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Root system emergence and health condition in Norway spruce (*Picea abies* (L.) Karst.) affected by yellowing of assimilatory apparatus in the region of the Krušné hory Mts

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Abstract

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The paper analyses the decline of Norway spruce stands over a region operated by the Forest Administration in Horní Blatná (Krušné hory Mts) and its causes. Root system analyses made in 238 trees (age 10–117 years, Forest Altitudinal Vegetation Zones 6 and 7, modal podzol) showed that all trees affected by yellowing of their assimilatory apparatus had a smaller root system, worse root pattern distribution, root systems malformed into a tangle, smaller rooting depth and lower biomass and vitality of fine roots. Until an age of about 10 years, trees at good health condition are those, which have created a large superficial root system. From an age of about 20 years, healthy trees are those, which have created a large anchoring root system with anchors reaching into the Bs horizon. Impaired vitality induced in affected trees invasion of the honey fungus causing the infestation of individual root system branches (namely anchors), and reducing the size and hence the functionality of the root system.

Keywords

rots, decline, root system, Norway spruce, yellowing of assimilatory apparatus

Introduction

Depositions of sulphur and nitrogen compounds in the last several decades of the 20th century that caused the large-scale decline of spruce stands in Central Europe induced changes to soil environment, which affect the vitality and growth of forest tree species for a long time. Many authors observed that soil environment acidification results in changes root distribution within the soil profile. Extremely flat root systems in the Norway spruce were described by Murach (1984, 1991), Raspe et al. (1989), Raspe (1992), Manderscheid and Matzner (1996) and by others. Studying root plates after a storm gale in 1991, Eichhorn and Grabowski (1991) found numerous dying or dead anchor roots protruding from the vital root system and bearing no fine roots. The authors assume that the rot on deep lying roots is induced by chemical stress in the soil. The dieback of anchor roots in old rowan trees in the Krušné hory Mts was reported by Palátová and Mauer (2002), too. In spruce stands aged 40 years, which essentially differed in soil conditions (saturation with bases) as well as in the degree of damage (yellowing of needles, defoliation), Fritz et al. (2000) detected a distinct vertical gradient of the density both live and dead fine roots with a conspicuous concentration of fine roots in the humus layer and the situation was most striking in localities with the lowest degree of saturation with bases. Similarly, Hruška and Cienciala (2001) inform that in acidified soils, a greater part of the root system is localized in organic horizons with only a minimum amount of roots reaching into mineral soil.

The withdrawal of fine roots from deeper horizons to the upper soil or forest floor induced by soil acidification and imbalanced nutrient contents may increase the danger of exposure to biotic and abiotic factors, drought in particular (Wolf and Rickli, 1987; Ulrich, 1987; Eichhorn and Grabowski, 1991). Climatic extremes (extreme drought, high insolation or high temperatures) represent stress factors for trees, which may also lead to impaired vitality and to a visible manifestation of damage symptoms (Dittmar et al., 2004). Apart from affecting the growth and production of above-ground biomass, namely the lack of water may affect the root system, too (Bartsch, 1987; Feil et al., 1992).

Changes in the amount, distribution and functionality of fine roots may impair the tree vitality due to limited supplies of nutrients and water. Tree nutrition and water regime may also be disturbed by root systems malformed due to incorrect technology of planting stock cultivation, improper planting methods or careless work. Deformations may affect either individual branches of the root system or the root system as a whole. The most serious root system malformation is considered to be a so called tangle (root coiling) because the mutual strangulation of horizontal roots induced by their swelling may restrain not only their conductive function (Sauer, 1984; Mauer, 1989, 1999; Jurásek and Martincová, 2001; Mauer and Palátová, 2004) but also the tree infestation by parasitic fungi, namely honey fungus (Mauer, 1989; Jurásek and Martincová, 2001).

The monitoring of air pollution corroborates that in the last decade a significant reduction occurred in the deposition of sulphates and a milder reduction was recorded also in the emissions of nitrogen oxides and hydrocarbon compounds. On the other hand, ozone concentrations remain high, only the number of days with high ozone concentrations has significantly decreased (Wienhaus, 2003). After the change of the emission situation, the condition of Norway spruce stands in the Czech Republic markedly improved. However, after the period of certain optimism, the forestry practice has to face another problem. The decline and dieback of spruce stands occur again, over this time having regional character, usually a distinctly demarcated territory, with the symptoms and course of decline often varying from region to region. In the western Krušné hory Mts, some stands of Norway spruce were recently affected by assimilatory apparatus yellowing and by subsequent defoliation. The injury appeared in stands of all age classes on a total forest area of 9,000 hectares. The goal of the study was to contribute to the identification of causes to the damage that would facilitate the implementation of efficient forest management measures.

