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Development and health condition of the root system of Norway spruce (*Picea abies* (L.) Karst.) in the region of the Jeseníky Mts

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Abstract

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The paper analyzes development and health condition of the root systems of visually healthy and declining Norway spruce (*Picea abies* (L.) Karst.) trees at three sites of the Jeseníky Mts. Affected by the decline were trees of all age classes. Unlike naturally regenerated trees, all of the analyzed declining trees had their root systems malformed into tangles. The root systems of all the declining and the majority of healthy trees were infested by honey fungus (*Armillaria* sp.). The declining trees did not show any nutritional deficiency. Up to the Forest Altitudinal Vegetation Zone 4 (GFT 4B), spruces do not grow in the ecological optimum. After weakening due water shortage, the root systems become infested by honey fungus which induces root, stem base and bole rots. As a result of malformations, the declining trees in Forest Altitudinal Vegetation Zones 7 and 8 (forest type group 7S, 8S) have always significantly smaller root systems colonized by honey fungus and characteristic lower rooting depth. Honey fungus does not affect root, stem base or bole rots. The declining trees have less biomass, lower vitality and suffer from mycorrhizal infection of fine roots.

Key words

decline, deformation, fine roots, honey fungus, Norway spruce, root system

Introduction and objectives

The intense industrial development since the 1950s has been associated with increase in noxious agents emitted into the atmosphere. These harmful substances caused damage to and dieback of forest stands – primarily in the mountain areas in the North of the Czech Republic. Kubačka (1992) notes that the air pollution damage in the Jeseníky Mts started to appear from the mid- 1970s, particularly in locations loaded by a combined effect of the air pollution and adverse climatic or microclimatic conditions. The most affected were windward localities such as ridges, isolated tops (even at lower elevations) and sites with permanent air streaming. The long-term SO_2 concentration averages from 1983 to 1993 at the Rejvíz station situated at 760 m a.s.l. amounted to ca. 19 μg m^{-3} (Balcar and Vacek, 1994). Chmelíček (1992) states that between 1982 and 1984, the damage was noticeably aggravated as a consequence of the impact of the previous stress factors (an abrupt fall in temperature at the turn of the years 1978/1979 and dry years 1981–1983). While the strong damage to forest stands in the region of the Hrubý Jeseník Mts in 1980 affected 50 ha, the total acreage of strongly and more damaged stands in 1984 amounted even to 5,212 ha (Balcar et al., 1994). The damage was evident on desiccation of individual trees and consequently on the dieback and disintegration of entire stands. Chmelíček (1992) suggests that the majority of the seriously damaged and declining stands were of unsuitable provenance. Also Kubačka

(1992) states that the autochthonous stands were more resistant to damage than the introduced ones. The total acreage of stands logged as the result of the air pollution disaster in the Hrubý Jeseník Mts was estimated at roughly 1,000 ha (Balcar et al., 1994). Between 1985 and 1991, the immission impacts were mitigated by aerial liming applied on 12,850 ha on which soil analyses detected deficiency of Mg, Ca, K and N. The liming was complemented with additional aerial spraying with liquid foliar fertilizers (Kubačka, 1992). The initial steep increase in damage gradually was damped thanks to favourable wet years without considerable climatic fluctuations. In the early 1990s, the decline of stands stagnated and their condition improved also visually (Chmelíček, 1992). Approximately in the last ten years, however, the decline of Norway spruce stands of all age classes started to reappear in all Forest Altitudinal Vegetation Zones in the Jeseníky Mts. The symptoms and progress of the decline vary according to the elevation. Rusting of the assimilatory apparatus, rapid defoliation and a relatively fast dieback of trees (a fairly healthy tree dies over a period of several months) occur in lower Forest Altitudinal Vegetation Zones (up to FAVZ 5). In higher Forest Altitudinal Vegetation Zones, yellowing of the assimilatory tissue (mainly after the winter season) takes place too, but defoliation is rather slow, the trees die gradually and the decline intensity (yellowing) varies from year to year. Since it is a well known fact that the root systems of trees tend to be affected earlier and more than their above-ground parts and that the belowground part are subjected to bigger changes (Mauer and Palátová, 1988; Mauer, 1989a, b; Murach, 1991; Mauer et al., 2004, 2008), the objective of this paper was to discuss whether an interrelationship exists between the decline, development and health condition of the root system of this tree species.

Material and methods

The surveys were realized in stands of FAVZ 4–8 in four forest districts of the Forest Administrations of Město Albrechtice and Karlovice LČR a.s. The characteristics of the surveyed stands are listed in Table 1. The objective of the survey was to compare the development and health condition of the root systems between healthy and declining trees of the same height (change in the assimilatory apparatus of 40–60%). Healthy trees served as a control (standard). The analyzed stands were monocultures of identical density growing on a slight slope (of up to 10%). Only non-marginal, co-dominant, trees undamaged by game and bark beetles were selected for partial analyses. The analysis in each stand included 6 to 30 declining and healthy trees.

