BIOGEOCHEMICAL CYCLES OF METALS IN THE ENVIRONMENT: FACTORS CONTROLLING THEIR CONTENT IN THE TISSUES OF SELECTED FOREST TREE SPECIES*

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Concentrations of Al, As, Ba, Be, Ca, Cd, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sr and Zn were studied in stem wood and bark of European beech and Norway spruce growing in soils developed on two contrast types of the bedrock (granite and sedimentary carbonates). Content of the elements was also determined in the assimilatory organs of beech, spruce, pine, alder and larch in dependence on the bedrock chemistry, site conditions and the organ age. Aim of the study was to assess the extent of incorporation of the elements into the forest vegetation as a background for the evaluation of their biogeochemical cycles. Variability in the concentration of the elements in the individual examined tree tissues is generally large. Higher concentrations of the elements in stem wood of the same tree species were found in trees grown on acidic bedrock and concentrations of Cd, Co, Cr, Mn, Pb and Zn were higher in the shallow rooting spruce stem wood, in accordance with their higher content in the topmost soil layers. The transfer indexes (*TI*) of the elements expressed as the relative intensity of their incorporation into the wood mass with respect to their availability in soil show very low values for the toxic trace elements As, Be, and Pb, whereas the nutritional metals and their homologues Cd, Rb and Sr show values by one to two orders higher. Concentrations of Al, Ba, Be, Ca, Fe, Mn and Sr in the tree assimilatory organs tend to increase with the age of the organ, whereas the content of Cu, K, Mg, Ni and Rb shows gradual decrease. Concentrations of Ba, Be, Ca, Cu, Mg, Ni, Rb, and Zn in the leaves of beech growing on granite bedrock with high water table are higher compared to the trees growing on places with deeper water table. Lower concentrations of Ba, Be, Cu, Mg, Mn, Rb and Sr in beech leaves of trees growing in soils developed on carbonates than on granite are explained by the poorer accessibility of the elements. Varying values for As, Pb and Zn are caused probably by different intensity of their atmospheric fallout.

nutritional elements; trace elements; forest trees; stem wood; assimilatory organs; catchment; biogeochemical cycles

INTRODUCTION

The metabolic uptake of nutritional elements by forest tree species represents a very important flux of matter in their cycles in the environment (Skřivan et al., 1995). Balance of elemental fluxes in experimental forested landscapes (catchments) reveals often notable fact that the metabolic uptake of several minor and trace elements from soils is actually their strongest flux in the system and that it considerably contributes to the mobilization of elements in the environment. The overall extent of the elemental input through roots and the above-ground part of trees is affected by a number of factors (Schleppi et al., 2000): first of all by the physiological function of the particular element, the specific character of the tree species, the availability of an element, by the bedrock bulk chemistry and the character of the locality, especially the height of the groundwater table. The above-ground inputs are affected mostly by the chemical composition and intensity of the bulk atmospheric deposition. The physiological function of the particular element may evidently afflict also its concentration changes in the tissues throughout the growing season, especially in the assimilatory organs. It reveals in addition, that several minor and trace elements which possess no specific physiological role, but which are homologues of significant nutritional elements (e.g. Rb, Cs, Sr, Ba, Cd and others), undergo the internal metabolic cycles of the forest vegetation to a considerable extent.

Aim of the presented results of our study, which is a part of broader research focused on the biogeochemical cycles and balances of selected elements in the environ-