Material and methods

The primary objective of the survey was to compare emergence and health condition in Norway spruce trees of identical height affected by yellowing (with defoliation or changed colour of assimilatory apparatus 40–60%) and healthy trees (with no visual symptoms of injury, possibly with a defoliation or changed colour of assimilatory apparatus up to 10%), growing in the same stand. The procedure could not be adhered to in Stand 64 because there were no longer healthy trees in it, and therefore an intact stand of the same age growing on the same site was chosen as a control. To be able to assess whether the injury occurs only in artificially established stands, the analyses included also the stands from natural regeneration. With the aim to find out the influence of liming on the emergence and health condition of the root system, the analyses included six limed and six unlimed stands growing very close one to another on the same site, aged from 42 to 117 years. Liming with dolomitic limestone was applied in years 2001 and 2003 at a dose of 3 t ha^{-1}. With respect to the fact that the effect of liming could not reflect on the root system architecture, only fine roots were analyzed in these stands. All analyzed stands were monocultures of identical stocking, growing on the flat ground or the mild slope (gradient up to 5%). Selected for analyses were only trees in the main level, undamaged by game and non-marginal, with an identical above-ground part height. Characteristics of the analyzed stands are presented in Table 1.

Table 1. Characteristics of analyzed forest stands

Stand number	Stand designation	Soil type	Forest type	Altitude [m asl]	Age	Air-pollution danger zone
2D1	14 healthy, 14 injured+	modal podzol	7K3	940	14	B
122A2/1a	13 healthy, 13 injured	modal podzol	6K1	900	13	C
2A1	10 healthy, 10 injured	modal podzol	7M3	890	10	C
1E2/1b	20 healthy, 20 injured	modal podzol	7M3	940	20	B
119A2	19 healthy, 19 injured	modal podzol	7M3	880	19	C
120A3	30 healthy, 30 injured	modal podzol	6M3	820	27	C
1B3	26 healthy, 26 injured	modal podzol	7M3	960	26	B

Table 1. Continued

Stand number	Stand designation	Soil type	Forest type	Altitude [m asl]	Age	Air-pollution danger zone
121B4	40 healthy, 40 injured	modal podzol	6K1	880	40	C
17A6	64 injured	modal podzol	7K3	900	64	C
108D6	64 healthy	modal podzol	7K3	900	63	C
121B6	64 healthy, 60 injured	modal podzol	7K3	860	59	C
120A6	Self-seeding smaller healthy, Self-seeding smaller injured	modal podzol	6K1	780		C
120A6	Self-seeding larger healthy, Self-seeding larger injured	modal podzol	6K1	780		C
102A4	40 liming (in 2003)	modal podzol	7M3	910	42	C
14E4	40 no liming	modal podzol	7M3	930	45	C
102A6	60 liming (in 2003)	modal podzol	7M3	910	63	C
14E7	60 no liming	modal podzol	7M3	920	71	C
118A12	100 liming (in 2001)	modal podzol	7M3	920	117	B
107B10	100 no liming	modal podzol	7M3	920	97	B

Analyses of root system architecture and health condition

All root systems were lifted by hand (the archaeological method). A minimum number of trees analyzed at all times in stands aged up to twenty years was 12. A minimum number of trees analyzed in stands aged 20 and more years was 6 (both healthy and injured). The effect of liming was studied in six stands aged 42–117 years. The total number of analyzed trees was 238.

Parameters measured and assessed in all trees were as follows: total height of above-ground part (from the ground to the end of terminal increment), stem diameter $d_{1.3}$, length of terminal shoots in 2004 and 2005, root system malformation into tangle, number and diameter of horizontal skeletal roots (diameter was established at 20 cm from the trunk in ten and twenty-year old trees, at 40 cm from the trunk in thirty-year old trees, and at 60 cm from the trunk in sixty-year old trees), number and diameter of anchoring roots (diameter was measured at 5 cm from the point of setting). Measured values were used to calculate the area index (hereinafter Index p, in Table of results Ip) to express relation between the root system size and the size of above-ground part. It was calculated as the ratio of cross-sectional areas of all horizontal skeletal roots and anchoring roots (anchors) at the point of measurement in square milimeters to the length of above-ground part of trees in centimeters. The greater the Index p value, the larger the tree root system. Rooting depth in the corresponding soil horizons was measured as a perpendicular distance from the soil surface to the tip of the anchoring root. The length of horizontal skeletal roots was measured from the stem base to their end. Regularity of the distribution of horizontal roots in the root network was assessed according to the maximal angle between the two outermost horizontal skeletal roots.

