of Krušné hory Mts. and from the region of Bohemian-Moravian Upland.
(5) Mutual comparison of trees (height 7 and 8 m) from planting and from self-seeding with no root system deformations from the region of Krušné hory Mts. and from the region of Bohemian-Moravian Upland.
(6) Mutual comparison of trees of the same height from planting with severe and small root system deformations in the region of Krušné hory Mts. and in the region of Bohemian-Moravian Upland.
(7) Mutual comparison of trees of the same age from planting at different thicknesses of humus horizons in the region of Krušné hory Mts.

Except for stand situation 7 the thickness of humus and humus-enriched horizons was greater than 20 cm at all times.

Root system development and health condition in the trees from self-seeding with no root system deformations

No essential variances were found in the studied parameters as to the root system development, architecture and health condition in the trees of identical

Table 1. Biometric parameters of the shoot part, root system type, deformation, rooting depth, rots

Stand marking	Stand situation	Shoot height (cm)	$d_{1.3}$ (mm)	Root system type (% of trees)[2]				Taproot (% of trees)	Dominance	Rooting depth (cm)		Rots (% of trees)			Deformation into tangle (% of trees)
				P	K	S	VR			horizontal roots	total	roots	stem base	bole	
KH-1-N-Bez		108 ± 13	13.3 ± 1.2[1]	0	62	0	38	100	62	11.2 ± 1.1	33.7 ± 3.1	0	0	0	0
V-1-N-Bez	1	98 ± 7	11.1 ± 1.1[1]	0	25	0	75	100	25	8.7 ± 1.0	34.5 ± 7.2	0	0	0	0
KH-3-S-Bez		334 ± 29	28.3 ± 4.9	0	0	0	100	100	0	18.0 ± 1.1	65.3 ± 5.1	0	0	0	0
KH-4-S-Bez	2	364 ± 45	37.3 ± 7.3	0	0	0	100	100	0	16.5 ± 0.8	61.0 ± 4.2	0	0	0	0
V-3-S-Bez		301 ± 21	27.8 ± 4.8	0	0	0	100	100	0	19.1 ± 2.6	69.3 ± 7.7	0	0	0	0
KH-2-N-Bez		221 ± 6	9.0 ± 1.4	0	0	0	100	0	0	11.1 ± 4.2	29.5 ± 2.2	0	0	0	0
KH-3-N-Bez		307 ± 31	22.7 ± 4.5	0	0	0	100	100	0	19.5 ± 2.6	50.5 ± 5.6	0	0	0	0
V-4-N-Bez	3	402 ± 65	27.5 ± 4.3	0	33	0	67	33	33	19.6 ± 1.8	52.8 ± 5.4	0	0	0	0
1V-4-N-Bez		401 ± 26	24.2 ± 1.7	0	0	0	100	100	0	17.0 ± 1.6	49.5 ± 4.6	0	0	0	0
KH-7-S-Bez		737 ± 42	73.6 ± 6.3	0	0	0	100	75	0	25.5 ± 0.6	88.6 ± 6.6	0	0	0	25
V-8-S-Bez	4	749 ± 39	78.2 ± 5.3	0	0	0	100	33	0	22.5 ± 1.8	66.3 ± 8.2	0	0	0	0
V-6-S-Bez		567 ± 20	54.5 ± 3.5	0	0	0	100	0	0	23.5 ± 0.5	70.0 ± 4.0	0	0	0	0
KH-7-S-Bez		737 ± 42	73.6 ± 6.3	0	0	0	100	75	0	25.5 ± 0.6	88.6 ± 6.6	0	0	0	25
KH-7-N-Bez	5	721 ± 32	71.1 ± 5.8	0	0	0	100	67	0	26.4 ± 0.8	91.3 ± 7.4	0	0	0	0
KH-8-N-Bez		824 ± 73	66.0 ± 5.7	0	0	0	100	67	0	23.6 ± 1.2	73.3 ± 4.7	0	0	0	0
KH-3-S-Def		302 ± 26	23.6 ± 2.7	100	0	0	0	0	0	21.6 ± 1.9	21.6 ± 0.9	0	0	0	100
KH-3-S-MDef		326 ± 29	21.5 ± 0.7	0	0	0	100	33	0	20.5 ± 3.5	47.5 ± 0.8	0	0	0	0
KH-4-S-MDef		372 ± 36	32.5 ± 6.1	100	0	0	0	0	0	15.7 ± 2.6	15.7 ± 2.6	0	0	0	100
KH-4-S-Bez	6	364 ± 45	37.7 ± 7.3	0	0	0	100	100	0	16.5 ± 0.8	61.0 ± 4.2	0	0	0	0
V-3-S-Def		299 ± 14	17.1 ± 1.4	0	0	0	100	0	0	17.8 ± 0.4	44.8 ± 4.2	0	0	0	100
V-3-S-MDef		295 ± 12	17.0 ± 1.5	0	0	0	100	50	0	16.2 ± 1.2	45.2 ± 3.1	0	0	0	0
V-3-S-Bez		301 ± 21	27.8 ± 4.8	0	0	0	100	100	0	19.1 ± 2.6	69.3 ± 7.7	0	0	0	0
KH-S-5 cm		81 ± 7	9.9 ± 0.9[1]	100	0	0	0	0	0	5.2 ± 0.6	5.2 ± 0.6	0	0	0	0
KH-S-12 cm	7	205 ± 14	10.8 ± 1.1[1]	100	0	0	0	0	0	12.3 ± 1.2	12.3 ± 1.2	0	0	0	0
KH-S-22 cm		382 ± 37	39.8 ± 6.2	0	0	0	100	100	0	18.4 ± 1.2	58.9 ± 5.4	0	0	0	0