Analyses of above-ground parts

The above-ground parts of the assessed trees were analyzed for the total height (from the ground surface up to the tip of terminal increment), stem diameter at $d_{1.3}$, terminal shoots lengths in 2007, 2008, 2009 and the length of needles (measured halfway the length of the last increment on the branch of the third whorl from above). Chemical analyses determining the content of the essential biogenic elements (N, P, K, Ca, Mg) in the last two generations of the assimilatory apparatus in stands 5-D-21-H, 5-D-21-D, 7-O-19-H and 7-O-19-D were conducted in an accredited laboratory. The occurrence of bole rots was evaluated on stem cross-sections (at the stem base and five other equal-length sections).

Analyses of root system architecture and health condition

All root systems were lifted by hand (archaeological method). After cleaning, each of them was assessed for the following characteristics: number and diameter of horizontal skeletal roots (diameter was assessed in self-seeded plants at a height of 10 cm, in 10-year old trees at 20 cm, in 15-year old trees at 40 cm, in 40-year old trees at 60 cm and in 70-year old trees at a height of 80 cm from the stem base); number and diameter of anchoring roots (diameter was measured at 5 cm from the setting point); number and diameter of substitute taproots, i.e. primary root branches shooting from anchor roots (diameter was measured at 5 cm from the setting point) and number and diameter of horizontal non-skeletal roots shooting from the stem base. Area index (hereinafter Index P, in the table of results I_p) was calculated from the measured values as the ratio of the sum of root cross-sectional areas of all skeletal roots (mm^2) to the tree height (cm). Index P expresses the relation between root system development and shoot development: the higher the value of Index P, the larger the tree root system. Functionality of the root system is, however, adversely affected by root rots and fungal pathogens, so the Index P was calculated in three ways: first as the total I_p (the calculation includes all roots in the root system); I_p of healthy roots (only healthy roots without rots were included) and I_p of functional roots (all roots without rots and with resin exudation of up to the 2nd degree inclusive were included). The rooting depth (perpendicular distance from the ground surface to the deepest reaching root segment) was determined first as the total rooting depth (the calculation involves all roots of the root system) and functional rooting depth (including only roots unaffected by rots and with resin exudation up to the 2nd degree inclusive). The lifted root systems were also surveyed for the occurrence of malformation into a tangle.

Health condition of the roots (incidence of rots) was assessed on a longitudinal section through each root and resin exudation was identified on each skeletal root and categorized as follows: 0 – without resin exudation, 1 – surface resin exudation of maximum ¼ of the root girth, 2 – surface resin exudation of maximum ½ of the root girth, 3 – surface resin exudation of up to

¾ of the root girth, 4 – surface resin exudation of above ¾ of the root girth.

Analyses of fine roots

There were analysed roots of less than 1 mm in diameter – which are decisive for nutrition and water uptake. In the selected stands (chiefly in healthy and declining trees), 30 soil cores to the depth of 20 cm were lifted by a soil pit of 5 cm in diameter. The cores were divided into humus and humus-enriched horizons and homogenized with respect to these layers. The fine roots were separated manually from soil samples (each with 100 ml of soil) taken by 6 from each homogenate. After cleaning, the biomass of fine roots (weight of fine roots after drying at 85°C in 100 ml of soil homogenate – the table of results shows the weight of fine roots in all humus and humus-enriched horizons) and their vitality (Joslin and Henderson, 1984) were determined and mycorrhizal infection was established quantitatively (Vignon et al., 1986).

Weather analyses

The assessment of weather history between 1961 and 2006 was carried out based on the data from the hydrometeorological station Karlova Studánka (780 m a. s.l.) of the Czech Hydrometeorological Institute (CHI). The measured daily values were smoothed with a regression line (linear regression, the method of least squares).

Statistical evaluation

The Results acquired in the individual stands were subjected to t-test. The results are graphically displayed in the tables of results: + significant difference (α – 95%), – insignificant difference.

Note

For better legibility, the analyzed stands were allocated codes that are used in the text as well as in the tables. The first code position means the number of the analyzed stand in the forest district, the second position is a letter identifying the surveyed locality in the region of the Jeseníky Mts (D – Dobrá voda, forest district Dobrá voda, O – Orlík, forest districts Polom and Drakov, S – Sokolí skála, forest district Vidly), the third position digit indicates the height of the analyzed tree in metres and the letters H and D in the fourth position stand for healthy and damaged trees, respectively. The addition of letter N to this position also means that the analyzed stands were regenerated naturally.

Results

The analyzed spruce stands manifested these common features: they grew on fertile (B) or fresh (S) sites (Table 1); on all monitored localities all of the declining as well as healthy trees were infested by honey fungus (*Armillaria* sp.) and nearly all healthy and declining trees (except for naturally regenerated stands) had root systems malformed into tangles. Nutrition deficiency was not identified in any of the localities. The state of the root system and response of the above-ground parts of the declining trees varied among the localities.

