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Mineral nutrition in relation to the Norway spruce forest decline in the region Horný Spiš (Northern Slovakia)

Ľ. Ditmarová[1], J. Kmeť[2], M. Ježík[1], J. Váľka[1]

[1]*Institute of Forest Ecology of the Slovak Academy of Sciences, Zvolen, Slovak Republic*
[2]*Faculty of Forestry, Technical University Zvolen, Zvolen, Slovak Republic*

ABSTRACT: In this contribution we present the results of analyses of selected mineral nutrients in assimilatory tissues of spruce trees at different developmental phases (plants, adult trees) in the region Horný Spiš. The very close connection between mineral nutrient cycling and other physiological processes in the plants has been well recognised. The presented analyses of mineral nutrient cycling were done within comprehensive eco-physiological research assessing the physiology and health status of spruce stands in the study area. The research was conducted directly in the stand (Hliníky locality, Horný Spiš – two research plots: 1. plot with spruce stand in advanced decline, 2. control plot – without visible decline symptoms) and, at the same time as a pot experiment. The objective of the pot experiment was to verify the supposed negative influence of soil environment (in the locality with advanced decline of spruce stands) on the growth of spruce trees and their mineral nutrient conditions. The analyses of the material sampled from the stands revealed high amounts of manganese (Mn_T) that were in the toxicity range on both examined plots. Another negative finding was high amounts of toxic aluminium, primarily in needles of adult trees growing on the plot with symptoms of acute stand decline. This reflects a very low value of pH/H_2O – 3.7 (pH/KCl – 3 to 2.8) and total exhaustion of the soil suffering, moreover, from the lack of soil water. As for the differences in amounts of individual macronutrients between the plot with intensive decline and the control plot, no significant differences were found, with the exception of Fe. On the other hand, evident significant differences in risk elements Pb, Hg and Al were found. As for the differences in nutrient contents in spruce seedlings in the pot experiment (variants 1 to 6), we can see significant differences in macronutrient contents (N, P, Ca, K, Mn), in some cases also in risk element contents (Al).

Keywords: nutrition; Norway spruce; stress; spruce decline

The progressive massive decline of forest woody plants, primarily spruce, spreading in the regions Orava, Kysuce, Tatry and Spiš in recent years is a well-recognised fact. Similarly affected stands can be found in border regions in Poland and in the Czech Republic, Germany and Italy. The general cause is supposed to be a complex of adverse factors – long-term impacts of airborne pollutants generated by both local and remote foreign sources, low stability of even-aged, spatially poorly differentiated conifer monocultures, global climate change entailing an increase in the mean air temperature and deficit of the available soil water content, gradation of biotic pests, primarily wood-destroying fungi and bark beetles, etc. These negative phenomena are accompanied by changes in the chemistry of plant assimilatory tissues and changes in soil chemistry.

Toxic substances dispersed in the atmosphere and diluted in vertical and horizontal precipitation cause damage especially to assimilatory tissues of forest woody plants. They impair the protective layer on leaves and penetrate into the tissues from which they leach Mg contained in chlorophylls, and other biogenic elements, primarily K, Ca and P (Tausz et al. 1996). Toxic substances in the environment also decrease the potential synthesis of assimilates and disturb the mechanism of leaf stomata control. In such a way, they increase water losses followed by

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leaf drying. The changes in enzymatic activities are progressive; the leaves are aging prematurely. The result is lowered frost resistance of trees and disturbances in photosynthetic activities.

Today, it is possible to study the impact of mineral nutrition corresponding to different levels of physiological structures and functions. However, the function of nutrients is dependent on a number of factors connected with tree growth, ontogenesis, soil conditions and meteorology; consequently, to meet the issue is frequently a really complex task. At the same time, it is necessary to remember that the various stress factors not only participate in changes in the chemistry of tissues and cells, but also they influence the tolerance or response of woody plants (Katzensteiner et al. 1992; Trimbacher, Weiss 1999; Zimmermann et al. 2000).

Nutrient concentrations in conifer needles strongly influence their biochemical capacity for photosynthesis and growth, and they can also be reflected in the leaf anatomy (Jokela et al. 1998). Mineral nutrition is indirectly coupled with stomatal frequency and conductance, since every change in the transpiration stream will also influence the transport of nutrients to the foliage (Bonan, Van Cleve 1992).