[1] Stem diameter 10 cm above the soil surface, [2] root system: P – superficial, K – taproot, S – heart-shaped, VR – fully developed

Table 2. Biometric parameters of the root system

Stand marking	Stand situation	Horizontal skeletal roots						Roots growing in positive geotropic direction				
		number	% proportion in the total number of roots	average diameter (mm)	average diameter of the largest diam. root (mm)	% proportion in the *Ip* value	length (cm)	number	% proportion in the total number of roots	average diameter (mm)	average diameter of the largest diam. root (mm)	% in the *Ip* value
KH-1-N-Bez		4.7 ± 2.3	55 ± 12	2.4 ± 0.6	3.3 ± 0.5	21 ± 12	not det.	0.7 ± 0.5	9 ± 2	6.0 ± 2.8	6.0 ± 2.8	28 ± 7
V-1-N-Bez	1	5.3 ± 1.4	58 ± 14	2.6 ± 0.7	4.1 ± 0.4	26 ± 13	not det.	0.9 ± 0.5		5.4 ± 2.1	5.1 ± 1.9	18 ± 8
KH-3-S-Bez		5.3 ± 1.5	48 ± 6	13.6 ± 5.7	20.6 ± 2.0	53 ± 10	372 ± 61	2.0 ± 0.3	18 ± 3	12.7 ± 3.9	13.3 ± 3.1	17 ± 5
KH-4-S-Bez	2	10.0 ± 4.2	59 ± 7	12.9 ± 4.8	21.5 ± 2.1	62 ± 6	211 ± 38	3.0 ± 1.2	17 ± 3	12.7 ± 7.6	21.5 ± 6.3	23 ± 5
V-3-S-Bez		5.7 ± 1.6	49 ± 7	12.5 ± 4.8	21.0 ± 3.4	51 ± 10	265 ± 29	2.2 ± 0.4	19 ± 4	11.9 ± 4.4	12.8 ± 3.0	22 ± 6
KH-2-N-Bez		5.0 ± 1.4	43 ± 4	4.9 ± 3.1	10.2 ± 4.2	49 ± 9	not det.	2.0 ± 1.3	17 ± 2	5.5 ± 3.7	8.0 ± 4.2	24 ± 5
KH-3-N-Bez		4.5 ± 1.9	55 ± 16	8.9 ± 4.1	14.0 ± 3.5	54 ± 19	221 ± 22	1.5 ± 0.5	18 ± 5	10.1 ± 2.9	11.0 ± 2.7	18 ± 8
V-4-N-Bez	3	4.0 ± 1.5	48 ± 9	8.3 ± 3.1	11.6 ± 3.4	37 ± 13	203 ± 34	1.0 ± 0.3	15 ± 3	15.5 ± 5.0	16.3 ± 5.1	34 ± 6
1V-4-N-Bez		6.5 ± 1.6	75 ± 11	7.5 ± 4.3	14.2 ± 4.9	85 ± 19	not det.	1.5 ± 0.5	18 ± 8	4.5 ± 1.8	5.5 ± 1.5	11 ± 3
KH-7-S-Bez		21.7 ± 6.5	75 ± 3	12.8 ± 5.7	23.2 ± 1.9	70 ± 7	380 ± 37	2.5 ± 1.0	9 ± 3	17.6 ± 4.0	21.2 ± 2.8	13 ± 3
