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Response of norway spruce (*Picea abies* /L./ Karst.) at lower elevations of the Bohemian-Moravian upland to the changing climatic conditions and to the weather course

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Abstract The Bohemian-Moravian Upland shows a large-scale decline and dieback of Norway spruce up to Forest altitudinal vegetation zone (FAVZ) 5: it has been observed in the last 7 years and its course is rapid. Healthy, declining and standing dry trees of identical height were mutually compared in nine forest stands (aged 3 – 73 years). Parameters measured were : increment dynamics, root system architecture, biomass, fine roots viltality and mycorrhiza, infestation by biotic and abiotic agents. Analyses were made of 414 trees, soil characteristics and weather course in 1961-2004. Predisposition factors are warming and precipitation deficit. Weakened trees are aggressively infested by honey fungus (*Armillaria mellea*), the trees die of root rots. The mechanism of damage and dieback of trees is described.

Key words: *Norway spruce, decline, weather change, root system, rots*

Introduction

In spite of the fact that Norway spruce is a climax species of higher and montane altitudes, it presently occurs in all forest altitudinal vegetation zones and in most forest sites of the Czech Republic, its spread having been induced by intentional and artificial cultivation by humans. Šindelář (1995) points out that at a turn of the 1st and 2nd millennium the share of spruce in the total area of Czech forests was about 15% and its today's representation is over 50%. The intentional cultivation of spruce showed also in lower FAVZs. Průša (2001) informs that in forest records from the Orlík estate (area 10,000 ha, altitude 354-570 m a.s.l., prevailing group of forest types /GFT/ 3S) spruce was just mentioned to occur in 1584, being recorded as an important admixture in 1708, taking up 57% of the estate area in 1877, which the figure increased to 70% of the estate area in 1980. The situation in other parts of the country was developing in a similar way. At the present time, spruce stands occupy over 40,000 ha in FAVZs 1 and 2, and over 500,000 ha only on water-unaffected sites in FAVZs 3 and 4.

The intentional large-scale use of spruce had one good reason – spruce has been always the most favourable tree species in economic terms – low number of planted out seedlings for regeneration, easy tending, relatively short rotation period, still most demanded wood raw material. Due to the same reasons –despite the existing knowledge about growth and health problems- the representation of spruce in current target compositions is much greater than in the natural composition. Although spruce was planted up to a very boundary of the species's ecovalence, its emergence did not bring any greater problems until the end of the last century. Being affected by large-scale calamities (wind, snow, insects) the spruce stands did not exhibit any decline and the calamities were ascribed to the monocultural system of forest management. At the end of the last century the stands of spruce were affected by large-scale decline and dieback, namely in higher elevations. Although the reasons to the situation were not exactly explained, the health condition of stands evidently improved after the change of emission situation. It can be therefore realistically deduced that the reason to spruce decline was the impact of air pollution in the broadest sense of the word. After the period of a certain optimism, however, foresters have to face a new and serious problem.The decline and dieback of spruce forest stands occurs again and the impact is shown much more (nearly on the whole area) by spruce stands in lower altitudinal vegetation zones (up to FAVZ 5) than in higher situated FAVZs.

Damage to spruce in lower FAVZs does not have symptoms of acute character but clearly those of chronic damage with trees dying individually after having exceeded the individual stress boundary. A number of surveys (PUHE et al. 1986; MURACH 1991; PERSSON et al. 1995; MURACH and PARTH 1999; HRUŠKA and CIENCIALA 2001; PALÁTOVÁ and MAUER 2004, etc.) indicate that a tree part which is affected first and most with hardly any regard to the cause of stress is as a rule the root system (changes in architecture, rots, affected functionality of fine roots and mycorrhizal links).