In this contribution we present the results of analyses of selected mineral nutrients in spruce assimilatory organs performed separately for the different developmental phases (seedlings, young trees – less than 20 years, adult trees) in the Horný Spiš region, because the very close relation between mineral nutrition and other physiological processes is a well-recognised phenomenon.

The presented analyses of mineral nutrients were carried out in the framework of a comprehensive eco-physiological research assessing the physiological and health status of spruce stands in the geographic area concerned.

MATERIAL A METHODS

The Hliníky locality (Horný Spiš), in which research was conducted, is situated in the region of the Slovenské rudohorie Mts., the unit Volovské vrchy Mts. In the territory of the Forest Management Unit Spišská Nová Ves medium stable forest ecosystems with the degree of ecological stability equal to 2 are evidently dominant. The main cause of lower stability is unfavourable species composition, secondarily modified in favour of spruce. The natural conditions in the area are not optimum for this woody plant due to subnormal precipitation (precipitation shadow of the High Tatra Mts.), and locally especially due to lower altitudes with favourable conditions for development of several generations of bark beetles in one growing season. The experimental plot is situated at 950 m above sea level. It is a remnant of an 80-years old homogeneous spruce stand, the major part of which was cut in salvage cuttings enforced by bark beetles calamities.

Research was conducted in the Hliníky locality (Horný Spiš) on five selected adult spruce trees (age of 100 years) on a plot exposed to air pollution (advanced stage of spruce stand decline), and on five sample trees on the control plot (without visible symptoms of decline until then). By the end of September 2004, we sampled assimilatory tissues from the branches of the fifth whorl in the upper crown part. Simultaneously we also sampled the material from a young spruce stand (age of 20 years, five sample trees).

Changes in the physiological and, consequently, health status of spruce trees were also studied in a pot experiment established in the Arboretum Borová hora. The aim of this experiment was to evaluate the supposed negative influence of soil environment (in a locality with advanced stage of spruce stand dieback) on the growth of spruce trees and state of mineral nutrition. We took the soil substrate for a pot experiment from the plot with intensive spruce dieback (almost decomposed spruce stand – Hliníky locality, Horný Spiš). For comparison, we also took the soil substrate from a beech stand in the same area (without the influence of spruce needle litter). At the same time, we selected several seedlings from the air-pollution plot in the Hliníky locality in two modifications – with symptoms of needle yellowing and apparently green seedlings without visible symptoms of depigmentation. The basic standard for comparison were bare-rooted even-aged seedlings from the tree nursery at Smižany (Horný Spiš), registration number 043448-020 (age 1/2, class 20–25 cm).

The pot experiment had the following six variants:

- Spruce seedlings with visible symptoms of yellowing needles in the soil substrate from the air-pollution plot Hliníky (10 seedlings);
- Spruce seedlings with symptoms of yellowing needles in the soil substrate from the beech stand (10 seedlings);
- Spruce seedlings, apparently green (without visible depigmentation of needles) in the soil substrate from the air-pollution plot Hliníky (10 seedlings);
- Spruce seedlings, apparently green (without visible depigmentation of needles) in the soil substrate from the beech stand (10 seedlings);

– Spruce seedlings from the tree nursery in the soil substrate from the air-pollution plot Hliníky (10 seedlings);
– Spruce seedlings from the nursery in the soil substrate from the beech stand (10 seedlings).

The primary goal of the pot experiment was to study the influence of soil properties on the physiological state of spruce seedlings and on the state of mineral nutrition. The experiment was conducted from 2004 to 2005.

The analysis of assimilatory tissues was focussed on the quantification of amounts of N, S (NCS-FLASH 1112 analyser), P, K, Ca, Mg, Mn, Fe, Al, Zn, Cu, B (in the mineralised material using the method AES-ICP), Ni, Cr, Cd, Pb (in mineralised material using the method AAS-ETA) and Hg (in solid samples, AMA 254).