V-8-S-Bez	4	15.8 ± 2.6	62 ± 5	14.1 ± 5.6	28.5 ± 5.7	65 ± 8	411 ± 26	2.0 ± 1.6	9 ± 3	17.5 ± 6.8	20.4 ± 7.9	13 ± 3
V-6-S-Bez		11.0 ± 1.1	61 ± 3	10.4 ± 5.2	22.0 ± 5.0	55 ± 7	not det.	1.5 ± 0.6	9 ± 3	8.0 ± 2.9	9.5 ± 2.5	19 ± 7
KH-7-S-Bez		21.7 ± 6.5	75 ± 3	12.8 ± 5.7	23.2 ± 1.9	70 ± 7	380 ± 37	2.5 ± 1.0	9 ± 3	17.6 ± 4.0	21.2 ± 2.8	13 ± 3
KH-7-N-Bez	5	5.2 ± 1.7	52 ± 5	15.8 ± 3.4	19.6 ± 1.7	54 ± 6	359 ± 46	2.3 ± 1.0	20 ± 4	17.5 ± 0.8	17.7 ± 2.1	24 ± 5
KH-8-N-Bez		15.3 ± 6.2	67 ± 9	10.3 ± 5.7	29.6 ± 11.1	73 ± 9	not det.	1.7 ± 0.5	9 ± 4	13.6 ± 7.2	14.6 ± 5.6	10 ± 4
KH-3-S-Def		17.4 ± 2.1	100 ± 0	6.0 ± 2.3	10.6 ± 2.1	100 ± 0	177 ± 18	0	0	0	0	0
KH-3-S-MDef		12.0 ± 1.4	61 ± 4	6.5 ± 1.4	8.7 ± 0.6	69 ± 8	165 ± 21	2.5 ± 0.7	13 ± 3	5.2 ± 2.1	5.7 ± 2.1	9 ± 3
KH-4-S-MDef		11.5 ± 3.8	100 ± 0	10.6 ± 4.0	20.0 ± 3.2	100 ± 0	not det.	0	0	0	0	0
KH-4-S-Bez	6	10.0 ± 4.2	59 ± 7	12.9 ± 4.8	21.5 ± 2.1	62 ± 6	not det.	3.0 ± 1.2	17 ± 3	12.7 ± 7.6	21.5 ± 6.3	23 ± 5
V-3-S-Def		10.4 ± 2.2	78 ± 6	5.6 ± 2.0	8.6 ± 1.1	91 ± 9	213 ± 17	1.2 ± 0.4	9 ± 3	4.8 ± 1.8	5.1 ± 1.7	3 ± 2
V-3-S-MDef		10.8 ± 2.3	61 ± 4	6.4 ± 1.8	7.9 ± 1.3	62 ± 11	221 ± 37	2.1 ± 0.3	12 ± 3	5.4 ± 1.9	6.3 ± 1.4	8 ± 3
V-3-S-Bez		5.7 ± 1.6	49 ± 7	12.5 ± 4.8	21.0 ± 3.4	51 ± 10	265 ± 29	2.2 ± 0.4	19 ± 4	11.9 ± 4.4	12.8 ± 3.0	22 ± 6
KH-S-5 cm		3.8 ± 1.3	100 ± 0	2.7 ± 0.8	3.9 ± 0.5	100 ± 0	67 ± 19	0	0	0	0	0
KH-S-12 cm	7	13.5 ± 2.2	100 ± 0	6.8 ± 1.4	9.4 ± 0.7	100 ± 0	156 ± 21	0	0	0	0	0
KH-S-22 cm		9.8 ± 3.8	59 ± 4	12.6 ± 3.9	19.5 ± 1.9	61 ± 7	205 ± 33	3.2 ± 1.4	19 ± 3	12.9 ± 5.5	19.3 ± 5.7	22 ± 5

height from self-seeding between the Krušné hory Mts. and the Bohemian-Moravian Upland (see stand situations 1 and 3) (Tables 1, 2, 3).