Table 1. Characteristics of the analyzed stands

Stand code	Forest district	Stand number	Forest Type Group	Stand age	Altitude [m]	Danger Zone
1-D-3-H	Dobrá voda	112B1b	4B	16	750	C
1-D-3-D	Dobrá voda	112B1b	4B	16	750	C
2-D-5-H	Dobrá voda	111C2/1c	4B	20	650	C
2-D-5-D	Dobrá voda	111C2/1c	4B	20	650	C
3-D-6-HN	Dobrá voda	112B3	4B	30	720	C
3-D-6-DN	Dobrá voda	112B3	4B	30	720	C
4-D-9-H	Dobrá voda	120C2b	4B	24	730	C
4-D-9-D	Dobrá voda	120C2b	4B	24	730	C
5-D-21-H	Dobrá voda	120C4	4B	47	780	C
5-D-21-D	Dobrá voda	120C4	4B	47	780	C

Table 1. Continued

Stand code	Forest district	Stand number	Forest Type Group	Stand age	Altitude [m]	Danger Zone
1-O-2-H	Drakov	419E2	7S	25	1,150	B
1-O-2-D	Drakov	419E2	7S	25	1,150	B
2-O-4-H	Polom	317B1	7S	16	1,040	B
2-O-4-D	Polom	317B1	7S	16	1,040	B
3-O-5-H	Drakov	420B2	7S	21	1,060	C
3-O-5-D	Drakov	420B2	7S	21	1,060	C
4-O-9-H	Drakov	419F1a	7S	10	1,050	B
4-O-9-D	Drakov	419F1a	7S	10	1,050	B
5-O-3-H	Polom	317F1a	7S	13	1,030	B
5-O-3-D	Polom	317F1a	7S	13	1,030	B
6-O-5-HN	Polom	317B2	7S	27	1,080	B
6-O-5-DN	Polom	317B2	7S	27	1,080	B
7-O-19-H	Drakov	419E7/1b	7S	73	1,110	B
7-O-19-D	Polom	318B7	7S	72	1,120	B
1-S-1-H	Vidly	725B2	8S	14	1,180	B
1-S-1-D	Vidly	725B2	8S	14	1,180	B
2-S-2-H	Vidly	725A2	8S	14	1,170	B
2-S-2-D	Vidly	725A2	8S	14	1,170	B
3-S-4-H	Vidly	725J2	7S	14	1,080	B
3-S-4-D	Vidly	725J2	7S	14	1,080	B

Dobrá voda locality (GFT 4B)

Statistically significant decrease in terminal increment was identified only in some of the analyzed stands, and no shorter needles were found in any of them (Table 2). Root rot was detected in almost all declining trees, and to a great extent (16–100%) also in healthy trees. In stands with the above-ground part over 5 m in height, at least 50% of injured trees showed stem base or bole rots; a high incidence (up to 66%) of these rots was found also in healthy trees (Table 2).

The root systems in all healthy and declining trees had horizontal skeletal roots infested by honey fungus, whilst the degree of infestation in declining trees was considerably higher than in healthy ones. In declining trees, between 20 and 68% of horizontal roots suffered from rots; rots of horizontal roots in healthy trees were exceptional (Table 3). Anchor roots in declining as well as healthy trees were colonized by honey fungus, and the degree of infestation was significantly higher in declining trees. In declining trees, 37 to 55% of sinker roots were attacked by rot; the range in sinker roots of healthy trees was between 10 and 34% (Table 4).

The rooting depth in healthy and declining trees did not differ. No crucial differences were found between the total rooting and rooting in functional roots in healthy trees. In declining trees, the rooting depth in functional roots was up to one half smaller than the total rooting depth (Table 4).

No marked differences in the total I_p values were identified between the healthy and damaged trees. Contrarily, the I_p values for healthy roots and primarily functional roots manifested decrease in all healthy trees. Identical tendency of decreasing values of the healthy roots I_p and of functional roots I_p was identified also in the damaged trees but with a much greater range of variance (the value of healthy roots I_p was ca. one half of the total I_p, the value of functional roots I_p amounted to ca. one half of the healthy roots I_p). It is statistically significant that all declining trees had lower biomass of the fine roots but more vital and extensive mycorrhizal infection (Table 5).

Table 2. Shoot increments, root system malformations and incidence of rots in visually healthy and declining Norway spruce trees

Stand code	Terminal increments [cm]			Trees with a tangle [%]	Trees with rot		
	2009	2008	2007		Stem base [%]	Stem [%]	Roots [%]
1-D-3-H	23.7±6.0	33.0±4.5	40.8±11.5	100	16	16	16
1-D-3-D	19.0±7.9–	22.7±8.9+	29.7±9.7+	100	0	0	100
2-D-5-H	84.7±13.0	93.3±7.6	77.0±6.5	100	25	0	25
2-D-5-D	82.0±13.1–	92.0±9.6–	64.0±12.5–	100	50	50	75
3-D-6-HN	56.6±8.5	64.2±5.1	45.8±5.7	0	20	20	20
3-D-6-DN	14.4±7.7+	16.6±7.7+	38.4±12.4–	0	0	0	100
4-D-9-H	31.4±18.4	45.2±6.6	40.2±14.8	100	66	66	100
4-D-9-D	14.0±9.8+	20.0±2.4+	24.0±4.8+	100	60	60	100
5-D-21-H	51.6±9.1	40.8±8.3	99.2±16.6	100	20	20	60
5-D-21-D	58.0±12.4–	56.7±8.4+	65.0±13.2+	100	60	60	100
1-O-2-H	48.0±9.2	37.3±12.3	27.5±5.6	100	0	0	0
1-O-2-D	7.0±1.7+	11.3±8.6+	19.3±5.4+	100	0	0	0
2-O-4-H	61.8±12.9	65.4±7.7	61.0±7.0	100	0	0	0
2-O-4-D	52.4±5.6+	40.8±11.5+	44.6±5.7+	100	0	0	0
3-O-5-H	47.3±13.3	44.7±6.4	43.7±6.3	100	0	0	0
3-O-5-D	25.6±6.1+	20.2±14.5+	30.2±7.9+	100	0	0	0
4-O-9-H	49.6±15.4	52.6±12.3	54.0±10.9	80	0	0	0
4-O-9-D	24.6±14.2+	38.4±7.9+	40.6±5.1+	100	0	0	0
5-O-3-H	58.6±12.9	49.2±9.2	41.2±12.4	80	0	0	0
5-O-3-D	40.8±3.8+	27.2±6.7+	22.4±12.9+	100	0	0	0
6-O-5-HN	57.4±3.2	58.0±4.6	53.2±7.1	0	0	0	0
6-O-5-DN	36.0±12.5+	61.7±8.1+	35.0±13.1+	0	0	0	25
7-O-19-H	25.7±5.1	31.0±4.1	23.2±7.5	60	0	0	20
7-O-19-D	8.0±2.8+	9.2±2.1+	10.0±2.8+	100	0	0	40