All lifted root systems were visually inspected for the occurrence of honey fungus according to resin exudations. Root rots were established from the longitudinal sections of all roots, stem rots were established from stem cross-sections. Regarding the fact that the root systems were affected by rots, some partial traits (Index p, rooting depth) were established separately both for the whole root system, and for the functional part of the root system, ie for the root system part not affected by rots (in tables as “Whole root system” and “Functional root system”). Fine roots (<1 mm) were sampled so that 30 soil cores were lifted from each analyzed stand (separately for healthy and injured trees) with a soil sampler of 5 cm in diameter. The cores were subsequently divided according to the soil horizons and homogenized. Surveyed were all humus horizons (Humus) and the mineral layer 0–10 cm under the humus horizons (Mineral). From each homogenate, six samples were taken for analysis, each of 100 ml (apparent volume). After separation and additional manual cleaning, the fine roots were desiccated and their biomass was established. In the stands aged 60 and 40 years, the biomass of fine roots was established in the entire rooting profile of anchors.

In all analyzed stands, 5 soil monoliths 20 × 20 cm were sampled from the humus horizons (separately for healthy and injured trees), from which fine roots were removed manually, cleaned and homogenized. The fine roots obtained in this way were assessed for their vitality by using the method of 2,3,5 triphenyltetrazolium chloride reduction (Joslin and Henderson, 1984). Results from the processing of the samples were subjected to correlation analysis and the vitality was calculated in percent. Mycorrhizal infection was established quantitatively by chemical methods described by Plassard et al. (1982) and Vignon et al. (1986). The type of mycorrhiza was assessed anatomically after staining the fungus with aniline blue in lactophenol. Morphological structure of the mycorrhiza was assessed visually by using a stereo-magnifying glass.

Tables of results present arithmetic means of the respective parameters and their standard deviations. Significance of results was tested by T-test at a significance level of 95%; test results are in the tables of results plotted graphically (+ significant variance, – insignificant variance).

Results

Analyses of root system architecture and health condition

The comparison of healthy and injured trees standing one close to another revealed that all analyzed injured trees lagged behind the healthy trees in the length of their terminal increment (Table 2), their root system being smaller and the number and diameter of their skeletal roots (both horizontal and anchors) being lower. This was markedly reflected in lower Index p values for the Whole root system (Table 3a and 3b). The healthy and injured trees did not differ in the length of their horizontal skeletal roots.

As compared with the healthy trees, all analyzed injured trees showed a shallow root system, lower number and diameter of anchoring roots and distinctly reduced rooting depth. The injured trees exhibited a worse distribution of root network (greater maximal angle between horizontal skeletal roots, Table 3a). With an exception of trees from self-seeding, all analyzed injured trees exhibited the most serious root system malformation – tangle, which occurred, however, in most healthy trees, too (Table 3b). Honey fungus occurred in all injured trees and in nearly all healthy trees with a greater number of infected roots detected in the injured trees than in the healthy trees (Table 2). In some older injured trees, the honey fungus evoked root rots. Other parasitic fungi were not found on the root systems or on the tree stems (analyzed were only trees undamaged by game).

The above evaluation might suggest a conclusion that injured trees are those with a lower rooting depth or with a lower Index p of the Whole root system. A mutual comparison of all healthy and injured trees of approximately the same height (eg smaller self-seeding and stand 10, stand 60 and stand 64, stand 30 and stand 26) indicates, however, that the dependence does not hold entirely because rooting depth or Index p of the Whole root system may be in a healthy stand lower than in an injured stand. Index p of the Whole root system in the injured trees is markedly affected by the honey fungus. If we calculate Index p values only for the Functional root system (with the calculation including only roots not affected by the honey fungus), and if we put into relation the rooting depth and the rooting within the soil horizons, we shall see that in the stands aged up to about ten years, the trees create mostly a

Table 2. Biometric parameters of the above-ground part and honey fungus incidence

Stand designation	Above-ground part length [cm]	Terminal increment [cm]		Honey fungus incidence	
				Number of affected trees	Number of affected roots
		2004	2005	[in %]	[pcs tree^{-1}]
14 healthy	428±48	46.8±8.2	47.8±9.4	100	1.8±1.3
14 injured	375±56	32.2±6.1+	45.4±8.4-	100	3.4±0.9+
13 healthy	389±11	64.7±9.5	61.3±2.3	100	2.0±0.7
13 injured	328±28	47.3±2.5+	43.0±6.8+	100	4.7±0.6+
10 healthy	307±29	55.3±16.1	53.0±10.7	100	1.5±0.7
10 injured	318±34	25.0± 4.1+	38.0± 6.6+	100	2.6±0.7+
20 healthy	517±71	71.2± 9.5	61.6±17.5	100	2.0±0.6
20 injured	458±30	54.2±10.4+	61.2±7.6-	100	3.4±1.8+