Work objectives and methods

The authors analyzed reasons to the decline of spruce stands in five regions of the Czech Republic – from FAVZ 2 to FAVZ 5 on nutrient-rich and acidic sites. With respect to the size of the paper and to the fact that results from all analyzed regions are consistent, surveys to be further extended upon in this paper will be those carried out in two localities of the Bohemian-Moravian Upland where 414 root systems were analyzed in 62 forest stand situations:

- Moravec (Forest administration LČR Nové Město na Moravě) – 480-520 m a.s.l., Forest types 4B1, 4B4, 4H1, air pollution damage zone C, age of analyzed forest stands 13-74 years, Norway spruce outside the optimum of its ecovalence. Decline shows in the last eight years, the course of dieback is very rapid (even a relatively little injured tree would turn into a snag within just several months – incidental felling of dead standing trees represents up to 80% of planned felling, snags are felled even five times a year). Visual symptom is yellowing of needles, which quickly turns into rusty-brow. At this stage the needles are shed. The colour change and the defoliation need not affect concurrently all branches of the 1st or higher orders. Namely in older trees the injury proceeds from the crown base to the crown top.
- Radiměř (FA LČR Svitavy) – 560-570 m a.s.l., Forest types 5K1, 5K2, air pollution damage zone C, age of analyzed forest stands 3-37 years, Norway spruce at a boundary of its ecovalence. The decline has been recorded in the last 2 years and has not required incidental felling yet. Visual symptom of the injury in all analyzed stands is yellowing of needles, which rapidly turns into rusty-brown in older stands. At this stage the needles are shed. The colour change and the defoliation do not affect all branches of the 1st or higher orders. Namely in older trees the injury proceeds from the crown base to the crown top and from the stem to the branch tip. Classical snags have not occurred yet.
- The two analyzed localities exhibit the following common features:
    - declining trees originate from all age classes
    - one stand includes healthy and injured trees growing side by side (in Moravec even dead standing trees)
- Primary objective of the survey: to mutually compare within one forest stand the emergence and health condition of the root system and of the above-ground part in declining and healthy trees of the same height with healthy trees as a control.
- Forest stands included in the analyses were monocultures with identical stocking growing on plain or on a mild slope (up to 5%), and trees chosen for partial analyses were only non-marginal co-dominant trees not injured by game.
- The analyses included in each of the stands 12 healthy trees, 12 injured trees and 12 snags up to an above-ground part height of 3 m, and at all times a minimum of 6 trees at an above-ground part height over 3 m.
- For an easy orientation and a better review the individual forest stands are in the below text designated with a 3-figure code as follows:
    - the first figure in the code (letter) is to designate locality (M – forest district Moravec, R – forest district Radiměř),
    - the second figure in the code (numeral) is to designate the above-ground part height of analyzed trees,
    - the third figure in the code (letter) is to express health condition of the analyzed tree (Z – healthy, P – injured, S – snag).

  (Example: M-23-Z = Forest district Moravec, above-ground part height 23 cm, healthy tree)
- Analyses of root system architecture and health condition
    - All roots were lifted by hand. Each root system was measured for up to 36 parameters and characteristics. Each tree was measured for 9 parameters of above-ground part growth. Tables of results contain only conclusive parameters. The parameter of Index p calls for an explanation: it is a calculated parameter to define the relation between root system and above-ground part size and its calculation was made as a ratio of the cross-sectional areas of all horizontal skeletal roots (HKK) and anchor roots (anchors) at the place of measurement (in mm²) to the length of above-ground part of trees in cm. The greater the Index p value, the larger the root system of the tree.
- Analyses of fine roots (< 1 mm) with a decisive significance for the assurance of nutrient uptake. analyzed parameters were as follows: biomass (weighing), vitality (by vital dyeing), mycorrhizal infection (quantitatively by chemical method and by measuring hyphal mantle thickness), type of functional mycorrhiza (anatomically after the fungus colouration in aniline blue).
- The two analyzed localities have the following common features: controls were trees with the defoliation (or with the changed colour of assimilatory apparatus) of up to 10%, injured were considered trees with the defoliation (or with the changed colour of assimilatory apparatus) of 40-60%.
- Rooting depth was monitored also in relation to individual soil horizons.
- Roots and stems were subjected to special analyses whose aim was to reveal their possible infestation by parasitic fungi (resin exudation is always induced

by honey fungus).