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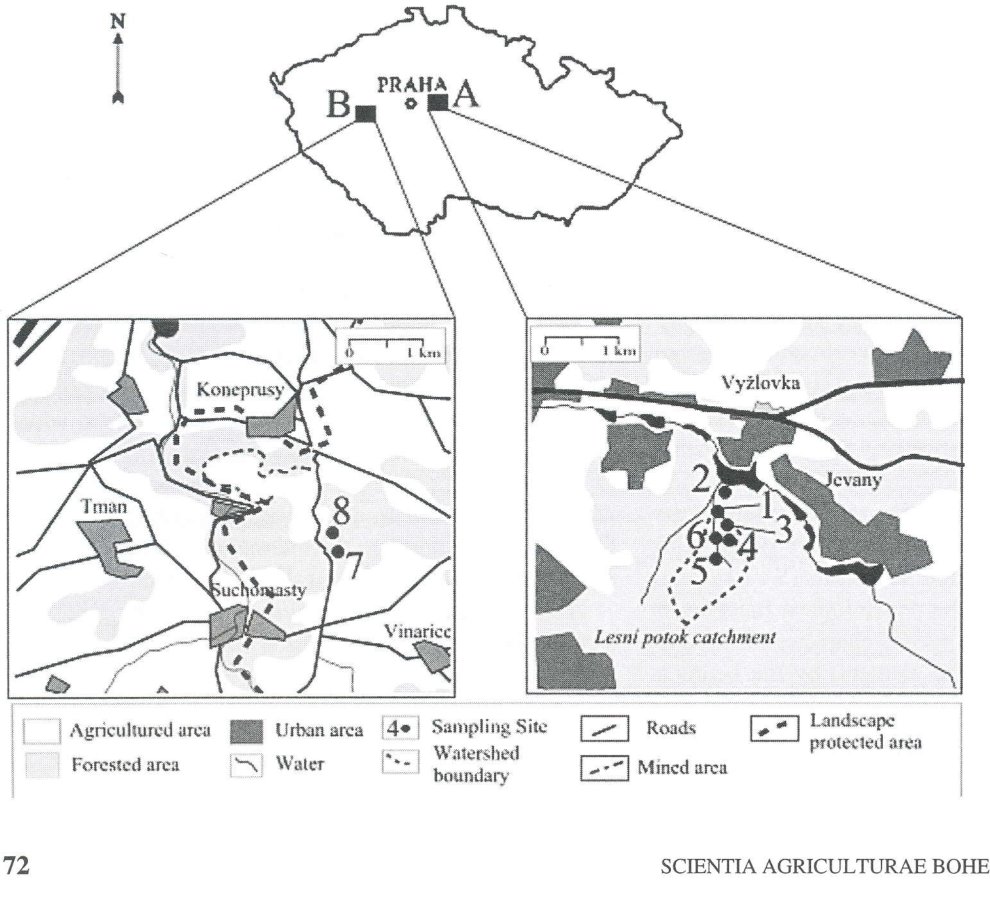
ment, was to obtain new pieces of information concerning the intensity of their internal metabolic cycles and to assess the significance of the above noted effects.

MATERIALS AND METHODS

The samples of selected tree tissues were collected in the experimental catchment Lesní potok in the Černokostelecko region, which is underlined by the Říčany granite (see Fig. 1). Detailed characteristics of the site was given earlier by Skřivan et al. (2000b). The comparative samples (of beech and spruce) were obtained from two localities close to the Čertovy schody quarry near Koněprusy (Fig. 1), where the bedrock is formed by sedimentary rocks (mostly calcite). The localities in the area of the Lesní potok catchment were selected with respect to the character of the sites, in particular to the height of the water table. Samples of the wood substance and bark of Norway spruce (*Picea abies* L. Karst, localities 2 and 8 – Fig. 1) and European beech (*Fagus sylvatica* L., localities 1 and 7) were collected in summer season (July) from 3 trunks in each locality of trees approx. 60 years old in a height 130 cm above ground. The wood cores were extracted from the tree boles up to the stem axis with the increment borer (Haglöf, Sweden, PTFE coated) after the rough bark and phloem were removed. Leaves of the studied deciduous species (European beech and Common alder – *Alnus glutinosa* Gaertn.) and twigs of conifers (Norway spruce, Scots pine – *Pinus sylvestris* L. – and European larch – *Larix decidua* L.) with needles were cut off by plastic scissors and sealed in polyethylene bags. Localities of sampling are depicted in Fig. 1 and they correspond to numbers presented in Tables I, II and III. Assimilatory organs of selected tree species were repeatedly sampled throughout the whole growing season in approx. monthly periods. Twigs of spruce were divided according to their age and all samples were then dried up to a constant weight at 80 °C in a flow box. Needles of spruce and larch were then removed from the twigs by plastic tweezers. Samples of the assimilatory organs were purposefully neither digested nor washed before their analysis. Thin poles of the wood mass from the borer were divided into three parts (inner, middle and outer) which were then analyzed separately. Samples of the stem wood and bark were treated in the analytical laboratories of the Analytika Ltd, Prague. They were wet decomposed by hot concentrated nitric acid (Merck, Suprapur) under pressure in a PTFE crucibles in a microwave oven and analyzed by the ICP-MS spectrometry (Varian UltraMass). Samples of the assimilatory organs were slowly mineralized by concentrated nitric acid (Merck, Suprapur) at room temperature throughout 14 days in glass volumetric flasks. The reaction products were then diluted by the bidistilled water and filtered through a previously leached nitrocellulose membrane filter (Sartorius, pore size 0,45 μm). The filter was then washed out by the bidistilled water and the filtrate was filled up to a known volume. Concentration of the elements was determined in the filtrate by the atomic absorption spectrometry (Geological Inst. AS CR, Prague, VARIAN SpectrAA 300, FAAS or ETA, in case of arsenic by the hydride technique). Calibration procedures were based on the synthetic standards,