Table 2. Continued

Stand designation	Above-ground part length [cm]	Terminal increment [cm]		Honey fungus incidence	
				Number of affected trees	Number of affected roots
		2004	2005	[in %]	[pcs tree^{-1}]
19 healthy	814±48	47.0±6.1	47.0±2.0	66	1.7±0.6
19 injured	732±68	33.0±9.5+	31.0±8.4+	100	4.6±0.6+
30 healthy	926±57	86.6±2.9	64.3±9.8	0	0
30 injured	935±81	57.5±3.5+	59.0±2.4–	100	4.1±1.2
26 healthy	835±49	85.5±16.2	87.5±3.5	100	1.3±0.6
26 injured	710±14	55.5± 6.4+	80.0±14.4–	100	3.3±1.4+
40 healthy	1,683±157	36.6±9.8	51.5±9.5	100	11.5±4.2
40 injured	1,508±118	16.7±7.9+	46.2±11.2–	100	14.9±2.9–
64 healthy	2,079±127	42.8±5.5	32.0±6.2	100	4.6±0.9
64 injured	1,832±140	31.5±5.9+	22.5±12.5–	100	6.3±2.3–
60 healthy	2,008±119	41.7±12.4	46.2±4.9	100	3.7±0.6
60 injured	1,805±153	27.2±3.2+	29.7±8.4+	100	11.8±5.8+
Self-seeding smaller healthy	306±24	52.6±14.2	52.7±9.2	100	1.8±0.8
Self-seeding smaller injured	259±26	25.3±4.2+	24.0±3.7+	100	5.0±2.8+
Self-seeding larger healthy	796±51	45.6±7.1	49.2±3.6	100	2.8±0.9
Self-seeding larger injured	645±17	7.3±2.2+	16.5±4.1+	100	7.3±0.6+

superficial root system; healthy trees are those with a larger root system. In the stands aged from approx. 20 years, the trees develop mainly an anchoring root system; healthy trees are those with the anchoring and at the same time larger functional root system. As to the rooting depth, it is not the depth itself that is important but the fact whether the anchors reach into the Bs horizon; healthy trees are those whose anchors reach the Bs horizon (Table 3b).

Analyses of fine roots

In the analyzed soil horizons (Humus, Mineral), no essential differences were found between the healthy and injured trees in the biomass of fine roots. However, the healthy trees showed a conspicuously higher occurrence of anchoring roots that further branch into fine roots in the upper part of Bs horizon. The injured trees showed lesser anchoring roots whose branching was minimal. By an additional survey in stands 40 healthy, 40 injured, 60 healthy and 60 injured we found out that in the healthy trees, there are further 70–80% of the biomass of fine roots (100% fine roots biomass in horizons Humus + Mineral into a depth of 10 cm), the amount of which under the horizons of injured trees does not exceed 7%. In both healthy and injured trees, a greater part of fine roots in the Humus horizon occur in its upper part. No differences in the mycorrhizal infection were found between the healthy and injured trees. All injured trees have a markedly worse vitality of the fine roots than the healthy trees (reduced by up to 50%). Liming did not affect the biomass of fine roots or their mycorrhizal infection but increased the vitality of fine roots (Table 4).