- Tree damage by biotic and abiotic agents was assessed visually.
- Both analyzed localities were subjected to chemical soil analyses and for both of them a record on the "Development of climatic conditions in 1961-2004" was elaborated. Values of global radiation were taken over from the ČHMÚ (Czech Hydrometeorological Institute) station in Znojmo-Kuchařovice, all other measurements were taken over from the ČHMÚ station in Velké Meziříčí (the station is situated at an altitude of 452 m and at a distance of 13 km from the analyzed forest stands in Moravec and 30 km from the analyzed forest stands in Radiměř). The presented data are values aligned to the regression line.

Results of the root system analysis – Moravec (Tabs. 1,2)

- Suppressed terminal increment was observed neither in the injured trees nor in the trees that became snags in the same year – this applying to all analyzed forest stands.
- Resin exudations on the roots and on the stem base were observed in nearly all healthy trees, in all injured trees and in snags – this applying to all analyzed forest stands.
- Rots of roots and stem base were observed to occur nearly in all healthy trees and in all injured trees; bole rots were recorded nearly in all trees over 20 m in height – this applying to all analyzed forest stands.
- Injured trees and snags with up to 5 m of above-ground part exhibited at all times a much worse root system pattern distribution than healthy trees with no essential differences found with respect to this parameter in older trees (see max. angle between HKK).
- All analyzed stands exhibited an intolerably high occurrence of tangle which is at all times smallest in healthy trees and shows a 100% incidence in snags.
- All snags and nearly all injured trees (with an exception of stand M-23-P) developed weaker root systems than the healthy trees; snags have a weaker root system than injured trees; both snags and injured trees exhibit a decreasing number of anchors in total Ip value (this applies to all stands – see Whole root system).
- Injury has a conspicuous link to root rots (applies to all stands – see Functional root system):
    - Ip value of the whole root system decreased by 30-60% in all injured trees, in older trees more than in younger trees,
    - rots affect anchors more than horizontal skeletal roots (the Ip value decrease in HKK is in all injured trees lower than the Ip value decrease for the whole root system; decreased was also the share of anchors in the Ip value for the whole root system),
    - rots affected healthy trees, too; younger trees were observed to have both HKK and anchors affected by rots, older trees only the anchors.
- All injured trees and snags created root system of a smaller rooting depth than the healthy trees; snags exhibited a smaller rooting depth than injured trees. In general, the rooting depth is given by tree age – older trees reach deeper soil horizons with their roots than younger trees (see Rooting depth of the whole root system).
- The disqualification of anchors (due to rots) considerably affected the original rooting depth in the injured trees (see Rooting depth of the functional root system).
- All injured trees exhibited an up to 50% decrease of fine roots biomass.
- Younger injured trees showed an evidently decreased vitality of fine roots while the fine roots vitality in older injured trees showed an increase.
- Mycorrhizal infection was not affected in younger injured trees while older injured trees exhibited an increased mycorrhizal infection.
- The injury had no influence on the type of functional mycorrhiza. Functional mycorrhiza is a light ectomycorrhiza; no incidence was detected of ectendomycorrhiza or pseudomycorrhiza. As compared with healthy trees, however, an about 8% occurrence was recorded of black ectomycorrhiza.

Results of the root system analysis – Radiměř (Tabs. 1, 2)

- Injured trees exhibited no essential decrease in terminal increment – this applying to all analyzed stands.
- All analyzed trees with above-ground part height over 3 m exhibited resin exudations on roots and all injured trees showed them also on the stem base. More than a 50% occurrence of resin exudations on the stem base was found also in all healthy trees.
- Nearly all analyzed injured trees with above-ground part height over 3 m exhibited root rots with the root rots (up to 100%) being detected also in some healthy trees. Stem base rots and bole rots were recorded in trees taller than 8 m. No trees were affected by rots up to above-ground part height of 2 m.
- All analyzed injured trees of above-ground part height greater than 3 m exhibited an evidently worse root pattern distribution (see max. angle between HKK) and a nearly 100% incindence of tangle. The intolerable root pattern distribution and the 100% tangle incidence were recorded in all analyzed trees (both healthy and injured) with above-ground part height of up to 2 m.