1. Map of the compared regions with the bedrock of granite (A) and sedimentary carbonates (B)

Location of the sampling sites (1 to 8)

SRM's were not used. Minimal determined concentrations of the analyzed elements are cited in the following table:

Element	Concentration (ppb)	Element	Concentration (ppb)
Al	1.0	Mn	0.5
As	0.5	Ni	0.5
Ba	5.0	Pb	0.5
Be	0.04	Rb	0.5
Cd	0.04	Sr	0.5
Cu	0.5	Zn	10.0
Fe	30.0		

Values of the relative error of determination for selected elements are listed below:

	Element	Concentration (ppb)	Rel. error (+/– %)
FAAS:	Fe	62.5	8.30
	Mn	40.9	3.10
	Zn	24.3	2.09
ETA:	Be	0.3	4.30
	Cu	2.0	5.12
	Mn	7.0	2.00
	Pb	1.0	10.90
Hydride technique:	As	2.3	2.33

Concentration of Ca and Mg was determined by the AA Spectrometry and K by the flame emission spectrometry (AAS 3, Zeiss), all in the Analytical Laboratory of the Institute of Applied Ecology, Faculty of Forestry, CUA, Kostelec n. Č. lesy). Concentration values of the studied elements presented in the following tables are recalculated to the dry weight of the analyzed samples.

RESULTS AND DISCUSSION

Volume-weighted mean concentrations of selected elements in stem wood and rough bark of spruce and beech from two sites with diverse types of the bedrock are shown in the Table I. Localities 1 and 2 close to the lower part of the LP catchment are characterized by high level of the water table and low pH value of stream water, owing to the low buffering capacity of the bedrock (pH approx. = 5, see also Skřivan et al., 2000b). These characteristics guarantee higher mobility of soil elements and better accessibility of their dissolved forms for the vegetation, than at the other two localities situated in the karst region. This is clearly shown in higher concentration of all the studied elements at LP localities (especially of Mn and Zn), with the exception of Ca, the most abundant cation of the bedrock in karst region. According to the experimental study of DeWalle et al. (1999), several tree species growing in acidified soils exhibit significant bole wood concentration decrease of Ca and Mg, accompanied by the increase of Mn. They recommend to compare the molar ratios of Ca/Mn and Mg/Mn as good indices to soil acidification. In our case, molar ratios of Ca/Mn and Mg/Mn in bole wood of beech growing on the sedimentary carbonates (loc. 7, see Fig. 1) are 50.1 and 15.8. They are much higher indeed than those for beech growing on the locality 1 in acidified soil developed on granite (19.6 and 9.66, respectively). The same holds for spruce growing on both compared types of bedrock and soil (see Table I). Considerably higher content of Cd, Co, Cr, Mn, Pb and Zn in stem wood of shallow rooting spruce in comparison with the corresponding stem wood of beech is another typical feature of Table I. It can be explained by more acid environment of the root zone of spruce, or by a commonly higher content of the elements in the near-surface layer of soil, resulting either from the metabolic cycling of elements through the root uptake, throughfall and litterfall (Mn, Zn, Co), or from the anthropogenic immissions (Pb, Zn, Cd) (Skřivan et al. 2000a). On the other hand, K, Rb (its close homologue), and Mg show higher concentrations in the xylem of beech than in spruce which should reflect the specific metabolic differences between the two compared tree species.