Table 3a. Root system architecture

Stand designation	Horizontal skeletal roots		Max. angle between horiz. skeletal roots	Anchoring roots		Average diameter*
	Number	Average diameter		% of trees with anchors	Number*	
	[pcs]	[mm]	[degrees]		[pcs]	[mm]
14 healthy	12.0±5.1	15.6±8.6	64±29	73	1.3±0.8	17.4±5.1
14 injured	12.2±2.7–	9.3±4.3+	110±57+	27	1.5±0.7–	13.3±3.1+
13 healthy	14.3±3.8	13.6±8.3	106±11	100	1.0±0.0	9.3±2.1
13 injured	9.2±0.9+	10.2±4.5+	210±60+	17	2.0±0.0	15.3±1.7+
10 healthy	11.5±4.3	12.6±7.4	110±52	27	2.0±0.6	8.1±2.0
10 injured	7.8±2.1+	8.2±3.6+	132±34–	0	0	0
20 healthy	12.4±1.9	22.0±12.6	70±29	100	3.6±1.5	16.5±6.4
20 injured	9.8±2.1+	13.8±7.9+	112±38+	17	1.0±0.0	29.0±0.0
19 healthy	15.3±2.3	27.6±16.8	40±9	100	7.5±2.1	21.6±8.5
19 injured	12.6±2.1+	18.7±11.9+	82±33+	17	4.0±0.0	25.2±15.1–
30 healthy	11.3±2.5	29.2±18.4	60±28	100	5.3±1.5	32.1±10.1
30 injured	8.5±3.5+	30.8±22.1–	85±21–	100	1.0±0.0	31.0±14.1–
26 healthy	15.5±0.7	18.2±11.1	80±26	100	6.5±4.9	17.3±3.9
26 injured	10.0±1.4+	17.7±9.2–	115±23+	0	0	0
40 healthy	16.2±2.1	42.1±25.9	42±11	100	16.0±4.3	39.1±14.3
40 injured	13.0±2.3+	32.4±13.5+	71±19+	100	12.2±3.1+	36.5±14.2–
64 healthy	16.6±4.1	49.5±26.4	56±11	100	24.1±3.5	39.1±13.3
64 injured	14.2±2.1–	52.5±28.5–	80±20+	100	5.2±1.9+	31.8±11.2+
60 healthy	19.8±1.7	44.3±21.4	38±9	100	17.2±4.3	45.1±16.6
60 injured	13.5±3.1+	40.0±25.8–	77±27+	100	12.7±2.5+	38.0±14.4+
Self-seeding smaller healthy	14.3±3.8	14.1±7.7	68±9	100	5.6±0.6	8.3±1.9
Self-seeding smaller injured	7.5±0.6+	11.7±3.8–	181±2+	100	3.0±1.0+	14.2±2.8+
Self-seeding larger healthy	15.3±2.9	26.8±12.6	73±7	100	7.4±2.7	20.8±7.6
Self-seeding larger injured	8.5±2.1+	17.6±6.9+	145±44+	100	4.5±0.6+	13.7±5.2+

*only in trees with anchoring roots

Table 3b. Root system architecture

Stand designation	Root system deformation into tangle [in % of trees]	Index p		Rooting depth [cm]	Roots reaching Horizon Bs
		Whole root system	Functional root system		
14 healthy	100	8.14±1.01	7.82±0.94	29.8±15.4	no
14 injured	100	3.02±1.40+	2.72±1.46+	20.4±14.2-	no
13 healthy	100	7.56±1.74	7.21±1.64	42.6± 4.1	no
13 injured	100	3.40±0.26+	2.81±0.24+	31.0± 6.0+	no
10 healthy	100	6.82±2.47	6.62±2.25	14.7±9.5	no
10 injured	100	1.75±0.42+	1.43±0.37+	12.6±6.9-	no
20 healthy	100	13.82±4.13	13.11±4.21	38.0± 6.8	yes
20 injured	100	4.46±1.19+	2.97±1.06+	14.8±10.7+	no
19 healthy	100	17.90±0.75	16.94±0.73	72.0±17.6	yes
19 injured	100	7.73±0.13+	5.73±0.31+	24.5± 3.5+	no
30 healthy	67	30.20±5.80	30.20±5.80	84.3± 5.8	yes
30 injured	100	11.20±4.20+	5.53±2.74+	40.5± 9.2+	no
26 healthy	17	8.80±1.55	8.52±1.48	40.0± 4.2	no
26 injured	100	4.35±1.06+	4.08±1.02+	10.0± 2.5+	no
40 healthy	33	34.92±6.30	21.73±5.64	89.6±13.8	yes
40 injured	100	16.77±1.10+	9.51±1.47+	64.0± 6.5+	no
64 healthy	unidentified	33.90±5.05	32.74±5.12	61.4± 9.9	yes
64 injured	unidentified	24.15±5.96+	17.33±4.81+	38.8± 4.4+	no
60 healthy	unidentified	36.53±4.30	34.88±4.17	120.0±23.4	yes
60 injured	unidentified	19.33±5.37+	10.44±4.29+	84.0±19.9+	no
Self-seeding smaller healthy	0	10.21±2.36	10.05±2.53	86.8±14.7	yes
Self-seeding smaller injured	0	5.20±1.55+	3.04±1.36+	40.5± 7.8+	no
Self-seeding larger healthy	0	18.40±1.21	17.55±1.28	86.7±14.9	yes
Self-seeding larger injured	0	4.81±0.84+	2.29±0.72+	59.5±16.3+	no

In spite of the fact that soil conditions of the analyzed stands are heterogeneous, the analyses of chemical and physical characteristics of soil horizons revealed that all injured stands have as compared with the healthy stands less calcium and a critical shortage of magnesium in horizon H, and a critical shortage of phosphorus and more iron in the Bhs horizon. The injured stands have the Humus horizons of lesser thickness, the Bhs horizon more shallowly situated and a greater share of 2–0.25 mm fractions in all horizons (detailed data are available from the authors).