Root system development and health condition in the trees from planting with no root system deformations

No essential variances were found in the studied parameters as to the root system development, architecture and health condition in the trees of identical height from planting between the Krušné hory Mts. and the Bohemian-Moravian Upland (see stand situations 2 and 4) (Tables 1, 2, 3).

Root system development and health condition in the trees of identical height from planting and from self-seeding with no root system deformations

Except for the Index *p* value which is significantly lower in the trees from self-seeding occurring in the region of Krušné hory Mts. at all times, no essential differences in the root system development and health condition were found either between the trees of identical height from self-seeding and from planting in the region of Krušné hory Mts. and in the region of Bohemian-Moravian Upland or in a mutual comparison between the two regions (see stand situation 5, mutual comparison of stand situation 2 and 3, mutual comparison of stand situation 4 and 5) (Tables 1, 2, 3).

Biomass, vitality and mycorrhizal infection of fine roots

Fine root biomass was not determined exactly. Although some samples were available for the analyses (see Material and Methods), their statistical evaluation documented that the methodological procedures could not be used for exact biomass establishment. The problem consists in the fact that the majority of fine roots of sycamore maple grow from roots occurring in the close proximity of the stem base and a much smaller portion of them grows from horizontal skeleton roots. In both cases the rooting of fine roots is very irregular – fine roots emerge in clumps. Based on a complementary survey (all fine roots were separated after the lifting of the entire root system and their volume was determined xylometrically) it is however possible to claim that no differences in the volume of fine roots were found between the mutually compared forest stands (Table 4).

Endo- and ectomycorrhiza were detected in all analyzed forest stands. Although the endomycorrhiza generally dominates, the ectomycorrhiza was found in some forest stand parts (or on a root system branch). Therefore, all analyses of vitality and mycorrhizal infection had to be made with regard to the type of mycorrhiza found.

It follows from the investigations which were made in two different dates and are therefore valuated separately that no essential differences were found in vitality and mycorrhizal infection between the forest stands in the regions of Krušné hory Mts. and Bohemian-Moravian Upland. Essential variances in the two regions under study were observed in the studied forest stands between ecto- and endomycorrhiza. Fine roots with endomycorrhiza exhibited lower vitality and lower mycorrhizal infection.

Impact of deformations on the root system development

Deformations due to the inappropriate planting biotechnics are a serious problem in the root system development. Root system deformations (and subsequent unnatural root system architecture) were observed to occur both in the region of Krušné hory Mts. and in the region of Bohemian-Moravian Upland (see stand situation 6).

Although the most serious malformation into a tangle does not inhibit the growth of the aboveground tree part so far, it provokes the development of a superficial root system whose rooting depth reaches only to the humus horizons. The Index *p* value of a deformed root system (designated in tables as Def) is very low. Root systems with smaller deformations (designated in tables as Def M) create a fully diversified root system whose Index *p* values are low, though. Root systems with no deformations (designated in tables as Bez) are always fully diversified and much stronger (Tables 1, 2, 3).

Impact of humus horizon thickness on the root system development

The thickness of humus horizons markedly affects not only the growth of the aboveground part but also the root system development (stand situation 6).

The lesser the thickness of humus horizons, the greater the retardation of shoot-part growth. At humus horizon thickness of 5 and 12 cm the tree develops a feeble superficial root system which can reach only to the depths of humus horizons; the magnitude of Index *p* values is proportional to the thickness of humus horizons. Only if the thickness