The relative amount of an element built-in into the wood mass of beech and spruce at both localities is more evident when expressed in the form of its transfer index (*TI*, see Table II) which is a measure of the relative intensity of incorporation of an element into the wood mass with respect to its availability in the corresponding soil. High values of *TI* should reflect on one hand the high uptake of a nutritional element and on the other hand its deficiency in soil. Extremely low values of *TI* should indicate the uselessness or even malignancy of the particular element in the tree metabolism. The indexes for beech (*TIB*) and spruce (*TIS*) were calculated as a ratio of the concentration of an element in the xylem and its labile bound content in soil (extractable in 0.1M HNO_3). Content of an element in the uppermost soil layer was used for the shallow rooting spruce, while the mean content of the labile bound element throughout the whole soil profile was used for deep rooting beech. The lowest *TI*'s of Pb, Be, and As reflect the toxicity of the elements, while the values > 1 document the essentiality of Ca, Co, Cr. Cu, K, Mg, Mn, Ni, and Zn. The remaining elements, Cd, Rb and Sr are significantly metabolized (at least on the acidic bedrock) due to their close similarity to Zn, K and Ca, respectively. Nevertheless, the values of *TI* for main nutrients Ca and K are more than one order higher compared with the values for their homologous counterparts Sr and Rb. Extremely high value of *TI* for Ca in comparison with K follows from a relatively low content of the mobile forms of the former element, resulting from the thorough leaching of highly mobile Ca^{++} ions by acid precipitation. On the contrary, content of leachable forms of K is by one order higher than those of Ca due to strong bonding of K by the clay minerals. Comparison of the *TI*'s on both types of the bedrock shows higher uptake of Be, Cd, Cu, Pb, Sr and Zn, and especially of Mn on the acidic bedrock. Strong uptake of Mn by the vegetation on acidic soils is commonly described in the

I. Mean concentrations of selected elements in stem wood and bark of beech and spruce growing on two diverse types of the bedrock (all in ppm d.wt.)
Molar ratios of *Ca/Mn* and *Mg/Mn* for stem wood of trees growing on both the types of the bedrock

Species	Tissue	Locality	As	Be	Ca	Cd	Co	Cr	Cu	K	Mg	Mn	Ni	Pb	Rb	Sr	Zn	*Ca/Mn*	*Mg/Mn*
Beech	stem wood	1	0.046	0.021	694	0.054	0.141	0.550	1.352	768	207	48.4	1.82	0.423	7.59	6.18	4.23	19.6	9.6
Spruce	stem wood	2	0.073	0.014	802	0.162	0.237	1.642	1.051	266	100	184	1.86	2.498	2.32	5.64	16.49	6.0	1.2
Beech	stem wood	7	0.043	0.003	760	0.021	0.063	0.456	1.110	770	145	20.8	1.56	0.063	1.83	1.36	1.84	50.1	15.8
Spruce	stem wood	8	0.025	0.003	861	0.164	0.067	0.559	0.727	244	55	39.0	1.19	0.166	0.37	3.16	3.79	30.3	3.2
Beech	bark	1	0.174	0.068	13 000	0.046	0.750	0.669	3.480	1 900	586	364	16.28	2.230	18.07	91.52	9.73		
Spruce	bark	2	0.271	0.078	9 140	1.239	2.777	0.609	4.140	1 110	798	1 380	15.13	2.234	27.42	61.75	103.66		
Beech	bark	7	0.210	0.019	16 600	0.300	2.050	0.590	5.530	1 520	429	130	48.79	1.680	1.70	34.53	3.58		
Spruce	bark	8	0.330	0.011	33 400	1.160	1.150	0.630	4.340	1 080	298	304	21.22	2.030	3.03	29.54	78.19		

II. Concentration of elements extractable in 0.1M HNO_3 in the uppermost soil layers (A), and their mean concentration in the whole soil profiles (B) near localities 1, 2 in the LP catchment and localities 7, 8 in the karst region (ppm d. wt.)
Transfer indexes (*TI*'s) of studied elements for spruce (*TIS*) and beech (*TIB*)