Discussion

The concerned region was not seriously affected by disastrous air pollution at the end of the last century, and currently there are damages belonging to the air-pollution zones B and C. The damage first appeared approximately in 1999 and its intensity varies every year. Some forest stands exhibit large-scale disturbances (with individual trees showing different degrees of damage), which are distinctly individual in some stands (with entirely healthy trees and trees with injuries of up to 80% growing next to one another). The injured trees do not die rapidly (the development of snags is gradual and it is sufficient if these are removed within the framework of planned silvicultural measures). Most damaged are stands on slopes (even mild) exposed to sunlight. All injured stands occur on poor sites (Forest Type Groups 6M, 7M, 6K, 7K).

The implemented analyses unambiguously indicate that the injured trees have a smaller-sized root system and a reduced rooting depth. All analysed stands grow on modal podzols. Thickness and stratigraphy of soil horizons are distinctly heterogeneous and often changing over a distance of just several meters (six different soil profiles were recorded in Stand 30 on an area

Table 4. Biomass, vitality and mycorrhizal infection of fine roots

Stand designation	Biomass of fine roots [g 100 ml^{-1}]			Vitality+	Mycorrhizal infection
	Humus	Mineral	Total	[%]	[g mg^{-1}]
14 healthy	0.309±0.011	0.043±0.002	0.352±0.011	100	unidentified
14 injured	0.317±0.010–	0.030±0.001+	0.347±0.011–	82	unidentified
20 healthy	0.190±0.008	0.023±0.001	0.213±0.009	100	9.53±0.68
20 injured	0.154±0.008+	0.012±0.001+	0.166±0.008+	71	9.56±0.54–
19 healthy	0.622±0.010	0.064±0.001	0.686±0.009	100	7.91±0.36
19 injured	0.463±0.007+	0.051±0.002+	0.514±0.008+	86	7.59±0.27–
40 healthy	0.860±0.008	0.112±0.005	0.972±0.019	100	7.63±0.26
40 injured	0.896±0.004+	0.220±0.005+	1.116±0.009+	71	8.35±0.53+
64 healthy	0.514±0.014	0.146±0.004	0.660±0.016	100	7.8±0.31
64 injured	0.633±0.015+	0.025±0.002+	0.658±0.014–	48	8.5±0.22–
60 healthy	0.638±0.006	0.162±0.005	0.800±0.009	100	8.52±0.28
60 injured	0.556±0.007+	0.144±0.008+	0.700±0.008+	77	7.04±0.08+
40 liming	1.035±0.019	0.098±0.004	1.133±0.021	100	8.67±0.39
40 no liming	1.059±0.022–	0.122±0.005+	1.181±0.012+	54	7.83±0.28+
60 liming	0.881±0.008	0.068±0.004	0.949±0.007	100	7.31±0.12
60 no liming	0.855±0.017+	0.154±0.004+	1.059±0.016+	62	8.79±0.31+
100 liming	0.520±0.013	0.110±0.005	0.630±0.017	100	9.50±0.55
100 no liming	0.474±0.009+	0.111±0.004–	0.585±0.012+	68	9.59±0.51–

+100% = vitality of fine roots in unaffected or limed forest stands of 40 × 40 m). In all injured trees, we found out that the reduced rooting depth results from the shallowly situated and for the roots impenetrable Bs horizon. In the healthy trees, the Bs horizon is penetrable for roots (up to 10 cm of its thickness) and the anchoring roots form in it brushes with fine roots. Although the injured trees create anchoring root systems too, the anchors do not reach the Bs horizon but rather remain in the Ep horizon, in which they hardly show any branching at all, and we recorded even some rots occurring on them. The fact that the roots do not grow into the Bs horizon may be contributed to by chemical changes in the Bhs horizon. The impenetrability of horizon Bs is not induced by chemical changes or by a layer of conglomerates developed in its upper part, but rather by its general mechanical impenetrability to roots (the horizon is difficult-to-dig even with a heavy picker). In both the healthy and injured trees, the root systems appear as if "trimmed" and there are usually no differences between the average and maximal rooting depths.

Less injured or healthy are even trees (stands) with high humus horizons. As a rule, the healthy trees (stands) have a thickness of humus horizons up to 2 times higher than the injured trees (stands). The thickness of humus horizons is not a decisive criterion of damage, though. In young trees, the lower rooting depth results also from root system deformations. It further follows from the analyses that the injured trees have a lesser number of low-diameter horizontal roots. The lower number and thickness of horizontal roots are induced by root system deformations at planting. The occurrence of tangle is a rule namely in younger stands; undecomposed containers were found on the root systems in stands 14 and 10 established with the containerized planting stock. The malformations do not affect the length of horizontal roots. By chemical analyses of basic nutrient contents we detected differences between the healthy and injured trees in the horizon H; the changes may be further deepened by drought (particularly critical being the content of magnesium).