Table 1 : Characteristics of above-ground part growth, root system development and health condition

Stand designation	Terminal increment (cm)		Honey fungus incidence (in % of trees)		Rots (in % of trees)			Max. angle between horizontal skeletal roots (degrees)	Deformation into tangle (in % of trees)	Index p						Rooting depth (cm)	
										Whole root system (with and without rot)			Functional root system (roots without rot)				
	2005	2004	Roots	Stem base	Roots	Stem base	Bole			Ip HKK	Ip HKK +anchors	% share of anchors	Ip HKK	Ip HKK +anchors	% share of anchors	Whole root system	Functional root system
M2-S-3-Z	31	41	100	17	100	0	0	55	33	4.4	7.6	38	4.2	7.2	36	47	47
M2-S-3-P	55	41	100	100	100	50	0	90	50	3.0	4.4	30	2.4	3.1	23	48	17
M2-S-3-S	47	60	100	100	100	100	0	160	100	1.8	2.2	15	-	-	-	17	-
M-S-5-Z	41	71	50	50	67	0	0	76	67	5.5	6.7	19	5.2	6.5	20	59	59
M-S-5-P	33	67	83	83	100	50	0	111	83	3.8	4.6		3.6	3.7	4	47	13
M-S-5-S	doesn’t apply		doesn’t apply		doesn’t apply			doesn’t apply		doesn’t apply			doesn’t apply			doesn’t apply	
M-S-7-Z	46	70	100	100	33	17	0	83	33	8.0	10.5	25	8.0	10.3	25	82	82
M-S-7-P	36	60	100	100	100	100	0	92	100	4.2	4.8	11	3.4	3.7	6	36	31
M-S-7-S	34	70	100	100	100	100	0	96	100	5.1	6.2	18	-	-	-	34	-
M-S-12-Z	34	41	100	100	0	50	0	71	50	12.6	17.5	28	12.6	17.0	28	125	125
M-S-12-P	12	18	100	100	100	100	0	76	100	6.1	9.4	33	6.1	6.8	11	98	56
M-S-12-S	19	20	100	100	100	100	0	77	100	7.2	7.9	8	-	-	-	76	-
M-S-23-Z	17	21	100	100	100	67	67	50	17	12.7	24.9	48	12.7	23.8	46	127	127
M-S-23-P	16	24	100	100	100	100	100	110	100	13.7	23.3	39	9.2	12.5	24	119	85
M-S-23-S	15	22	100	100	100	100	100	71	100	6.3	11.4	45	-	-	-	88	-
M-S-25-Z	28	44	100	100	100	50	50	35	0	9.8	20.4	62	9.8	18.9	47	169	169
M-S-25-P	44	52	100	100	100	100	100	70	50	4.9	14.7	52	3.4	6.1	41	124	102
M-S-25-S	29	34	100	100	100	100	50	55	100	6.2	12.3	45	-	-	-	105	-
M-S-27-Z	29	41	100	100	100	100	67	42	50	17.8	26.5	32	17.8	24.9	28	130	130
M-S-27-P	26	35	100	100	100	100	83	63	50	6.9	11.8	42	3.5	5.5	32	105	85
M-S-27-S	31	38	100	100	100	100	83	72	100	2.9	11.0	73	-	-	-	113	-
R-S-1-Z	35	22	33	0	0	0	0	121	100	2.2	2.2	0	2.2	2.2	0	17	17
R-S-1-P	28	12	50	50	0	0	0	187	100	0.2	0.7	69	0.2	0.7	69	21	21
R-S-2-Z	61	38	50	50	0	0	0	83	100	6.3	6.6	0	6.3	6.6	0	27	27
R-S-2-P	60	27	83	17	0	0	0	145	100	1.8	2.2	20	1.8	2.2	20	29	29
R-S-3-Z	42	48	100	100	100	0	0	73	17	8.1	8.8	8	8.1	8.7	7	48	48
R-S-3-P	33	36	100	100	100	0	0	165	100	3.3	3.5	5	3.1	3.2	1	25	25
R-S-5-Z	50	51	100	50	0	0	0	80	50	6.9	7.0	1	6.9	7.0	1	27	27
R-S-5-P	42	45	100	100	100	0	0	185	100	5.4	5.8	6	3.5	3.6	4	33	18
R-S-8-Z	87	75	100	67	0	0	0	48	17	10.9	15.9	24	10.9	12.9	9	72	72
R-S-8-P	82	71	100	100	100	33	17	77	83	9.3	12.7	15	6.7	6.9	4	61	17