Table 2. Continued

Stand code	Terminal increments [cm]			Trees with a tangle [%]	Trees with rot		
	2009	2008	2007		Stem base [%]	Stem [%]	Roots [%]
1-S-1-H	33.5±3.2	22.8±6.3	20.0±3.7	100	0	0	0
1-S-1-D	23.7±3.8+	18.5±6.2–	18.2±7.7–	100	0	0	0
2-S-2-H	32.5±6.9	42.8±8.9	35.8±3.7	100	0	0	0
2-S-2-D	18.2±8.2+	17.7±7.8+	22.1±8.1+	100	0	0	0
3-S-4-H	51.4±6.8	65.4±9.2	64.5±6.8	100	0	0	0
3-S-4-D	40.0±10.4-	60.5±7.2-	58.4±5.5-	100	0	0	0

Table 3. Health condition and rooting depth in horizontal roots of visually healthy and declining Norway spruce trees

Stand code	Trees affected by rot of horizontal skeletal roots (HSR) [%]	HSR with rot [%]	Trees affected by honey fungus in HSR [%]	HSR infested by honey fungus [%]	Honey fungus infestation [degree]	Rooting depth [cm]
1-D-3-H	16	0	100	64	1.9±0.9	10.0±1.0
1-D-3-D	100	20	100	92	0.8±0.7+	10.0±1.0–
2-D-5-H	0	0	100	89	1.1±0.6	9.4±1.6
2-D-5-D	20	21	100	100	2.2±0.7+	10.0±1.0–
3-D-6-HN	0	0	100	70	1.0±0.2	10.1±0.7
3-D-6-DN	100	68	100	79	1.5±1.2+	9.8±1.2–
4-D-9-H	25	7	100	98	1.9±0.6	10.1±0.9
4-D-9-D	50	30	100	100	2.5±0.8+	9.8±0.9–
5-D-21-H	20	12	100	77	1.1±0.7	14.5±1.2
5-D-21-D	80	47	100	96	2.7±1.2+	14.9±3.2–
1-O-2-H	0	0	100	45	0.5±0.5	12.3±1.9
1-O-2-D	0	0	100	100	2.2±0.6+	11.1±1.6–
2-O-4-H	0	0	100	65	0.9±0.8	10.7±1.1
2-O-4-D	0	0	100	100	1.8±0.6+	10.6±0.9–
3-O-5-H	0	0	100	60	0.7±0.7	13.3±1.5
3-O-5-D	0	0	100	100	2.3±0.7+	11.3±1.9–
4-O-9-H	0	0	100	67	0.8±0.7	8.6±1.6
4-O-9-D	0	0	100	93	1.6±0.7+	10.4±1.1–
5-O-3-H	0	0	100	62	0.7±0.6	12.1±1.8
5-O-3-D	0	0	100	100	2.0±0.7+	12.7±2.7–

Table 3. Continued

Stand code	Trees affected by rot of horizontal skeletal roots (HSR) [%]	HSR with rot [%]	Trees affected by honey fungus in HSR [%]	HSR infested by honey fungus [%]	Honey fungus infestation [degree]	Rooting depth [cm]
6-O-5-HN	0	0	100	72	0.9±0.7	13.9±1.9
6-O-5-DN	25	3	100	94	1.8±0.9+	11.3±1.7–
7-O-19-H	20	1	100	64	0.7±0.7	21.8±6.7
7-O-19-D	0	0	100	100	2.4±0.6+	16.1±3.6+
1-S-1-H	0	0	100	64	1.2±0.4	8.6±1.3
1-S-1-D	0	0	100	81	1.5±0.6+	8.4±1.1–
2-S-2-H	0	0	100	69	1.6±0.7	8.4±1.3
2-S-2-D	0	0	100	85	1.8±0.8–	8.8±1.5–
3-S-4-H	0	0	100	63	1.4±0.6	10.2±0.9
3-S-4-D	0	0	100	83	1.6±0.9-	10.0±0.9-

Table 4. Health condition and rooting depth in anchor roots in visually healthy and declining Norway spruce trees