Relations following out from the comparison of results of root system analyses and all other complementary surveys are as follows: Injured trees have a weaker root system, which reaches into lower depths. In the injured trees, the biomass of fine roots is not essentially affected in upper soil horizons; however, the total biomass of fine roots is reduced in the injured trees by up to a half. The mycorrhizal infection in the injured trees is not affected but lower vitality of fine roots was detected (lower abundance of fine roots and their lower vitality markedly impair the capacity of injured trees to uptake nutrients and water). All root system parameters are affected also by the method of planting, the essential influence, however, is that of stratigraphy and both chemical and physical characteristics of soil horizons, which distinctly differ between the individual stands or just within a few meters (damages are observed also on self-seeded trees, without the root system deformation). Stands in the concerned region were not heavily affected by air pollution. In spite of the fact that sulphur depositions near Přebuz are still increasing – up to 1.93 g m^{-2} (Hadaš, 2007). Lomský et al. (2007) report that the assimilatory apparatus of Norway spruce in the region contains the lowest amount of sulphur in the entire Krušné hory Mts. Šrámek et al. (2005) recorded in the surroundings of Přebuz a pronounced increase in both diameter and height increment in the Norway spruce since 1990, which they attributed – similarly as Hadaš (2007) – to the increased nitrogen depositions in the area (up to 28 kg ha^{-1} year^{-1}). The increased depositions of nitrogen may be another important predisposition of the damage. Although the stands grow on poor sites, Šrámek et al. (2005) did not find in the surroundings of Přebuz any critical deficit of some element in the nutrition. Remeš et al. (2007) observed hardly any response of Norway spruce stands to fertilization in the region of study. The effect of these reclamation measures is currently not apparent in stands that were treated with fertilizers and lime in the earliest of the 1990s (Šarman, 1992). Compared with our results, the results in question are different, as they point to a possible disturbance of nutrition. However, the variation results from different methodological procedures of research (health condition of surveyed forest stands, applied fertilizers, methods used in the assessment of nutrient contents, date of sampling for analyses).

By analyzing the development of climate and weather in the concerned region in 1961–2004 (data taken over from the ČHMU hydrometeorological station Nová Ves v Horách, altitude 726 m asl), Bagár (2007) observed mean annual temperatures and growing season temperatures increased by 1.2 °C, insolation extended by 180 hours, number of days with average daily temperature of +5 °C, +8 °C and +10 °C increased by 18, 19 and 26, resp., global radiation since 1984 increased by more than 3,000 J cm^{-2} (which is eg global radiation of the whole month of April). In spite of the fact that according to Bagár (2007) the fitted series showed total precipitation amounts in the growing season increased by 34 mm, the total intensity of precipitation decreased by 0.4 mm, Lang coefficient dropped by 8.5 and potential evapotranspiration increased by 93 mm. The author claims that in the last 15 years, the precipitation amount was markedly lower in April and May with the character of precipitation being in general rather torrential and conspicuously fluctuating in the individual years. A pronounced humidity deficit occurred in years 1989, 1990, 1994, 1998 and 2003.

The above analysis suggests that the predisposing factor for injury is the root system size and quality, which are conditioned by careful planting, particularly by stratification and by the chemical and physical parameters of individual soil horizons. The triggering factor is weather extremes, namely the moisture deficit.

This may be an explanation of striking differences in the course and intensity of damage in individual years or reasons why such a distinct decrease of terminal increment occurred in 2004.

A question remains why the damage to the stands appears only in the recent years. On normal sites, the tree develops a root system, that is to a certain extent capable to eliminate stress factors (root system is "oversized"). In the concerned region, the trees have developed root systems, sufficient in providing for basic life functions (with the index of forest stands being low, though), but the quality of which is not enough for the elimination of a newly emerging stressor – drought, which limits the uptake of water and nutrients. Colour changes to the assimilatory apparatus suggest that an important cause of the decline is the lack of nutrients. The response of Norway spruce assimilatory apparatus to the typical water deficit is somewhat different. The reduced acidity of esp upper soil horizons by liming markedly improves the vitality of fine roots, which makes it possible for trees to increase the uptake of nutrients and water. However, regarding the fact that it does not affect the rooting depth, it may to a certain extent enhance the health condition of the stands but it cannot in general prevent their injury (eg at weather extremes).