Table 3. Biometric parameters of the root system – continued

Stand marking	Stand situation	Slant roots					Roots in total		
		number	% proportion in the total number of roots	average diameter (mm)	average diameter of the largest diam. root (mm)	% proportion in the *Ip* value	number	average diameter (mm)	*Ip* value
KH-1-N-Bez		2.7 ± 1.5	36 ± 8	4.8 ± 1.9	8.1 ± 2.0	51 ± 14	8.1 ± 2.6	3.5 ± 1.3	1.03 ± 0.15
V-1-N-Bez	1	3.1 ± 1.7	33 ± 7	4.4 ± 1.7	7.8 ± 2.1	56 ± 12	9.3 ± 1.8	3.4 ± 1.5	0.83 ± 0.21
KH-3-S-Bez		3.7 ± 0.6	34 ± 5	12.6 ± 3.2	16.3 ± 0.6	30 ± 6	11.0 ± 1.7	13.1 ± 4.6	4.83 ± 0.61
KH-4-S-Bez	2	3.5 ± 0.4	24 ± 4	10.3 ± 3.1	12.2 ± 2.6	15 ± 3	16.5 ± 4.9	12.2 ± 5.5	5.25 ± 0.91
V-3-S-Bez		3.7 ± 0.5	32 ± 5	12.1 ± 3.1	18.4 ± 0.9	27 ± 7	11.6 ± 1.4	12.9 ± 4.4	4.93 ± 0.72
KH-2-N-Bez		4.5 ± 0.7	40 ± 5	4.2 ± 1.3	5.5 ± 2.1	27 ± 6	11.5 ± 2.1	4.7 ± 2.6	1.20 ± 0.09
KH-3-N-Bez		2.0 ± 1.4	27 ± 3	9.5 ± 5.3	10.3 ± 5.0	28 ± 4	8.0 ± 2.1	9.3 ± 4.6	2.12 ± 0.79
V-4-N-Bez	3	3.1 ± 1.6	37 ± 6	9.2 ± 4.3	10.8 ± 5.1	29 ± 7	8.1 ± 2.1	9.6 ± 4.5	1.82 ± 0.45
1V-4-N-Bez		0.5 ± 0.8	7 ± 12	5.0 ± 1.0	6.0 ± 0.0	4 ± 10	8.5 ± 1.1	6.8 ± 4.1	1.06 ± 0.49
KH-7-S-Bez		4.3 ± 1.7	16 ± 3	13.9 ± 4.3	19.0 ± 6.2	17 ± 3	28.5 ± 9.4	13.4 ± 5.4	6.32 ± 1.01
V-8-S-Bez	4	8.2 ± 2.7	29 ± 4	12.0 ± 4.3	18.6 ± 5.8	22 ± 3	26.0 ± 5.1	13.8 ± 5.7	6.06 ± 1.11
V-6-S-Bez		5.5 ± 0.4	30 ± 2	13.6 ± 8.6	23.5 ± 7.5	26 ± 7	18.0 ± 1.1	10.9 ± 5.8	4.52 ± 1.05
KH-7-S-Bez		4.3 ± 1.7	16 ± 3	13.9 ± 4.3	19.0 ± 6.2	17 ± 3	28.5 ± 9.4	13.4 ± 5.4	6.32 ± 1.01
KH-7-N-Bez	5	3.3 ± 0.7	29 ± 5	13.0 ± 2.6	15.5 ± 3.0	22 ± 4	10.8 ± 2.6	15.3 ± 3.2	2.82 ± 0.63
KH-8-N-Bez		4.7 ± 1.1	24 ± 5	10.0 ± 2.5	13.1 ± 1.7	17 ± 4	21.7 ± 7.7	10.4 ± 5.1	3.00 ± 0.53
KH-3-S-Def		0	0	0	0	0	17.4 ± 2.1	6.0 ± 2.1	1.67 ± 0.58
KH-3-S-MDef		5.3 ± 0.6	26 ± 5	5.7 ± 1.8	7.5 ± 2.1	22 ± 5	19.8 ± 0.8	6.1 ± 1.7	1.96 ± 0.47
KH-4-S-MDef		0	0	0	0	0	11.5 ± 3.8	10.6 ± 4.0	3.25 ± 0.58
KH-4-S-Bez	6	3.5 ± 0.4	24 ± 4	10.3 ± 3.1	12.2 ± 2.6	15 ± 3	16.5 ± 4.9	12.2 ± 5.5	5.25 ± 0.91
V-3-S-Def		1.6 ± 0.7	13 ± 5	3.7 ± 1.5	4.6 ± 1.4	6 ± 4	13.4 ± 2.4	5.0 ± 2.1	0.94 ± 0.22
V-3-S-MDef		4.8 ± 0.6	27 ± 4	4.3 ± 1.4	4.9 ± 1.4	30 ± 6	17.8 ± 2.6	6.3 ± 1.7	1.90 ± 0.39
V-3-S-Bez		3.7 ± 0.5	32 ± 5	12.1 ± 3.1	18.4 ± 0.9	27 ± 7	11.6 ± 1.4	12.9 ± 4.4	4.93 ± 0.72
KH-S-5 cm		0	0	0	0	0	3.8 ± 1.3	2.7 ± 0.8	0.28 ± 0.10
KH-S-12 cm	7	0	0	0	0	0	13.5 ± 2.2	6.8 ± 1.4	2.43 ± 0.58
KH-S-22 cm		3.6 ± 0.5	22 ± 3	9.8 ± 3.3	13.2 ± 2.4	17 ± 4	16.6 ± 3.5	12.3 ± 4.7	5.15 ± 0.57