Table 2 : Biomass, vitality, mycorrhizal infection of fine roots and the type of mycorrhiza

Stand designation	Biomass (%)+ (%)	Vitality (%)+ (%)	Mycorrhizal infection (%)	Type of mycorrhiza
M-3-Z	100	100	100	ecto
M-3-P	56	86	96	ecto
M-5-Z	100	100	100	ecto
M-5-P	43	56	96	ecto
M-7-Z	100	100	100	ecto
M-7-P	62	64	149	to
M-12-Z	100	110	100	ecto
M-12-P	40	112	121	ecto
M-23-Z	100	100	100	ecto
M-23-P	58	125	134	ecto
M-25-Z	100	100	100	ecto
M-25-P	57	137	122	ecto
R-3-Z	100	100	100	ecto
R-3-P	49	142	140	ecto
R-5-Z	100	100	100	ecto
R-5-P	46	126	130	ecto
R-8-Z	100	100	100	ecto
R-8-P	40	163	174	ecto

Note: +relative expression, in all stand situations 100% of healthy trees

- All analyzed injured trees developed a weaker root system than healthy trees; the difference is diminishing with the increasing tree age. Injured trees in younger analyzed stands showed a higher share of anchors in the Ip value than healthy trees; the situation is opposite in older stands (see Whole root system).
- The injury has a linkage to root rots (see Functional root system):
  - Ip value of the whole root system decreased by 10-15% in all injured trees with root rot, in older trees more than in younger ones,
  - rots affected anchors rather than horizontal skeletal roots (the decrease of Ip values in HKK was in all injured trees lesser than the decrease of Ip values for the whole functional root system; the share of anchors in the Ip value for the whole functional root system was decreased, too),
  - rots affected healthy trees as well, in most cases only their anchors.
- All injured trees of above-ground part height over 3 m created root systems with a lesser rooting depth than healthy trees. Trees with above-ground part height of up to 2 m did not show any essential difference in the rooting depth of the whole root system (see Rooting depth of the whole root system).
- By the disqualification of anchors (due to their rots) the original rooting depth diminished in injured trees (see Rooting depth of the functional root system).
- All injured trees were observed to exhibit up to 60% decrease in the biomass of fine roots.
- All injured trees were observed to exhibit up to 60% increase in the vitality of fine roots and up to 70% increase in the mycorrhizal infection of fine roots.
- The injury had no impact on the type of functional mycorrhiza. Functional mycorrhiza is at all times light ectomycorrhiza; no incidence was recorded of ectendomycorrhiza and pseudomycorrhiza; injured trees exhibited a 5% incidence of black ectomycorrhizas.