Conclusions

The paper analyzes emergence and health condition of root system in the Norway spruce affected by yellowing of its assimilatory apparatus in the area managed by the Forest Administration Horní Blatná. The analyses included 238 trees in twelve forest stands (aged 10–64 years, Forest Type Groups 6K, 7M, modal podzol). The effect of liming was monitored in six forest stands aged 42–117 years.

- The comparison of equally high trees growing one very close to another within one stand, healthy and injured, showed that the injured trees have:
  - Smaller and less functional root systems than the healthy trees
  - Lower number and smaller diameter of skeletal roots (both horizontal and anchoring), which particularly reflects in lower Index p values
  - Reduced rooting depth, worse root pattern distribution and a nearly 100% occurrence of the most serious malformation – tangle
  - Increased incidence of honey fungus inducing root rots in some older trees
  - Biomass of fine roots reduced by up to 70% over the entire profile studied, with no essential variances found in the upper soil horizons
  - Vitality of fine roots reduced by up to 50%
  - Similar variances between the root systems of healthy and injured trees were observed both in trees established by planting and in trees from natural regeneration.
- The comparison of healthy and injured trees of approximately the same height occurring in the concerned region revealed that:
  - Healthy trees until an age of approx 10 years are those, that have developed large superficial root system; healthy trees from about 20 years are those, that have developed a large anchoring root system with anchors reaching into Bs horizon
  - In the injured trees, impaired vitality cleared the ground for the honey fungus, which reduces the size and hence the functionality of the root system by affecting individual root system branches (anchors in particular)
  - Liming affected neither the biomass of fine roots nor their mycorrhizal infection however, it increased their vitality.

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Vývin a zdravotní stav kořenového systému smrku ztepilého *(Picea abies* (L.) Karst.) postiženého žloutnutím asimilačního aparátu v oblasti Krušných hor

Souhrn

Práce analyzuje příčiny chřadnutí smrkových porostů na LS Horní Blatná (Krušné hory). Cílem šetření bylo srovnat vývin a zdravotní stav kořenového systému stejně vysokých žloutnutím postižených stromů (s defoliací nebo změnou barvy asimilačního aparátu 40–60 %) a zdravých stromů (bez vizuálních symptomů poškození, případně s defoliací nebo změnou barvy asimilačního aparátu do 10 %), rostoucích v jednom porostu.

V porostech do věku dvacet let bylo vždy analyzováno minimálně 12 stromů, ve dvacetiletých a starších porostech minimálně 6 stromů (zdravých i poškozených). Kořenové systémy byly vyzvednuty ručně a jejich vývin byl posuzován ve vazbě na půdní horizonty. U každého stromu byly měřeny a hodnoceny: celková výška nadzemní části, tloušťka kmene v $d_{1,3}$, délka terminálních výhonů v letech 2004, 2005, deformace kořenového systému do strboulu, počet a tloušťka horizontálních kosterních kořenů, počet a tloušťka kotevních kořenů. Z naměřených hodnot byl vypočítán Index ploch (I_p), který udává vztah mezi velikostí kořenového systému a nadzemní části. Dále byla zjišťována hloubka prokořenění, délka horizontálních kosterních kořenů, úhly mezi horizontálními kosterními kořeny, výskyt václavky, hniloby kořene a kmene, biomasa, životnost a mykorhizní infekce jemných kořenů

- Ze srovnání stejně vysokých a vedle sebe v jednom porostu rostoucích stromů zdravých a poškozených vyplynulo, že poškozené stromy mají:
  - menší a méně funkční kořenový systém než stromy zdravé,
  - menší počet i tloušťku kosterních kořenů (horizontálních i kotevních), což se výrazně projevuje v menších hodnotách Indexu p,
  - menší hloubku prokořenění, horší rozložení kořenové sítě a téměř stoprocentní výskyt nejzávažnější deformace – strboulu,
  - větší výskyt václavky, která vyvolala i hniloby kořenů,
  - až o 70 % nižší biomasu a až o 50 % menší životnost jemných kořenů,
  - stejné rozdíly mezi kořenovými systémy zdravých a poškozených stromů byly zjištěny jak u stromů založených sadbou, tak u stromů z přirozeného zmlazení.
- Ze srovnání všech přibližně stejně vysokých stromů zdravých a poškozených v celé zájmové oblasti vyplynulo, že:
  - do věku cca 10 let jsou zdravé ty stromy, které vytvořily velký povrchový kořenový systém, od cca 20 let jsou zdravé ty stromy, které vytvořily velký kotevní kořenový systém a kotvy prorůstají do horizontu Bs,
  - snížení vitality vyvolalo u poškozených stromů nástup václavky, která napadáním jednotlivých větví kořenového systému (obzvláště kotev) snižuje velikost a tím i funkčnost kořenového systému.