Table 1. Description of the research locality

Locality	Hliníky – Horný Spiš region, Slovenské rudohorie Mts.
Longitude	20°33´655´E
Latitude	48°56´646´N
Altitude	950 m a.s.l.
Aspect	south-south-western
Forest enterprise	ML – Spišská Nová Ves
Slope	10%
Topography	moderate slope
Parent rock	conglomerates
Soil	Podzolic Cambisol
Mean annual temperature	6.8°C
Mean annual precipitation total	700 mm
Climate area	moderately cold
Forest vegetation zone	5
Group of forest types	*Abieto-fagetum*
Mean stand age	20 years
Species composition	spruce 100%

Statistical analyses

We carried out statistical analyses of differences in the studied elements between the plot with acute symptoms of spruce stand decomposition and the control plot (without apparent symptoms of damage to the stand) and also between the individual variants of the pot experiment. The applied method was Mann-Whitney's *U* Test, the calculations were performed using statistics software (SAS Institute, CA, USA).

RESULTS AND DISCUSSION

The extent of physiological damage to spruce trees of various age categories in the area of Horný Spiš is almost unambiguously consistent with the level of mineral nutrition. We conducted our research, being provided with a wide spectrum of data reported by Maňkovská (1997), Bergmann (1988), Weikert et al. (1989) and Fiedler and Höhne (1985). It is necessary to point out several important facts. High contents of manganese (Mn_T) reaching the range of toxicity were found on both plots (Tables 2 and 4). Manganese is an essential element, it is however toxic in higher concentrations. Its mobilisation indicates disturbances of physiological equilibrium reflected in the changed ratio of this element to iron (originally 1:2 or 0.5). Market et al. (1996) suggested that among the studied parameters mainly Mn content in spruce needles was correlated with the needle loss. For this reason, the Mn content is used as an indicator of damage to woody plants. In such a way, the trace element becomes a toxic one. Another negative finding is a high content of aluminium, primarily in needles of adult spruce trees on the plot with acute symptoms of decomposing stands (Tables 3 and 5). These symptoms respond to a very low pH/H_2O value – 3.7 (pH/KCl – 3 to 2.8) and overall soil exhaustion connected with the lack of

Table 2. Contents of macronutrients (mg/kg in dry mass) in the needles of adult spruce trees growing on a plot with symptoms of acute forest decline (Horný Spiš region, needle year-class: 2003)

Sample tree	N	S	P	Ca	Mg	K	Fe	Mn	Zn	B	Cu
Sp 3	17,000	1,240	1,443	3,832	1,495	2,339	248	1,587	24.2	30.7	7.58
Sp 32	14,000	1,020	1,322	4,021	858	3,530	226	1,239	17.7	28.4	6.46
Sp 36	12,500	1,930	1,193	3,750	1,037	2,720	167	1,236	19.1	24.2	6.18
Sp 37	15,200	1,490	1,456	4,002	1,209	3,042	212	1,458	16.8	28.8	6.74
Sp 38	16,500	1,390	1,709	8,002	1,075	3,192	211	2,180	24.9	23.8	5.37
Average	15,040	1,414	1,425	4,721	1,135	2,965	213	1,587	20.5	27.2	6.47
St. dev.	1,839	338	191	1,837	237	455	30	388	3.76	3.03	0.81
$s_{\bar{x}}$	823	151	86	822	106	204	13	173	1.68	1.36	0.36

Table 3. Contents of risk elements (mg/kg in dry mass) in the needles of adult spruce trees growing on a plot with symptoms of acute forest decline (Horný Spiš region, needle year-class: 2003)

Sample tree	Ni	Pb	Cd	Hg	Cr	Al
Sp 3	< 0.20	1.48	0.048	0.056	0.282	274
Sp 32	3.18	1.88	0.096	0.063	0.119	239
Sp 36	3.73	1.99	0.105	0.061	0.157	214
Sp 37	4.42	0.86	0.034	0.054	0.209	262
Sp 38	1.07	2.11	0.068	0.063	0.404	217
Average	2.52	1.66	0.070	0.059	0.234	241
St. dev.	1.80	0.508	0.030	0.004	0.113	27
$s_{\bar{x}}$	0.81	0.227	0.014	0.002	0.050	12

soil water. The rapid decomposition of adult spruce stands is also promoted by low contents of basic cations (primarily potassium and partially calcium) that are not sufficient for the compensation of toxic influences of manganese and mainly of aluminium. The low content of potassium also indicates the insufficiency of water regimen both in soil and in individual spruce trees. The generally hypothesised deficiency of magnesium and increased heavy metal contents in needles of spruce trees growing in the region Horný Spiš were not however confirmed.

