

The chemical properties of the spruce, beech, and mixed forest sites in the Moravian–Silesian Beskids Mountains

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Abstract: The survey of plant nutrition gave the information about the soil chemistry of tree types of forest sites from the Natural Forest Region (NRF) Moravian-Silesian Beskids. The soil horizons investigated: forest floor - (F + H), organomineral (epipedon) - A_h and mineral horizons (A + B) reaching the depth of about 40 cm differ significantly in the pH value with the lowest in the spruce sites with $pH_{H_2O} = 3,98$ in (F + H), $pH_{H_2O} = 4,00$ in A_h and $pH_{H_2O} = 4,36$ in the (A + B) horizons and in the highest values on the beech sites with $pH_{H_2O} = 4,41$ in (F + H), $pH_{H_2O} = 4,33$ in A_h and $pH_{H_2O} = 4,51$ in the (A + B) horizons. The values of mixed sites were between this of spruce and beech and this was symptomatic for all characteristics investigated.

The contents of P, Ca and Mg show a decreasing tendency in the last fifteen years, especially on the spruce sites. The nutrient level according to the content in spruce needles has decreased (N, P, K) or has kept its level (Ca and Mg).

Abstrakt: Průzkum výživy lesa poskytl informace o půdním chemizmu tří typů lesních stanovišť z Přírodní lesní oblasti (PLO) Moravsko-slezské Beskydy. Šetřené půdní horizonty: nadložní organický materiál – (F + H), organominerální (epipedon) – A_h , a minerální horizonty (A + B) do hloubky asi 40 cm se významně liší v hodnotě pH s nejnižší hodnotou u smrkových stanovišť s $pH_{H_2O} = 3,98$ v (F + H), $pH_{H_2O} = 4,00$ v A_h a $pH_{H_2O} = 4,36$ v (A + B) horizontech a nejvyššími hodnotami v bukových stanovištích s $pH_{H_2O} = 4,41$ v (F + H), $pH_{H_2O} = 4,33$ v A_h a $pH_{H_2O} = 4,51$ v (A + B) horizontech. Hodnoty smíšených stanovišť byly mezi smrkovými a bukovými, což je příznačné pro všechny šetřené charakteristiky.

Obsahy P, Ca a Mg mají snižující se tendenci v posledních patnácti letech zvláště na smrkových stanovištích. Úroveň výživy podle obsahů ve smrkových jehlicích se snížila (N, P, K) nebo zůstala na své úrovni (Ca a Mg).

Keywords: forest sites, wood composition, acidification, deterioration, plant strategy

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The periodical survey of forest nutrition was done in the Natural Forest Region (NFR) of Moravian-Silesian Beskids – a mountain massif in Moravia's north-eastern part of the Czech Republic. This survey was repeated in 15 years (2003 – 2018). This region is adjacent to an industry area, a significant producer of air pollution in the late 20th century. The forest biocenosis were damaged and impoverished by pollution during the industrial boom in the 1960s and 1970s. In the 1990s, when desulphurizing devices were applied by a pollution producer, the pollution decreased. It seems that a new period of forest ecosystems starts but the increased NO_2 and high concentration of dust particles (PM10) are going on. Even if ČERNÝ et al. (2001) talked about no trends in the development of defoliation in the Moravian-Silesian Beskids, FISCHER et al. (2007) and stated a developed defoliation within the multiple effects of N a S deposition on forests. Raised temperature and CO_2 concentration typical for central Europe (JONNARD et al. 2014) occur now and symptoms of “new forest damages” described as “neuartige Waldschäden” are still evident. The diminished immunity may contribute to the development of honey fungus (*Armillaria mellea* Quél.) and salvage cutting recently. From this point of view, a survey of forest nutrition state and a stadium of the development of chemical properties of soil environments within the last fifteen years keeps its importance. The species composition of forest sites has been developed into three stand types: spruce, beech and mixed. The evaluation of the soil properties and its development was done with respect of this wood composition.

The current form of forest sites in the NFA is the result of commercial forest management within the last two or three centuries. The stand composition in the year 1880, represented by the spruce: 45 – 65 %, fir: 20 – 26 % and beech: 8 – 18 %, has changed as follows: spruce - 73,6 %, fir - 1,3 % and beech - 19,6 % (<http://www.UHUL.2001>). The sites with its characteristic properties influenced by a tree composition have been developed. The survey of forest nutrition (2018) provides the data sufficient for evaluation of three varieties of forest sites – spruce, beech and mixed. The management of this commercial forest is arranged by the forest management planning based on the forest typology and the actual forest needs assessed by the actual condition and development forecast. From this point of view, we can distinguish a) the influence of natural condition, b) the influence of plant species (geobiocenoids) and c) the environmental influence (pollution). The goal of this research is to evaluate the rate of long-term species trees effect on the development of forest sites (by its description) and the effect of pollution loading in the last fifteen years.