Element		As	Be	Ca	Cd	Co	Cr	Cu	K	Mg	Mn	Ni	Pb	Rb	Sr	Zn
Localities	layer															
1, 2	A	0.68	0.14	6.35	0.1	0.05	0.26	1.16	66.1	4.12	18.2	0.94	30	6.927	2.36	4.6
	TIS	**0.108**	**0.099**	**126.3**	**1.622**	**4.733**	**6.316**	**0.906**	**4.029**	**24.27**	**10.10**	**1.976**	**0.083**	**0.335**	**2.39**	**3.584**
1, 2	B	0.361	0.801	6.12	0.029	0.152	0.944	0.859	75.0	7.09	8.586	0.297	18.97	9.984	1.121	2.771
	TIB	**0.127**	**0.026**	**113**	**1.90**	**0.928**	**0.583**	**1.574**	**10.25**	**29.15**	**5.638**	**6.143**	**0.022**	**0.760**	**5.513**	**1.528**
7, 8	A	0.42	0.82		0.58			5.16			1.104		34		5	24
	TIS	**0.060**	**0.004**		**0.284**			**0.141**			**0.035**		**0.005**		**0.60**	**0.158**
7, 8	B	0.244	0.908		0.264			3.52			448.8		13.06		7.116	9.2
	TIB	**0.178**	**0.004**		**0.08**			**0.315**			**0.046**		**0.005**		**0.191**	**0.20**