As for the differences in individual macronutrients between the plot affected by intensive decline and the control plot, we can conclude that, except for Fe-content, there were not found any significant differences between the two plots. On the other hand, there are evident significant differences between the studied plots in Pb, Hg and Al (Table 6, Mann-Whitney's *U* Test).

We carried out the pot experiment with the objective to confirm the supposed negative influence of soil environment, and certain soil exhaustion (in a locality with advanced stage of spruce stand decline) on the growth of spruce trees and contents of mineral nutrients.

As for the differences in element contents in needles of spruce seedlings in the pot experiment (variants 1 to 6), we can see significant differences in macronutrients (N, P, Ca, K, Mn), in some cases also in risk elements (Al).

Significant differences in the content of N were mostly indicated when spruce seedlings taken from the acutely decomposing stand were planted in the soil taken from the same plot – compared with variants when the spruce seedlings were planted in the soil taken from the beech stand (without the influence of spruce litter) (variants 1–6, 2–3, 3–4, 3–6, Table 7).

The role of N in physiological processes, mainly photosynthesis, is commonly well recognised because changes or differences in the level of nitrogen nutrition are mostly reflected in changes in the structure and function of the photosynthetic apparatus (lowered efficiency of utilisation of photosynthetically active radiation).

Similarly, we recorded significant differences in another macroelement Ca, primarily in those variants of the experiment in which we compared the seedlings planted in the soil with intensive impact of spruce litter and the seedlings planted in the substrate from the beech stand (without the influence of acid litter).

In the case of P and K we observed significant differences between variants 5 and 6 (5 – spruce seed-

Table 4. Contents of macronutrients (mg/kg in dry mass) in the needles of adult spruce trees growing on a plot without symptoms of acute forest decline (Horný Spiš region, needle year-class: 2003)

Sample tree	N	S	P	Ca	Mg	K	Fe	Mn	Zn	B	Cu
Sp 3	19,500	1,830	1,063	3,147	915	2,385	65.50	1,915	11.90	22.30	3.80
Sp 32	15,800	1,110	1,349	5,685	1,147	2,962	165.00	3,055	33.30	23.60	6.03
Sp 36	17,900	1,620	1,298	7,188	1,812	2,091	73.60	3,508	29.10	34.20	4.67
Sp 37	18,000	1,680	1,254	4,232	977	2,745	70.90	3,182	14.70	23.50	4.00
Sp 38	12,000	890	1,608	6,538	1,621	2,930	89.50	3,445	27.50	37.90	5.13
Average	16,640	1,426	1,314	5,358	1,294	2,623	92.90	3,021	23.30	28.30	4.73
St. dev.	2,909	404	197	1,659	400	375	41.28	646	9.42	7.21	0.90
$s_{\bar{x}}$	1,301	181	88	742	179	168	18.50	289	4.21	3.23	0.40

Table 5. Contents of risk elements (mg/kg in dry mass) in the needles of adult spruce trees growing on a plot without symptoms of acute forest decline (Horný Spiš region, needle year-class: 2003)

Sample tree	Ni	Pb	Cd	Hg	Cr	Al
Sp 3	2.360	0.840	0.071	0.042	0.102	133
Sp 32	< 0.200	0.500	0.063	0.045	0.182	185
Sp 36	2.790	0.730	0.096	0.040	0.092	153
Sp 37	2.300	0.220	0.061	0.041	0.156	128
Sp 38	2.730	0.770	0.115	0.040	0.093	160
Average	2.080	0.610	0.081	0.042	0.125	152
St. dev.	1.071	0.041	0.023	0.254	0.041	23
$s_{\bar{x}}$	0.480	0.019	0.010	0.113	0.019	10

lings from the forest nursery planted in the substrate from the declining forest stand, 6 – spruce seedlings from the nursery planted in the soil substrate from the beech stand).