Stand code	Trees with anchor roots [%]	Trees affected by rot of anchor roots [%]	Anchor roots affected by rot [%]	Trees infested by honey fungus in anchor roots [%]	Anchor roots infested by honey fungus [%]	Honey fungus attack [degree]	Total rooting depth [cm]	Rooting depth of functional roots [cm]
1-D-3-H	100	33	10	100	100	1.3±0.7	34.8±8.9	33.2±8.6
1-D-3-D	100	50	42	100	100	2.8±0.9+	25.9±7.2+	15.4±8.2+
2-D-5-H	100	25	17	100	100	1.7±0.5	39.0±17.7	39.0±16.5
2-D-5-D	100	75	37	100	100	2.3±0.6+	46.7±5.2–	17.7±4.8+
3-D-6-HN	100	20	7	80	100	1.4±1.0	37.5±10.8	35.2±11.2
3-D-6-DN	100	100	55	100	100	1.5±1.0–	37.8±13.8–	28.2±12.2–
4-D-9-H	100	100	34	100	100	1.7±0.6	47.6±12.9	43.3±11.2
4-D-9-D	100	100	52	100	100	2.7±1.1+	51.7±18.8–	17.5±6.6+
5-D-21-H	100	60	17	100	100	1.7±0.9	60.7±22.8	56.2±21.6
5-D-21-D	100	100	39	100	100	2.5±1.2+	64.3±18.3–	28.9±10.3+
1-O-2-H	0	0	0	0	0	0	0	0
1-O-2-D	0	0	0	0	0	0	0	0
2-O-4-H	0	0	0	0	0	0	0	0
2-O-4-D	0	0	0	0	0	0	0	0

Table 4. Continued

Stand code	Trees with anchor roots [%]	Trees affected by rot of anchor roots [%]	Anchor roots affected by rot [%]	Trees infested by honey fungus in anchor roots [%]	Anchor roots infested by honey fungus [%]	Honey fungus attack [degree]	Total rooting depth [cm]	Rooting depth of functional roots [cm]
3-O-5-H	33	0	0	100	100	3.0±0.7	56.0±4.2	0
3-O-5-D	0	0	0	0	0	0	0	0
4-O-9-H	100	0	0	100	94	1.7±0.6	43.3±12.2	25.0±0.8
4-O-9-D	100	0	0	100	100	3.1±1.0+	44.7±9.3–	0
5-O-3-H	80	0	0	80	83	1.1±0.6	40.1±6.4	38.1±2.8
5-O-3-D	0	0	0	0	0	0	0	0
6-O-5-HN	40	0	0	40	100	1.8±0.4	62.5±0.7	54.4±10.5
6-O-5-DN	100	25	20	100	100	2.6±1.3+	26.0±6.6+	0
7-O-19-H	100	0	0	100	84	1.3±0.8	59.5±17.8	55.7±9.5
7-O-19-D	100	40	29	100	100	3.3±1.0+	42.0±10.3+	0
1-S-1-H	66	0	0	33	60	1.0±0.3	21.6±1.8	21.6±1.8
1-S-1-D	33	0	0	33	66	1.4±0.2–	18.0±6.9–	18.0±6.9–
2-S-2-H	50	0	0	0	0	0	23.5±3.5	23.5±3.5
2-S-2-D	16	0	0	16	25	1.1±0.2	23.5±4.8–	23.5±4.8–
3-S-4-H	50	0	0	50	66	1.0±0.3	35.3±8.3	35.3±8.3
3-S-4-D	33	0	0	33	100	1.5±0.7–	22.3±4.5+	22.3±4.5+

Table 5. Index P, biomass, vitality and mycorrhizal infection of fine roots in visually healthy and declining spruce trees

Stand code	Total I_p	I_p of healthy roots	I_p of functional roots	Biomass [g 100 ml^{-1} of soil]	Vitality [in % of control]	Mycorrhizal infection [µg of glucosamine . g of dry matter^{-1}]
1-D-3-H	5.1±1.3	4.4±1.1	4.0±1.0	*	*	*
1-D-3-D	4.4±0.9–	2.2±0.6+	0.9±0.4+	*	*	*
2-D-5-H	5.8±2.7	4.9±1.6	4.1±1.3	*	100	11.94±0.59
2-D-5-D	5.4±1.8–	3.3±0.9–	2.4±0.8+	*	121	11.54±0.53–
3-D-6-HN	8.7±1.8	8.6±1.8	8.6±1.8	0.653±0.008	*	*
3-D-6-DN	7.6±1.4–	3.5±0.7+	3.1±0.7+	0.478±0.011+	*	*
4-D-9-H	16.0±4.4	13.1±3.8	10.6±1.8	0.512±0.014	100	11.04±0.48
4-D-9-D	15.7±4.3–	8.7±2.6+	4.9±1.1+	0.429±0.007+	118	13.37±0.35+