III. Concentration of elements in the assimilatory organs of selected forest tree species (ppm d.wt.)

Species	Age (years)	Sampling locality	Sampling date	Concentration of an element (ppm d.wt.)																
				Al	As	Ba	Be	Ca	Cd	Cu	Fe	K	Mg	Mn	Ni	Pb	Rb	Sr	Zn	K/Rb
Spruce	0^*	4	25.4.	17.56	< 0.16	1.746	< 0.01	712	0.142	5.89	31.05	13 800	1020	161.7	3.687	< 0.16	45.3	0.906	58.21	*305*
	0^*	4	10.5.	18.63	< 0.20	4.407	< 0.02	1 242	0.096	4.05	24.0	11 300	705.1	208.3	1.80	< 0.20	36.0	1.843	37.26	*314*
	0^*	4	2.8.	19.95	< 0.15	*18.8*	< 0.01	3 424	0.028	2.02	22.0	9 070	758.8	390.9	0.383	< 0.13	24.4	*21.4*	38.32	*371*
	1	4	25.4.	25.50	< 0.13	7.49	< 0.01	2 813	0.069	0.95	27.4	3 840	515.2	394.6	0.329	< 0.18	4.7	4.056	24.48	*821*
	2	4	25.4.	33.93	1.26	8.112	< 0.01	3 640	0.062	1.30	33.93	3 120	484.3	431.8	< 0.15	0.19	3.3	6.076	28.38	*937*
	3	4	25.4.	32.20	0.27	10.49	< 0.01	4 508	0.054	2.15	42.93	3 970	453.4	552.7	0.349	< 0.13	3.6	5.42	32.2	*1096*
	4	4	25.4.	56.62	0.58	12.2	< 0.02	5 340	0.064	1.50	49.16	4 240	318	775	< 0.29	< 0.29	4.9	6.131	39.33	*862*
Pine	0^*	5	25.4.	275.2	0.58	5.07	0.02	1 738	0.077	2.75	67.6	5 550	439	294.5	0.773	< 0.24	11.6	3.09	16.9	*479*
	0^*	5	2.8.	297.1	< 0.22	–2.22	< 0.02	1 109	0.062	2.57	23.5	8 910	572.1	181.8	2.794	< 0.22	66.5	1.95	19.07	*134*
Larch		4	25.4.	45.01	0.29	57.28	< 0.02	2 373	0.556	13.83	69.56	12 200	1140	1110	0.736	< 0.20	12.2	7.979	33.14	*1004*
		4	10.5.	36.84	< 0.22	47.29	< 0.02	1 978	0.172	6.58	47.29	7 570	907.1	911.4	0.215	< 0.22	6.6	7.739	18.49	*1151*
		4	2.8.	38.13	< 0.22	62.5	< 0.02	2 902	0.112	4.60	93.57	8 170	1150	1400	0.67	*7.86*	4.7	12.41	19.64	*1743*
Beech		1	25.4.	22.90	0.47	47.88	0.03	8 462	0.248	23.84	94.0	13 800	1540	624.6	3.089	< 0.34	100.7	17.19	26.19	*137*
		1	10.5.	25.69	< 0.17	48.87	0.02	8 796	0.161	13.33	87.26	10 600	2310	781.8	3.421	< 0.17	80.3	25.9	24.08	*132*
		1	2.8.	45.08	< 0.19	60.11	0.12	10 368	0.071	7.81	97.67	9 280	2250	1040	1.653	< 0.19	60.1	31.1	18.41	*154*
		1	4.10.	37.12	< 0.23	68.15	0.20	14 403	0.150	9.27	186.3	7 950	1900	1480	1.50	0.32	40.6	37.94	20.0	*196*
		1	1.11.	52.59	< 0.22	78.88	0.22	16 039	0.180	8.02	140.2	5 570	1930	1340	1.183	0.53	12.2	35.19	19.72	*457*
Beech		7	2.11.	45.98	0.34	42.13	< 0.02	23 640	0.188	5.73	130.0	15 800	842.6	346.4	4.189	0.29	5.3	7.27	27.0	*2957*
Beech		4	25.4.	23.10	< 0.20	27.0	0.02	4 066	0.239	9.97	62.55	12 200	1380	711.5	0.90	< 0.20	46.9	18.69	24.63	*260*
		4	10.5.	23.39	< 0.22	38.81	0.02	5 848	0.098	7.84	62.0	9 660	1440	1130	0.40	< 0.22	48.7	41.38	12.85	*198*
		4	2.8.	27.20	< 0.22	34.45	0.04	5 369	0.125	5.55	98.43	11 600	899.3	850.1	< 0.20	0.27	13.6	17.76	13.0	*853*
		4	4.10.	32.49	< 0.22	36.06	0.08	6 118	0.177	5.47	120.6	11 600	784.1	999.6	< 0.20	0.34	10.3	17.49	14.65	*1131*
Beech		6	4.10.	21.89	0.26	52.13	0.13	6 299	0.109	5.30	78.19	6 520	1090	2480	< 0.20	< 0.22	5.0	38.4	17.81	*1305*
Alder		3	25.4.	23.51	0.27	21.0	0.14	6 596	0.064	20.05	90.43	17 800	2830	558.5	5.372	< 0.27	63.8	46.6	48.94	*279*
		3	2.8.	28.05	< 0.13	20.15	0.24	7 677	< 0.01	10.53	63.76	7 680	3530	484.6	9.691	< 0.13	40.8	68.86	30.6	*188*
		3	4.10.	30.90	< 0.21	32.53	0.42	10 522	0.033	9.69	75.16	4 890	3630	914.4	10.23	0.42	7.2	66.81	23.0	*681*

* current year needles

Concentrations of elements in italics are probably erratic (due to contamination) literature (Beneš, Pabianová, 1987) as a result of high content of accessible forms of Mn.

Concentrations of the studied elements in rough bark of beech and spruce growing on both chosen types of the bedrock (see Table I) are considerably – to moderately higher than in the stem wood, in descending order from Ca > Co > Ni > Sr > Pb > Zn > Cd > Mn > As > Rb > Mg > Be > Cu > K > Cr (with Ca > 20 to Cr = 1). Magnitude of the ratio of content of an element in bark and in stem wood is a result of impacts which involve its physiological role, extent of its deposition flux and mobility (forms in the atmospheric deposition). Generally higher content of As, Cd, Mn, Rb and Zn was found in spruce bark, more K, Ni and Sr contains the beech bark. Considerably higher concentrations of Be, K, Mg, Mn, Rb, Sr and Zn show the trees growing on granite.