An unfavourable situation in the content of Mn (limit-exceeding values in adult spruce trees in both localities) was also observed for spruce seedlings in the pot experiment (the limit values were exceeded many times). Significant differences were confirmed again, primarily in those variants of the pot experiment in which we compared yellowing spruce seedlings planted in the soil with intensive impact of spruce litter and green spruce seedlings planted in the soil from the beech stand (Table 8).

We observed significant differences in risk element contents, mainly for Al, between the variants when both yellowing and green seedlings were planted in the soil from the decomposing stand and compared with both yellowing and green seedlings planted in the soil from the beech stand (Table 8).

Phenomena of decline in two spruce (*Picea abies* [L.] Karst.) forests in different locations in Austria were described on a biochemical and ultrastructural level by Tausz et al. (1996). They established that nitrogen, calcium, and potassium contents of the needles were significantly correlated with chlorophyll concentrations in visibly yellowed needles (from declining trees with more than 40% needle loss and visible needle chlorosis). In the other locality (apparently healthy trees with less than 40% needle loss) nutritional factors did not seem to play a dominant role in the initial stages of needle yellowing.

Most studies concerning the interaction of pollutant stresses and mineral nutrient concentrations reported effects on plant growth and yield (Pfanz et al. 1994; Trimbacher, Weiss 1999; Ewald 2005). Ke and Skelly (1994) studied relationships between symptoms expressed by Norway spruce foliar and soil elemental status. They found out that foliar concentrations of Mg, Ca, K, P, Mn, Pb and Zn were positively correlated with concentrations of corresponding soil elements. Principal component regression analysis of the data provided an assessment of interactions and balances among foliar elements, and among soil elements and their possible influences on crown symptoms (crown discoloration and crown

Table 6. Significance of differences in element contents in spruce needles (adult trees) between the declined and control spruce forest

Nutrients	Sample size	Significance level	Risk elements	Sample size	Significance level
N	5	0.3095	Ni	5	0.4206
S	5	1.0000	Pb	5	0.0079**
P	5	0.4206	Cd	5	0.5476
Ca	5	0.5476	Hg	5	0.0079**
Mg	5	0.6905	Cr	5	0.0556
K	5	0.3095	Al	5	0.0079**
Fe	5	0.0079**			
Mn	5	0.0158*			
Zn	5	0.6905			
B	5	0.6904			
Cu	5	0.0158*			

Mann-Whitney's *U* Test, $^{*}P < 0.05$, $^{**}P < 0.01$

Table 7. Significance of differences in element contents (N, S, P, Ca, Mg) in spruce needles between the variants in a pot experiment

Variants	Sample size I	Sample size II	N	S	P	Ca	Mg
1–2	8	8	0.0379*	0.5737	0.1949	0.0499*	0.1605
1–3	8	6	0.6216	0.1419	0.6620	0.0593	0.1079
1–4	8	10	0.1457	0.2743	0.2743	0.1220	0.6334
1–5	8	10	0.1672	0.8968	0.0434*	0.1011	0.8286
1–6	8	9	0.0152**	0.0927	0.9626	0.0006**	0.3704
2–3	8	6	0.0016**	0.2824	0.3450	0.0047**	0.4136
2–4	8	10	0.5148	0.8968	0.8968	0.6334	0.4082
2–5	8	10	0.8148	0.7618	0.0434*	1.0346	0.5148
2–6	8	8	0.2766	0.6058	0.0274*	0.1388	0.1388
3–4	6	6	0.0193**	0.6354	0.3676	0.0017**	0.1179
3–5	6	6	0.0420*	0.2198	0.0160*	0.0009***	0.0727
3–6	6	6	0.0009***	0.6889	0.5287	0.0004***	0.0120*
4–5	10	10	0.9682	0.5787	0.0753	0.9705	0.7959
4–6	10	10	0.2775	0.7802	0.0653	0.0947	0.5490
5–6	10	10	0.6665	0.4002	0.0006***	0.2110	0.4002

Mann-Whitney's *U* Test, $^{*}P < 0.05$, $^{**}P < 0.01$

Table 8. Significance of differences in element contents (K, Fe, Mn, Zn, Al) in spruce needles between the variants in a pot experiment