Evaluation of results

- Symptoms of injury, detected tendencies and root system parameters of both injured and non-injured trees were nearly identical in the two localities whose site conditions (altitude and amount of nutrients) are little favourable (Radiměř) or even unfavourable (Moravec) for growing Norway spruce. This is corresponded to by the condition of the stands which are up to now less affected in Radiměř than in Moravec.
- The basic predisposition factor of tree injury is feeble root system; all healthy trees always developed larger root systems than injured trees, snags had an even smaller root system than injured trees (understood is the original root system – whole root system with rots and without them). Differences in the root system size were contributed to by the method of planting (see Root system malformations into a tangle) and forest stand tending.
- Up to the above-ground part height of 2 m and exceptionally also in some older trees the differences in the size of the functional root system are induced only by the planting method (root system rots were not detected). Nearly all these trees have their root systems deformed into the most serious malformation – tangle; injured trees have a markedly worse root system pattern distribution with deformations having evoked according to their severity development of the root system with a lesser count of lower-diameter root branches.
- Although it also holds that that the tree"naturally" developed a weaker root system with the increasing degree of injury from an above-ground part height of 3 m, the root system size was still impacted by rots on its individual root branches. Values of the originally developed root system (whole root system with rots and without rots) begin to markedly differ from those of the functional root system (root system without rots).

- Rots of individual roots affected all injured trees and a greater percentage of healthy trees (with the injured trees showing a much greater amount of affected roots than the healthy trees); dead standing trees exhibited all or nearly all root pattern branches affected by rots.
- Rots of roots, stem base and bole were evoked by honey fungus. As indicated by resin exudations, trees with above-ground part height of about 2 m exhibited the presence of honey fungus on roots or on the stem base; there were however no rots detected. In trees with above-ground part height from about 2-8 m the honey fungus induced –apart from the resin exudations- also the rots of individual root branches. In trees with above-ground part height over ca. 8 m the honey fungus induced rot was detected –apart from resin exudations and rots of individual roots- also on the stem base and on the bole itself. (It can be deduced that the impact of honey fungus is of a long-term character in the concerned localities, particularly in Moravec).
- The massive spread of honey fungus in the analyzed forest stands can be indirectly corroborated by the occurrence of a great number of trees with swallen stem bases, by resin exudations on the bole (e.g. the percentage of trees with stem resin exudations in Stand M-25 was visually established at 80%), or by the occurrence of sporocarps (e.g. in the immediate vicinity of analyzed forest stands in the Radiměř forest district a 100-year old sruce stand was felled in winter that did not show any visual symptoms of injury; however, at the end of the next growing season all stumps exhibited a massive occurrence of honey fungus fruit bodies).
- Honey fungus would never infest the entire root system but rather its individual roots. First to be infested by rots in trees with a pronounced anchoring root system are the anchors, later on the horizontal skeletal roots (HKK). Trees with a little expressive anchoring root system exhibit a simultaneous infestation of horizontal roots as well.
- Rots would first affect anchors shooting from the base or from the immediate vicinity of stem base. Both anchors and horizontal roots begin to putrefy from their tips.
- It does appear that the tree injury would be primarily induced by stem base rot or by bole rot but clearly by root rots. Dying are trees with no (or just mild) stem base rot or bole rot, some trees with these rots are still without any greater visual symptoms of injury.
- That it is not a weakening of the root system as a whole can be demonstrated by the fact that root system branches unaffected by rot increase their performance (namely in older trees which have adapted more and created a relatively large root system). Although the biomass of fine roots is observed to shrink due to the disqualification of individual root system branches, the fine roots exhibit a higher vitality, mycorrhizal infection, and no negative changes of the functional mycorrhiza are observed to occur; similarly, no essential changes have occurred up to now in the vertical distribution of the fine roots. The tree would concentrate a greater part of its energy to height growth (diameter increment is retarded in the injured trees).
- That root rots represent a tree-damaging factor can be documented by the fact that the original root system size of a now injured tree would be unambiguously enough to assure the successful tree growth.
- The analyses included only tree undamaged by game. However, there are also trees damaged by wildlife occurring in the two localities, which are subsequently aggressively infested by red heart rot (*Stereum sanguinolenteum*). The synergic action of the two aggressive fungal pathogens accelerates tree decline (25% rot of girth provokes an expressive decline also in trees with the Ip value decreased by 20%).
- Scheme of the gradual damage to trees:
    - honey fungus infests the root system and gradually disqualifies individual root branches from their function,
    - the functional root system is diminishing and so is the rooting depth,
    - the disqualification of individual root branches is responded to by the increased performance of healthy roots with energy being concentrated to height increment – assimilatory apparatus begins to show symptoms of injury,
    - after breaking "certain bounds" the remaining functional root system is no more capable of assuring nutrition and water – honey fungus very rapidly infests by rot also the remaining part of the functional root system and the tree dies,
    - the principle of damage is identical in trees with above-ground part of about 2 m – the injured trees have a small functional root system; size of the functional root system is however not affected by root rots but rather by root system malformations (development of a feeble root system).
- A question is what enables the aggressive attack by honey fungus and why trees with the small functional root system without rots die soon after plantation. Following out from the facts that:
    - the analyzed localities were not and are not affected by air-pollution,
    - the soil nutrients supply is sufficiently high and soils are of corresponding acidity,
    - spruce occurs on the very margin of the species' ecovalence in both localities,
    - the tree injury is observed in a few recent years and its course is rapid,