Table 5. Continued

Stand code	Total I_p	I_p of healthy roots	I_p of functional roots	Biomass [g 100 ml^{-1} of soil]	Vitality [in % of control]	Mycorrhizal infection [µg of glucosamine . g of dry matter^{-1}]
5-D-21-H	21.6±5.7	17.0±4.1	12.8±2.7	0.372±0.011	100	9.57±0.64
5-D-21-D	17.6±3.6–	10.2±2.8+	5.8±0.9+	0.464±0.010+	133	11.54±0.56+
1-O-2-H	7.37±1.52	7.37±1.52	7.37±1.52	*	*	*
1-O-2-D	3.22±0.66+	3.22±0.66+	1.99±0.86+	*	*	*
2-O-4-H	7.82±2.50	7.82±2.60	7.82±2.50	0.561±0.008	100	*
2-O-4-D	3.33±2.05+	3.33±2.05+	3.14±1.19+	0.475±0.010+	68	*
3-O-5-H	9.19±2.59	9.19±2.59	7.59±0.18	0.508±0.012	100	12.20±0.70
3-O-5-D	3.48±0.52+	3.48±0.52+	2.05±0.56+	0.365±0.005+	81	11.27±0.45+
4-O-9-H	8.50±2.24	8.50±2.24	7.54±2.07	*	*	*
4-O-9-D	5.78±3.24+	5.78±3.24+	4.96±1.85+	*	*	*
5-O-3-H	4.95±1.18	4.95±1.18	4.95±1.18	0.726±0.008	100	11.94±0.55
5-O-3-D	2.82±0.87+	2.82±0.87+	2.18±0.18+	0.514±0.006+	82	9.02±0.48+
6-O-5-HN	9.67±2.56	9.67±2.35	9.48±2.41	0.929±0.011	100	12.57±0.44
6-O-5-DN	4.92±1.45+	4.54±1.47+	3.82±2.08+	0.749±0.011+	64	11.79±0.53+
7-O-19-H	29.02±7.90	28.23±2.45	23.36±1.97	0.937±0.006	100	11.95±0.64
7-O-19-D	9.11±2.85+	4.54±1.47+	3.82±2.08+	0.552±0.010+	57	10.95±0.51+
1-S-1-H	2.98±0.83	2.98±0.83	2.98±0.83	*	*	*
1-S-1-D	1.55±0.66+	1.55±0.66+	1.55±0.66+	*	*	*
2-S-2-H	3.96±0.81	3.96±0.81	3.96±0.81	*	*	*
2-S-2-D	2.28±0.76+	2.28±0.76+	2.28±0.76+	*	*	*
3-S-4-H	2.67±0.84	2.67±0.84	2.67±0.84	*	*	*
3-S-4-D	1.16±0.34+	1.06±0.46+	1.06±0.46+	*	*	*

*Not determined.

Orlík locality (GFT 7S)

At this locality, all the analyzed declining trees had evidently smaller terminal increments compared to the healthy trees (Table 2). In one of the stands, there were observed also significantly shorter needles (values not given). In the declining trees, root rot was detected only in two of the seven analyzed stands, in the extent of up to 40%. The proportion of horizontal and anchor roots affected by rots was nonetheless fairly low (not exceeding 3% in horizontal roots and 30% in anchor roots). Stem base or bole rots were not identified in any of the analyzed either healthy or declining trees (Table 2).

Honey fungus infestation was identified in horizontal skeletal roots of all healthy and declining trees, but the degree of attack was significantly higher in the declining than in the healthy trees. In the damaged trees, the level of infestation of horizontal skeletal roots by honey fungus (Table 3) reached 100% and in healthy trees 50%. As a result of malformation into tangle, not all the analyzed trees had developed sinker roots. The developed sinker roots in healthy as well as declining trees were infested by honey fungus. The degree of attack in declining trees mostly exceeded the value of 3 (Table 4). The absence of anchor roots or their high infestation by honey fungus severely limited the rooting depth in functional roots in the declining trees (Table 4).

In all declining trees, the identified value of total I_p was up to 50% lower than in healthy trees. With regard to the low incidence of root rots and the 3rd-degree and higher infestation of the roots by honey fungus, the total I_p, I_p of healthy roots and I_p of functional roots in healthy and declining trees did not vary in most stands. The overall trend was however preserved – I_p values of healthy roots and of functional roots in declining trees were roughly half of the healthy trees values. All the declining trees had significantly lower biomass of fine roots, lower vitality, and they suffered from mycorrhizal infection (Table 5).

Sokolí skála Rock locality (GFT 7S, 8S)

In the selected stands at the locality Sokolí skála Rock, we detected a decrease in the terminal increment and changes in the needle length. In contrast to the locality in FAVZ 4, this site did not have any incidence of root, stem base or bole rots in either healthy or declining trees (Table 2). The horizontal skeletal roots of all healthy and declining trees were infested by honey fungus. In healthy trees, honey fungus infestation affected ca. 60% of the roots, and in declining trees ca. 80%. In both cases, the degree of honey fungus infestation was identical and did not exceed 1.8 (Table 3). The incidence of honey fungus in anchor roots of healthy and declining trees was more or less the same. No significant differences in the degree of anchor roots infestation by honey fungus were identified, and its value in healthy and declining trees did not exceed 1.5 (Table 4). Nevertheless, the total I_p value in declining trees amounted only to one half of the healthy trees. Since the roots were not attacked either by rot or by honey fungus of the 3rd degree or higher, the same trend and absolute values were detected for the I_p of healthy roots and I_p of functional roots (Table 5).