Concentrations of elements in the assimilatory organs of the studied tree species and in selected cases their concentration changes throughout the growing season are presented in Table III. First set of the data shows the concentration changes of elements with the age of spruce needles. Concentration of the low mobile and typical toxic trace element Pb (commonly present in the anthropogenic atmospheric fallout coming from the vehicular and industrial emissions) in the needles was always below the detection limit. On the other hand, concentration of lead in leaves of beech (and alder) apparently gradually rises. This approves that the distinct amount of (mostly atmospheric) Pb (and possibly of other poorly mobile elements which are present in the solid atmospheric aerosol – Al, As and Fe) is irreversibly incorporated into the assimilatory organs in the course of their lifetime. In spite of this, one may suppose that the concentration growth of other (generally essential) elements in the assimilatory organs results mainly from the internal biochemical reasons, as their content in the atmospheric aerosol is low compared with the detected content in the tissues. The physiological role of an essential element designates evidently its gradual concentration changes in the tissues of assimilatory organs. Table III shows that the concentration of Al, Ba, Be, Ca, Fe, Mn and Sr tends to increase with the age of the assimilatory organ, whereas the content of Cu, K, Mg, Ni and Rb shows the gradual decrease. The increase of Mn in spruce needles was described by Wyttenbach et al. (1995a) who found this behavior of Mn at high concentrations (> 100 ppm), whereas at low concentrations they observed its temporal decrease. The authors explain the increase in Mn by its fixation in needles in the form of $MnC_2O_4.2H_2O$ and they notice similar dynamic behavior of Mn and Ca, whose concentration ratio remains constant in different age classes. The temporal increase of all the alkaline – earth elements (Ca, Sr, Ba) is described in detail by Wyttenbach et al. (1995b). The authors explain the increase by the fixation of all these elements in tissues in the form of their oxalates, $MeC_2O_4.H_2O$. The decrease of Rb (and Cs) was also observed in Norway spruce needles by Tobler et al. (1994), who found that the two elements finally reached constant values in old needles and that they are retranslocated from older into younger needles. The authors also found similar dynamic behavior of Rb and Cs to K, Mg, Cu (and P, Cl) which was described in (Wyttenbach et al., 1995a).The papers also describe a strong increase of the ratio K/Rb with the needle age which is in agreement with our observations. The same shift generally holds also for the assimilatory organs of other studied tree species (see Table III). The increase in Al and Fe could be attributed to the deposition and capture of poorly soluble solid forms of these typical terrigenous elements, the temporal changes in other elements have probably deeper and meaningful physiological reasons. The comparison of concentrations of the individual elements in leaves of single tree species (beech) growing on stands with the same bedrock, but with different nutrition conditions (the height of the subsurface water table, chemistry of the corresponding soil profiles) shows currently higher concentrations of Ba, Be, Ca, Cu, Mg, Ni, Rb, and Zn in the beech leaves of the flat alluvial locality 1 with high water table, compared with the prone and drier terrain of the loc. 4 (see Table III). Considerable differences in the content of elements in beech leaves of trees growing on various types of bedrock (loc. 4 and 7, sampling date 1/2.11.) are necessary to ascribe to their accessibility in the bedrock (Ba, Be, Ca, Cu, K, Mg, Mn, Rb, Sr) or to the different amount of atmospheric fallout (As, Pb, Zn). The contradictory differences in K (higher concentration in beech leaves growing on carbonates) and Rb (higher on granites) is reflected in highly diverse values of the ratio K/Rb. The same trends were observed in the concentrations of Ca and Sr. These major differences have to be attributed to the distinct types of sources of the compared elements in the corresponding soils.

Evidence of considerable areal and temporal differences in the concentration of elements in assimilatory organs and stem wood of the individual tree species, even when they are growing on the same type of bedrock, is the main finding of the presented study results. This fact necessitates extended and thorough sampling of these tissues if they are designed to the refinement of the biogeochemical cycles of elements in the experimental landscapes.

CONCLUSIONS

Study of the content of Al, As, Ba, Be, Ca, Cd, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sr and Zn in tissues of selected tree species growing on soils developed on two contrast types of the bedrock (granite and sedimentary carbonates) revealed the following facts:

Higher concentrations of the studied elements in stem wood of the same tree species were found in trees grown on acidic bedrock.

Higher concentrations of Cd, Co, Cr, Mn, Pb and Zn were found in the shallow rooting spruce stem wood, in accordance with their higher content in the topmost soil layers.