it is obvious that there is another stress factor participating in the tree injury.

- It is not only forestry that finds under the influence of climatic fluctuations and changes in the concerned localities. The analyses showed that gradual changes occurring in these localities since 1961 are as follows (Tab. 3):
    - annual sums of global radiation increased in 2005 by 40,702 J.cm^2 as compared with 1984. The increase approximately represents the sum of global radiation in the month of April,
    - mean annual temperatures were gradually growing and their increase as compared with the year 1961 was by 1.2 °C,
    - mean air temperatures in April-September were gradually growing and their increase as compared with the year 1961 was by 1.3 °C (with the greatest temperature increase in July and August),
    - annual solar radiation increased in the aligned series by 210 hours,
    - mean air temperatures of 0 °C exhibited the onset date gradually diminished by 18 days and the ending date extended by 7 days,
    - aligned annual total precipitation amounts are lower by 37 mm being in recent years strongly affected by torrential rains; the number of days without precipitation is considerably increasing (esp. in May-August),
    - annual Lang’s coefficient was rapidly falling (difference of 17.8)
- It follows from the annual precipitation sums (as compared with the average values of evapotranspiration for spruce in FAVZ 4) that the precipitation does not provide enough moisture for the successful growth of Norway spruce stands. Aligned water balance values for 1984-2004 exhibit a passive moisture balance for the period I-IX.
- It can be deduced from the carried out bioclimatic measurements and from the response of Norway spruce stands that a triggering factor of the injury is the change of climatic conditions ("drought"):
    - least injured are trees with a large root system which is capable of assuring more water and nutrients than a small root system,
    - after the tree weakening by drought the root system is infested by honey fungus,
    - rots of individual roots reduce the root system size; the “preferred” disqualification of anchors cuts the tree from groundwater, which further deepens the water deficit.
- Although the causes, the symptoms and the course of injury are identical in the two localities it can be assumed (on the basis of root system analysis, with the persisting current climatic situation) that the course of damage will be more expressive in Moravec (worse site conditions) than in Radiměř. The injury will affect in both localities young plantations and young stands whose root system is weaker as compared with older stands and reaching lesser rooting depths. In general, it is necessary to count with increased incidental felling in the already injured (weakened) older stands.