Table 4. Vitality and mycorrhizal infection of fine roots

Stand marking	Month of sampling	Mycorrhiza type	Vitality of fine roots		Mycorrhizal infection	
			measured value	% of vitality	µg glucosamine per 1 mg DM	% myc. infection
KH-3-S-MDef	June 05	ecto	0.82	98	9.02	111
KH-3-S-Bez	June 05	ecto	0.51	61	6.22	77
KH-7-S-Bez	June 05	ecto	0.83	100	8.34	103
KH-8-S-Bez	June 05	endo	0.44	53	6.81	84
V-4-N-Bez	June 05	ecto	0.83	100	9.11	112
V-8-S-Bez	June 05	ecto	0.83	100 – control	8.07	100 – control
KH-4-S-Bez	August 06	endo	0.63	93	6.75	121
V-3-S-Bez	August 06	endo	0.68	100 – control	5.54	100 – control

of humus horizons is greater than 20 cm, the tree can create the natural root system architecture and no growth retardation of its aboveground part will occur (Tables 1, 2, 3).

DISCUSSION

In both regions the sycamore maple from both self-seeding and planting creates an identical, nearly uniform fully diversified root system with dominant horizontal roots which form more than 50% of branches in the root system and whose proportion in the Index *p* value is higher than 50%. The proportion of positively geotropic and aslant growing roots in the root system development is approximately the same. Roots growing in the positive geotropic direction and aslant growing roots shoot from the stem base or in its close proximity.

The root system of sycamore maple is built of a large number of small-diameter root branches (horizontal, positively geotropic and aslant) whose diameter is only very slowly decreasing towards the tip.

Published papers often claim that the sycamore maple develops taproot system or root system with a dominant position of taproot (Pfeil 1860 in Köstler et al. 1968; Mössmer, Ammer 1994). Our study revealed that such a situation occurred only at the earliest stages of self-seeding development. During the further development, a fully diversified root system is developed by trees with intact root systems originating both from self-seeding and from planting. Even at the earliest developmental stage of trees from self-seeding with a dominant taproot system, the taproot grows hardly ever in the positive geotropic direction; it distinctly undulates, deflecting from the positively geotropic growth direction and beginning to branch from the tip. In the further development the taproot will lose its dominant position, its diameter often becoming smaller than that of other positively geotropically growing roots.

Nor can we corroborate the statements of the authors according to whom the sycamore maple mainly roots into a depth during the initial stages and the development of other root branches starts only after the end of deep rooting (Hoffmann 1959 in Köstler et al. 1968). Our research showed that both the rooting depth and the development of horizontal and aslant roots were limited by tree age (length of the aboveground part). The older (taller) the tree, the greater its root system depth and length. Small (young) trees reach with their horizontal roots only into the upper humus horizons and the whole profile of humus horizons is being occupied by them only from an aboveground part length of about 6 m.

The sycamore maple forms a relatively regular circular pattern of its horizontal roots and the length of its horizontal roots reaches sometimes even twice farther than the crown projection. The horizontal roots ending in sheaf branching and knee-shaped roots provide a high measure of mechanical tree stability.

Hardly any of the roots (horizontal, positively geotropic and aslant) grow in straight direction but they markedly undulate instead. The undulation is caused not only by mechanical obstacles the sycamore maple has to pass by but also by the generally different chemical composition of soils – roots will always penetrate to places with the best soil conditions (in the Krušné hory Mts. region always to places with a higher content of organic matter).