Discussion

According to Latner (1994), the damage to the forests in the Hrubý Jeseník Mts became apparent since the turn of the years 1978/1979 when an extreme drop in temperature caused the latent syndrom turn into obvious symptoms. The damage to the stands culminated in 1985 (Balcar et al., 1994). Henžlík (1994) states that medium up to severe damage occurred in the area from Keprník to Praděd and in the direction toward Loučná, while more severe damage was identified around Medvědí vrch Hill and Orlík. In the early 1990s, the decline of stands stopped, and their condition was improved (Chmelíček, 1992). According to Vacek et al. (1994), 28% of the acreage of montane forests was classified into the pollution damage zone B and 71.9% of the area into zone C. Roughly in 2000, the damage to the Jeseníky Mts could be noticed again. At present, some parts of the mountain range are classified in the pollution damage zone B (the pollution damage zone nevertheless does not express the degree of air pollution load but assess the tree species growth on the site in a complex manner).

The decline of spruce stands occurring in numerous regions of the country from the 1970s onwards was manifested in various ways. Materna (1994) described defoliation induced by increased concentrations of sulphur dioxide, and subsequent dieback of stands, as well as manifold colour changes in needles either across the whole crown or only on several branches – affecting equally all generations of needles or only some of them and apparent throughout the whole year or only in some seasons. The author also characterized the type of colour changes which impacted older generations of needles with increasing intensity, and colour transition from green in the youngest generations to gradual yellowing and browning in older generations and their premature shedding. He pointed out that this trend may lead to the dieback of individual trees and their entire groups. The author notes that such cases were known from the ridges of the Šumava Mts, Jeseníky Mts and the western Krušné hory Mts. Apart from this particular type of yellowing, there was also distinct uniform yellowing of spruce needles associated with more extreme manifestations with a smaller increment present in mountain locations, chiefly at exposed sites or secondarily impoverished soils. Affected were especially young plantations and young-growth stands before canopy closing. Colour changes in needles were linked with disorders in mineral nutrition, especially with the lack of basic cations of Mg and Ca washed out from the soil due to the long-term impact of acidic depositions (Zöttl and Hüttl, 1986; Blanck et al., 1988; Schulze et al., 1989; Block, 1991; Evers, 1994; Hüttl and Schaaf, 1997 and others). The fact that the principal cause was the nutritional deficiency in magnesium was verified by the positive response to fertilization by magnesium in different forms (Materna, 1994). This cause of decline does not seem likely in the analyzed stands since the concerned sites were fertile or fresh (4B, 7S, 8S) and leaf analysis did not ascertain any deficiency of Mg in the needles.

The assessed stands are situated at altitudes of 650–1180 m a.s.l., i.e. in FAVZ 4–8, while the intensity and progress of decline in lower and higher Forest Altitudinal Vegetation Zones varied. Our analyses determined also altitude-based variations in development and health condition of the root system.

The root systems of declining trees at the Dobrá voda locality (GFT 4B) were seriously infested by honey fungus, and had a large share of roots attacked by rot. Root rot affected primarily anchor roots, which resulted in the significantly decreased rooting depth of functional roots and reduced capacity of trees to use groundwater. Gradual loss of functionality of the individual roots due to rot renders the tree incapable of ensuring sufficient water uptake, and the tree quickly dies back. This fact followed out from the analysis of climatic data from the hydrometeorological station Karlova studánka (780 m a.s.l.). The data smoothed by linear regression show that between 1961 and 2007, the mean air temperature in the period April–September increased by 1.3 °C, precipitation totals for the same period decreased by 113.5 mm, mean annual temperature rose by 0.8 °C, annual hours of sunlight increased by 265 hours and potential transpiration increased, too. All of these phenomena may induce spruce weakening, and represent predisposition factors of its decline. Also Latner (1994) drew attention to the increase in average monthly air temperatures and adverse precipitation conditions, chiefly in the area of the Jeseníky Mts in 1993. Similar symptoms of decline and infestation by honey fungus of trees hitherto visually healthy – in connection with the rise of mean temperatures and fall of precipitation, were detected on fertile sites in the Bohemian-Moravian Upland (Mauer et al., 2008).

In higher Forest Altitudinal Vegetation Zones (Orlík and Sokolí skála Rock localities), spruces grew on fresh sites (GFT 7S and 8S). In contrast to lower altitudes, declining trees at these localities had significantly smaller root systems than healthy trees (see Table values of total I_p). The small root systems of declining trees were always caused by their malformation into tangle which did not develop only in naturally regenerated trees. Root system deformations are irreversible and can arise during incorrect cultivation of containerized, ball and balled planting stock (Mauer, 1999; Jurásek and Martincová, 2001; Pampe and Häseker, 2003; Jurásek et al., 2004) or at inappropriately chosen outplanting method (Sauer, 1984; Strohschneider, 1987; Jurásek et al., 1999; Nörr 2003a, b, 2004). The state of the analyzed stands in which the tangle malformation originated cannot be identified with certainty but the concerned trees may suffer very serious consequences. According to Jurásek and Martincová (2001), the deformations increase the risk of honey fungus infestation due to higher concentration of saccharides in the bends of malformed roots. Sauer (1984) equally assumes that malformations lead to physiological weakening of the plants (even though this is not obvious from the growth of shoots at first) which heightens the risk of attack on the tree by secondary harmful agents. Both healthy and declining trees had horizontal skeletal roots decayed by honey fungus, anchor roots were not always attacked, and the intensity of the 3rd degree and higher was reached only in isolated cases. Due to malformations in some stands (particularly at the Orlík locality), the root systems did not develop any anchor roots at all. This led to low rooting depth and a limited possibility of water uptake from deeper soil layers. Compared to lower altitudes, in these localities the root systems of declining trees were not impacted by rots to a greater extent. It can be thus said that the health condition of root systems in higher altitudes was better than in lower situated sites. Insufficient water to trees resulting from the deteriorated health condition of their root system is not probable. This means that the decline of spruce stands in higher Forest Altitudinal Vegetation Zones of the Jeseníky Mts is probably also due to another stress factor with a long-lasting effect. High shoot increments together with lower levels of biomass and mycorrhizal infection of the fine roots could indicate increased nitrogen depositions (Heinsdorf, 1991). We cannot even exclude the possibility that the decline is attributed to soil microorganisms inducing changes to fine roots – which would conform to the assumption of Nechwatal and Osswald (2003) made based on their experiments.