Variants	Sample size I	Sample size II	K	Fe	Mn	Zn	Al
1–2	8	8	0.0830	0.7984	0.0002**	0.5054	0.0046**
1–3	8	6	0.4908	0.8518	0.6620	0.7546	0.0593
1–4	8	10	0.1220	0.0434*	0.0005**	0.9654	0.0008**
1–5	8	10	0.8968	0.9654	0.3599	0.6334	0.8286
1–6	8	9	0.0206*	0.0274*	0.0001**	0.5414	0.0001**
2–3	8	6	0.2284	0.9497	0.0007**	0.8518	0.0593
2–4	8	10	0.5148	0.2743	0.5148	0.8968	0.9654
2–5	8	10	0.0117*	0.6334	0.0002***	0.3154	0.0205*
2–6	8	8	1.0374	0.2359	0.2359	0.6730	0.4807
3–4	6	6	0.4278	0.5622	0.0017	0.6354	0.0109**
3–5	6	6	0.2198	0.6354	0.4278	0.7128	0.4278
3–6	6	6	0.0879	0.6070	0.0008***	0.2721	0.0004**
4–5	10	10	0.0753	0.0753	0.0001***	0.4359	0.0089**
4–6	10	10	0.7197	0.9682	0.6038	0.5490	0.0349*
5–6	10	10	0.0076**	0.0435*	0.0001***	0.1333	0.0002***

Mann-Whitney's *U* Test, $^{*}P < 0.05$, $^{**}P < 0.01$

defoliation). The knowledge of nutrient deficiency ranges may help diagnose foliar symptoms, but their exclusive use may overly simplify relationships between foliar symptoms and foliar elements.

CONCLUSION

Study of changes in the plant tissue chemistry is an important component of eco-physiological analyses. It contributes significantly to evaluation of the physiological and, consequently, health status of forest stands.

The results of analyses of mineral nutrient contents in assimilatory tissues of spruce stands allow us to conclude that the mineral nutrition of spruce trees growing in the region Horný Spiš is considerably disturbed. This is evident from high contents of manganese and aluminium and low contents of calcium and primarily potassium in spruce assimilatory tissues. At the same time, certain exhaustion of the soil exploited by several generations of spruce stands alien to the area is also evident.

References

BERGMANN W., 1988. Ernährungsstörungen bei Kulturpflanzen. Enstehung, visuelle und analytische Diagnose. Jena, VEB Gustav Fischer Verlag: 762.

BONAN G.B., VAN CLEVE K., 1992. Soil temperature, nitrogen mineralization, and carbon source-sink relationship in boreal forests. Canadian Journal of Forest Research, *22*: 629–639.

EWALD J., 2005. Ecological background of crown condition, growth and nutritional status of *Picea abies* (L.) Karst. in the Bavarian Alps. European Journal of Forest Research, *124*: 9–18.

FIEDLER H.J., HÖHNE H., 1985. Mengen und Spurenelementgehalt der Eibennadeln und Fichtennadeln in Abhängigkeit von biologischen und standortkundlichen Faktoren. In: Mikronährstofforschung. Pflanzenernährung Jena, Publishers Indy: 29–31.

JOKELA A., SARJALA T., HUTTUNEN S., 1998. The structure and hardening status of Scots pine needles at different potassium availability levels. Trees, *12*: 490–498.

KATZENSTEINER K., GLATZEL G., KAZDA M., STERBA H., 1992. Effects of air pollutants on mineral nutrition of Norway spruce and revitalization of declining stands in Austria. Water, Air, and Soil Pollution, *61*: 309–322.

KE J., SKELLY J.M., 1994. Relationship between symptoms expressed by Norway spruce and foliar and soil elemental status. Water, Air, and Soil Pollution, *74*: 289–305.

MAŇKOVSKÁ B., 1997. Concentrations of nutritional and trace elements in spruce and beech foliage as an environmental indicator in Slovakia. Lesnictví, *43*: 117–124.

MARKET B., HERPIN U., MAŇKOVSKÁ B., 1996. A comparison of heavy metal deposition in select Eastern European countries using the moss monitoring method, with special emphasis on the “Black triangle”. Science Total Environment, *193*: 85–100.

PFANZ H., VOLLRATH B., LOMSKÝ B., OPPMANN B., HYNEK V., BEYSCHLANG W., BILGER W., WHITE M. V., MATERNA J., 1994. Life expectancy of spruce needles under extremely high air pollution stress: performance of trees in the Ore Mountains. Trees, *8*: 213–222.