Essential differences were found in the development of the root system from self-seeding and from planting out transplants without any root system deformation. Although the developing root system type is the same in the two cases – similarly like the rooting depth and the length of horizontal roots – a difference is recorded in the Index *p* value. Trees from self-seeding have fewer and smaller-diameter roots at all times, which makes the resulting Index *p* value lower by as much as a half as compared with the same parameter of trees from planting (which indicates that the root system of trees from self-seeding is weaker at the same height of the aboveground part than the root system of trees from planting). It results from the fact that transplants have more abundant roots than naturally developing seedlings already from the nursery and the root system is mechanically treated during their planting out, which will induce the development of additional roots.

As in most other tree species, there is a serious problem in sycamore maple with root system deformations due to the inappropriate planting biotechnics. Namely deformations to a tangle but also single-side taproot deformations (absence of positively geotropic roots) provoke essential changes in the root system architecture. A deformed root system is only superficial with roots growing irregularly (not covering a circular pattern) only in humus horizons, which may adversely affect not only the mechanical stability of the tree but also the tree nutrition and even the general vitality of the tree in the case of a strong impact of stressors on the soil surface. Even small root system deformations exert an inhibiting influence on the stem growth, markedly reducing the rooting depth.

The sycamore maple forms both ectomycorrhiza and endomycorrhiza with endomycorrhiza occurring much more frequently. It happens relatively often, however, that the root system of the same tree is colonized by both ecto- and endomycorrhizal fungi. As to the vitality and mycorrhizal infection of fine roots there were no essential differences in these parameters between the Krušné hory Mts. and the Bohemian-Moravian Upland.

It was a significantly positive fact that neither any rots on the root system nor its infestation by aggressive parasitic fungi were observed.

CONCLUSIONS

The objective of this study was to assess the development, health condition and growth of sycamore maple in forest altitudinal vegetation zones 6 and 7 in pollution damage zones A and B in the air-polluted region of Krušné hory Mts. Trees of sycamore maple of the same height growing in forest altitudinal vegetation zones 4 and 5 on more fertile sites in pollution damage zone D of the Bohemian-Moravian Upland served as a control. The basic investigation was done in 22 forest stands (forest stand groups) in which 175 trees at an age of 5–22 years were lifted by hand. Main conclusions derived from the surveys are as follows:

– Provided that the sycamore maple was cultivated in the region of Krušné hory Mts. on sites with the thickness of humus horizons over 20 cm, it developed a root system absolutely identical with that created by the sycamore maple on more fertile sites outside the air-polluted region of Krušné hory Mts. This applies both to artificial planting and to natural regeneration.
– In the regions of Krušné hory Mts. and Bohemian-Moravian Upland the sycamore maple developed a fully diversified root system with a prevailing proportion of horizontal roots, with the functional ectomycorrhiza and endomycorrhiza, with identical biomass, vitality and mycorrhizal infection of fine roots, with no rots occurring on the root system and on the aboveground part of the tree.
– Root system deformations provoked by the inappropriate biotechnics of planting cause the same negative deviations as planting on the site with the low humus horizon thickness (only a superficial and feeble root system).

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Received for publication March 14, 2007
Accepted after corrections June 4, 2007

Vývin a zdravotní stav kořenového systému javoru klenu (*Acer pseudoplatanus* L.) v imisní oblasti Krušných hor

ABSTRAKT: Práce obsahuje výsledky sledování vývinu, zdravotního stavu a odrůstání javoru klenu v 6. a 7. lvs v pásmech ohrožení A a B v imisní oblasti Krušných hor ve srovnání se stejně vysokými stromy ve 4. a 5. lvs v pásmu ohrožení D na Českomoravské vysočině. Klen vytváří všestranně rozvinutý kořenový systém. Na rozhrnutých valech vytváří pouze povrchový kořenový systém a jeho růst je retardován. Pro odrůstání klenu je limitující vrstva humusových horizontů. Je-li vyšší než 20 cm, kořeny klenu prorůstají i do minerálních horizontů.

Klíčová slova: javor klen; kořenový systém; humus; zalesňování; valy

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