The identified changes to the root system and expected future climate trend suggest for the field forestry measures excluding spruce from regeneration aims on fertile sites up to FAVZ 4 inclusive. At present, the reconstruction of spruce stands runs with broadleaved species of a wide ecovalence. For lower altitudes may be recommended pine and oak, for higher altitudes beech and sycamore maple. During regenerations, a proper care is to devote to bio-technique of planting (elimination of root system deformations) and spruce cultivation manner assuring the largest possible root system.

Conclusions

The paper analyzes the development and health condition of the root system of healthy and declining Norway spruce trees at three localities in the Jeseníky Mts. The analyzed stands in all locations are situated on fertile sites with no detected nutritional deficiency. The decline was manifested in all age classes of naturally as well as artificially regenerated trees. All of the analyzed trees were affected by root system malformation into tangle and infested by honey fungus (*Armillaria* sp.).

Up to FAVZ 4 (GFT 4B), spruce trees do not meet their ecological optimum. After their weakening by water deficiency, the root system becomes aggressively infested by honey fungus which is fast to induce rots of the roots, stem base and stem. The weakened trees become attacked by bark beetle, too.

In FAVZ 7 and 8 (GFT 7S, 8S), declining trees always have a substantially smaller root system characterised with smaller rooting depth and colonized by honey fungus – as a consequence of malformations. Honey fungus does not cause rots of the roots, stem base or stem. Declining trees have lower biomass, vitality and suffer from mycorrhizal infection of fine roots.

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Vývin a zdravotní stav kořenového systému smrku ztepilého (*Picea abies (*L.) Karst.) v oblasti Jeseníků

Souhrn

V posledních přibližně deseti letech se v Jeseníkách začalo opět projevovat chřadnutí porostů smrku ztepilého. Protože je známo, že kořenový systém bývá často dříve a více ovlivněn než nadzemní část stromu, cílem práce bylo posoudit, zda existuje vzájemný vztah mezi chřadnutím a vývinem a zdravotním stavem kořenového systému této dřeviny.

Šetření byla realizována v celkem 16 porostech na LS Město Albrechtice a Karlovice LČR s.p. V každém porostu byly vzájemně srovnávány stejně vysoké zdravé a chřadnoucí stromy (změna asimilačního aparátu 40–60 %). Kontrolou byly stromy zdravé. Na nadzemní části každého analyzovaného stromu byly měřeny a hodnoceny: celková výška, tloušťka kmene v $d_{1,3}$, délka terminálních výhonů v letech 2007, 2008, 2009 a délka jehlic. Ve vybraných porostech byly realizovány chemické analýzy dvou posledních ročníků jehlic. Na příčných řezech kmenem byl zjišťován výskyt hnilob kmene. Kořenové systémy byly vykopány ručně a na každém z nich byly zjišťovány: počet, tloušťka a délka horizontálních kosterních kořenů, počet a tloušťka kotevních kořenů, počet a tloušťka panoh a počet a tloušťka nekosterních horizontálních kořenů vyrůstajících z báze kmene. Z naměřených hodnot byl vypočítán Index ploch. Na vyzvednutých kořenových systémech byl zjišťován výskyt deformace do strboulu. Zdravotní stav kořenů (výskyt hnilob) byl posuzován na podélném řezu každým kořenem. Ve vybraných porostech byla zjišťována biomasa, životnost a mykorhizní infekce jemných kořenů.

Ze šetření vyplynuly následující závěry:

Na všech lokalitách rostly analyzované porosty na živných stanovištích, kde nebyla zjištěna deficience ve výživě. Chřadnutí se projevovalo u stromů všech věkových tříd, a to jak u stromů z přirozené tak i z umělé obnovy. Všechny analyzované stromy měly kořenové systémy deformovány do strboulu a byly napadeny václavkou (*Armillaria* sp.).

Do 4. lesního vegetačního stupně (SLT 4B) nerostou smrky v optimu ekovalence. Po jejich oslabení nedostatkem vody je kořenový systém agresivně napadán václavkou, která rychle vyvolává hniloby kořenů, báze kmene i kmene. Oslabené stromy jsou napadány i kůrovcem.

V 7. a 8. lesním vegetačním stupni (SLT 7S, 8S) mají chřadnoucí stromy vždy v důsledku deformací podstatně menší kořenový systém, který je kolonizován václavkou a má menší hloubku prokořenění. Václavka nevyvolává hniloby kořenů báze kmene nebo kmene. Chřadnoucí stromy mají nižší biomasu, životnost a mykorhizní infekci jemných kořenů.

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