The transfer indexes (*TI*) of elements expressed as the relative intensity of their incorporation into the wood mass with respect to their availability in soil show very low values for the toxic trace elements As, Be, and Pb, whereas values by one to two orders higher were found for the nutritional and essential metals (K, Ca, Zn) and their chemical homologues Rb, Sr and Cd.

The highest *TI* value was found for Ca in trees grown in soil developed on granite which shows deficiency in this element.

Generally higher *TI* values of the elements were found in trees grown on acidic soils.

Concentration of Al, Ba, Be, Ca, Fe, Mn and Sr in the assimilatory organs of examined tree species generally tends to increase with the age of the organ, whereas the content of Cu, K, Mg, Ni and Rb shows the gradual decrease due to their relocation into new tissues.

Concentrations of Ba, Be, Ca, Cu, Mg, Ni, Rb, and Zn in the leaves of beech growing on the flat alluvial locality on granite bedrock with high water table are higher compared with trees growing on the prone terrain with the same bedrock and deep water table.

Lower concentrations of Ba, Be, Cu, Mg, Mn, Rb and Sr in beech leaves of trees growing in the karst region than on granite bedrock are explained by their poorer accessibility. Differing values for As, Pb and Zn probably result from various intensity of their atmospheric fallout.

Chemical variability of the examined tree tissues is high which has to be taken into account in the refinement of the biogeochemical cycles of elements.

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Biogeochemické cykly kovů v přírodním prostředí: Faktory kontrolující jejich obsah ve tkáních vybraných druhů lesních dřevin.

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V práci jsou popsány výsledky studia koncentrací Al, As, Ba, Be, Ca, Cd, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sr a Zn v dřevní hmotě a borce buku a smrku, rostoucích na půdách vyvinutých na dvou výrazně odlišných typech horninového podloží (granitu a sedimentárních karbonátech). Obsah těchto prvků byl také stanoven v asimilačních orgánech buku, smrku, borovice, olše a modřínu v závislosti na stáří orgánů, chemickém složení podloží a podmínkách stanoviště. Cílem práce bylo posoudit intenzitu zabudovávání prvků do stromové vegetace jako součást podkladů pro výpočet jejich biogeochemických cyklů. Variabilita koncentrací prvků v jednotlivých studovaných typech tkání stromů je obecně velká. Vyšší koncentrace prvků v dřevní hmotě téhož druhu byly nalezeny vždy u stromů rostoucích na kyselém podloží, přičemž vyšší koncentrace Cd, Co, Cr, Mn Pb a Zn byly zjištěny v dřevní hmotě mělce kořenícího smrku, v souhlase s vyšším obsahem těchto prvků v nejsvrchnějším půdním horizontu. Hodnoty tzv. indexů přestupu (*TI*) prvků, vyjadřujících relativní intenzitu zabudovávání do dřevní hmoty vzhledem k jejich dostupnosti v půdě, jsou nízké u toxických stopových prvků As, Be, Pb, zatímco nutriční kovy a jejich homology Cd, Rb a Sr mají hodnoty *TI* o jeden až dva řády vyšší. Koncentrace Al, Ba, Be, Ca, Fe, Mn a Sr v asimilačních orgánech ukazují vzrůstající trend s jejich stářím, zatímco obsah Cu, K, Mg, Ni a Pb se zde postupně snižuje. Koncentrace Ba, Be, Ca, Cu, Mg, Ni, Rb a Zn v listech buku rostoucího na granitickém podloží s vysokou hladinou podzemní vody jsou vyšší ve srovnání se stromy rostoucími v místech s hlubší hladinou. Nižší koncentrace Ba, Be, Cu, Mg, Mn, Rb a Sr v listech buku rostoucího na půdách s podložím karbonátů než u stromů rostoucích na granitu jsou vysvětlovány jako důsledek horší dostupnosti těchto prvků v příslušné půdě, zatímco rozdílné hodnoty koncentrací As, Pb a Zn na obou lokalitách jsou pravděpodobně způsobeny různou intenzitou atmosférického spadu.

nutriční prvky; stopové prvky; lesní stromy; dřevní hmota; asimilační orgány; povodí; biogeochemické cykly

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