Table 3 : Development of climatic data in 1961-2004 and comparison with normal values in 1961-1990

Period	Characteristics and measured values	
	Mean annual air temperatures (°C)	Mean air temperatures in IV-IX (°C)
1961 - 1990	7.2	13.5
1961	6,8	13.1
2004	8.0	14.4
	Annual precipitation sums (mm)	Precipitation sums in IV-IX (mm)
1961 - 1990	594.3	366.6
1961	605.3	383.1
2004	568.2	337.4
	Annual Lang’s coefficient	Lang’s coefficient in IV-IX
1961 - 1990	82.5	27.2
1961	89.2	29.3
2004	71.4	23.5
	Absolute occurrence frequency of days with average daily air temperature +5 °C	Annual sums of average daily temperatures +5 °C
1961 - 1990	213.6	1 702
1961	211	1 625
2004	218	1 900
	Potential evapotranspiration in IV-IX (mm)	Moisture deficit cummulated in IV-IX (mm)
1961	440.4	28.8
2004	507.6	-46.2
	Precipitation abundance (mm.precipitation day-1)	Global radiation annual sums (J.cm-2)
1961	3.56	390 391 (year 1984)
2004	3.27	431 093

- The analyses indicate that reasons to the decline are as follows:
    - planting of Norway spruce outside the optimum of its ecovalence,
    - increased global radiation,
    - weather course change (spells of drought),
    - weak and malformed root system (induced by planting biotechnics and forest stand tending),
    - planting of non-autochthonous Norway spruce.
- A question remains to be asked what forestry measures can be applied to reduce (eliminate) the injury. Following out from two basic facts that:
    - no direct methods of protection exist against honey fungus, only indirect procedures focused on the assurance of good tree vitality,
    - foresters cannot affect the course of climate,

  one of possibilities is to grow a large root system of the tree, to use a high-quality stock for a careful planting (hole planting), to submerge the plants, to add organic matter to their roots – by this way it is possible to increase the root system size up to 3-times. From early age to carry out radical tending measures in order to strengthen the root system. After canopy enclosure (at a height of 4 m at the latest) to reduce the number of trees to 1,200. ha^{-1}. (After four years from the measure the root system size of released trees would increase by up to 60%). It is however a risky procedure since it was demonstrated by the survey that honey fungus can colonize also healthy trees inducing rots of some of their roots, i.e. that the suggested procedure can (with the persisting climate change) only zoom out the damage and the subsequent disintegration of forest stands.
- The only effective and long-term solution consists in a changed species composition. Norway spruce is to be entirely eliminated from regeneration targets up to FAVZ 3 and it should be also eliminated from regeneration targets on nutrient-rich and extreme sites of FAVZs 4 and 5. On acidic and water-enriched sites of FAVZs 4 and 5 Norway spruce should be used only as an individual admixture up to 30%. Similar conclusions were arrived at by Kantor (2002). In the case that it is decided to maintain Norway spruce at a greater share (even in lower FAVZs), it is a must to switch onto planting the spruce ecotype of wooded hills (there is only one seed orchard established up to now).
- It is necessary to minimize the incidence of solar radiation on soil in the existing Norway spruce groups of stands.

Conclusion

Norway spruce decline and dieback in lower Forest altitudinal vegetation zones has become one of the most serious problems of our forestry. It was induced by two factors – planting of spruce on the very bounds of its ecovalence and climate change (weather course) in the recent period of time. Weather course affects the condition of forest stands in individual years and in various aspects (with higher precipitation – wet year – the symptoms of injury are lesser and so is the injury of stands at sheltered aspects). Nevertheless, an unambiguous fact is that the stands are infested by honey fungus at nearly 100% - the same conclusions were published also by Jankovský and Cudlín (2002) . and it is therefore only a question of time when the parasitic fungus triggers the tree death (in the last 7 years we have among other things analyzed 2,600 Norway spruce root systems up to FAVZ 5 until the establishment of young plantations – 84% of young trees were infested by honey fungus, losses of Norway spruce after planting were by 25% higher than in FAVZ 6). In this situation it does not matter to foresters whether the climate change has been induced by anthropogenic activities or by objective factors. If we agree to the principle of "preliminary caution" –and this should be of priority importance in forestry- the current situation should be essentially and on principle resolved. The weather sway of several last years can provoke a total disintegration of not only the spruce stands. Also, it is time to give up the practice that Norway spruce is a pioneer tree species.

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