TAUSZ M., ZELLNIG G., BERMADINGER-STABENTHEINER E., GRILL D., KATZENSTEINER K., GLATZEL G., 1996. Physiological, structural, and nutritional parameters of Norway spruce needles from declining forest stands in Austria. Canadian Journal of Forest Research, *26*: 1769–1780.

TRIMBACHER C., WEISS P., 1999. Needle surface characteristics and element contents of Norway spruce in relation to the distance of emission sources. Environmental Pollution, *105*: 111–119.

WEIKERT R.M., WEDLER M., LIPPERT M., SCHRAMEL P., LANGE O.L., 1989. Photosynthetic performance, chloroplast, pigments and mineral content of various needle age classes of spruce with and without the new flush: an experimental approach for analysing forest decline phenomena. Trees, *3*: 161–172.

ZIMMERMANN F., OPFERMANN M., BAUCKER E., FIEBIG J., NEBE J., 2000. Nutrition-physiological responses of spruce to different levels of sulphur dioxide stress in the Erzgebirge Mountains and the Thuringian Forest, Germany. Forstwissenschaftliches Centralblatt, *119*: 193–207.

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Minerálna výživa vo vzťahu k odumieraniu smreka v oblasti Horného Spiša (severné Slovensko)

ABSTRAKT: V rámci príspevku uvádzame výsledky analýz vybraných prvkov minerálnej výživy asimilačných orgánov smreka v rôznych vývojových štádiách (sadenice, dospelé jedince) v oblasti Horného Spiša, nakoľko je všeobecne známa veľmi úzka previazanosť minerálnej výživy i ostatných fyziologických procesov. Prezentované analýzy minerálnej výživy sú súčasťou komplexného ekofyziologického výskumu, v rámci ktorého bol hodnotený fyziologický a následne i zdravotný stav smrekových porastov v danej oblasti. Časť výskumu bola realizovaná priamo v poraste (lokalita Hliníky, Horný Spiš – 2 výskumné plochy, prvá plocha s pokročilým stupňom rozpadu smrekového porastu, druhá plocha kontrolná – bez viditeľných známok rozpadu porastu) a časť prostredníctvom nádobového experimentu. Cieľom nádobového experimentu bolo zistiť predpokladaný negatívny vplyv pôdneho prostredia (na lokalite s pokročilým stupňom odumierania smrekových porastov) na rast smreka i stav minerálnej výživy. V rámci analýz vzoriek z porastu boli zistené vysoké obsahy mangánu (Mn_T), ktoré sa pohybujú v oblasti toxicity, a to na obidvoch skúmaných plochách. Ďalším negatívnym zistením sú vysoké obsahy toxického hliníka, zvlášť v ihliciach dospelých smrekov na ploche s akútnymi príznakmi rozpadu porastu. Je to odraz veľmi nízkeho pH/H_2O – 3,7 (pH/KCl – 3 až 2,8) a celkového vyčerpania pôdy spolu s nedostatkom pôdnej vody. Čo sa týka rozdielov v obsahu jednotlivých makroživín medzi plochou postihnutou intenzívnym rozpadom a kontrolnou plochou, môžeme konštatovať, že až na obsah Fe neboli zistené významné rozdiely medzi plochami. Na druhej strane pri porovnaní obsahu rizikových prvkov sú medzi sledovanými plochami zjavné signifikantné rozdiely u Pb, Hg a Al. Čo sa týka rozdielov v obsahu elementov v ihliciach sadeníc smreka v rámci nádobového pokusu (varianty 1 až 6), môžeme konštatovať, že boli zistené významné rozdiely jednak na úrovni makroživín (N, P, Ca, K, Mn), jednak v niektorých prípadoch i na úrovni obsahu rizikových prvkov (Al).

Kľúčové slová: minerálna výživa; smrek; stres; odumieranie smreka

Corresponding author:

RNDr. Ľubica Ditmarová, Ph.D., Ústav ekológie lesa SAV, Štúrova 2, 960 53 Zvolen, Slovenská republika
tel.: + 421 455 320 313, fax: + 421 455 479 485, e-mail: ditmarova@sav.savzv.sk