Material and methods

The Natural Forest Region (NFR) of Moravian-Silesian Beskids Mts. is situated on the Outer Western Carpatians Foot in the eastern part of the Czech Republic. It is a belt of highland on the Czech – Slovakia border with the mountain massif rising sharply from the rolling land and divided by deep valleys. There are some of summits over 900 m above the sea level. Lysá hora Mt. is the highest (1326 m).

The prevalent parent rock is the sandstone and claystone with its characteristic alteration called flysch. The most expand soil types are cambisol (subtyp modal - 82,6% and gley – 3%), podzol modal - 5,9%, kryptopodzol modal - 5,9 %).

The grain structures do not differ significantly. The content of clay ($<1\ \mu\text{m}$) of fine earth of spruce sites are: 9,3% and 10,5% in the A_h and (A + B) horizons respectively; beech stands: 7,1% and 7,7% in the A_h and (A + B) horizons respectively and in the mixed sites: 8,8% and 8,6% in the A_h and (A + B) horizons respectively. The content of silt ($1 - 50\ \mu\text{m}$) is: spruce sites 26,0% and 24,5%; in the A_h and (A + B) horizons respectively; beech stands: 18,0% and 19,9% in the A_h and (A + B) horizons respectively and on the mixed sites: 24,1% and 23,4% in the A_h and (A + B) horizons respectively.

The parent rocks of the predominant part of soil profiles investigated are sandstone. Its species composition is relatively poor. The predominant component of clay fraction is silica with representation from 21% to 77 %. It is a prevailing mineral in each profile. The occurrence of chlorites, which are the source of magnesium and potassium, ranges from 2% to 21%. The occurrence of illits which are rich in potassium is higher (MELKA, ŠTASTNÝ, 2014). The orthoclase represents 1 – 16% and plagioclases 4 – 15% of clay minerals. These sources of potassium and calcium are therefore very small.

The climate is continental – moderate and warm on the foothills and cold in higher locations with a relatively high precipitation during summer. The average annual temperature varies from 7,4°C in Frenštát (400 m.a.s.) to 2,5°C on Lysá Hora Mountain (1324 metres above the sea), and the precipitation varies from 946 mm to 1532 mm on these sites respectively. The climate is strongly moderated by the world sides exposition and by prevailing direction of winds.

The pollution of the atmosphere decreased significantly during the 90s, but the concentration of NO_2 and SO_2 was still high and recently the increase has been recorded. The annual wet deposition of N-NO_3^- was 41,2 $\text{kg}\cdot\text{ha}^{-1}$ in 1997, 19,55 $\text{kg}\cdot\text{ha}^{-1}$ in 2015 and 25,18 $\text{kg}\cdot\text{ha}^{-1}$ in 2017. The concentration of S-SO_4^{2-} was 92,6 $\text{kg}\cdot\text{ha}^{-1}$ in 1995, 64,0 $\text{kg}\cdot\text{ha}^{-1}$ in 1998, 18,58 $\text{kg}\cdot\text{ha}^{-1}$ in 2015 and 17,86 $\text{kg}\cdot\text{ha}^{-1}$ in 2017. The set of information of precipitation chemistry shows the predominance of acid compounds over the alkaline ones.

http://portal.chmi.cz/files/portal/docs/uoco/isko/tab_roc/tab_roc_CZ.html

There occurred liming of a forest in small discontinuous areas in the 70s of the last century by application of 4,000 $\text{kg}\cdot\text{ha}^{-1}$ of dolomitic carbonate.

In the sense of forest typology, the sites of the whole timber area are classified in the edaphic category: B – nutrient-rich (24,81 %), F – slope-stony (16,38 %) and S – nutrient-medium (39,60%). The representation of main altitudinal vegetation zone: 4. AVZ (15,50 %), 5. AVZ (73,61 %) and 6. AVZ (8,87 %).

121 research sites (75 spruce sites, 28 beech sites and 18 mixed sites) were displaced in the whole area with the respect of typological classification of the most expanded forest sites. The plants are about 90 years old and predominantly single trees. The mixed plants consist of the spruce (50 – 65 %), followed by the beech (50 – 35 %). The maple, birch, linden and crane are only admixed. 109 research sites were sampled repeatedly after 15 years.

Sampling and chemical analysis

Sampling and analysis

Three soil horizons were taken up in the site of sampling. Holorganic subhorizons (F + H) were collected from the square of 25 x 25 cm from the forest floor down to the boundary with organomineral horizon (epipedon). The whole organic material from this area was collected except large material over 20 mm in diameter and macroscopic living material (vegetation, mosses, fungi, roots, etc.) which were removed. This horizon was taken the only one on the sampling site and was chosen with respect for the vegetation belonging to the forest type. Mineral horizons (epipedons -A_h and minerals – (A + B) involving the most of root zone, important for assessing the nutrient ability of soil. Upper organomineral horizon (A_h) (epipedon) was taken down to round 0,1 m and mineral horizon (A + B) down to 0, 4 m of the soil profile. The mineral soil samples (from both organomineral and mineral horizons) were taken from 3 holes all around the sampling site to obtain higher representativeness of mineral horizons. Both the holorganic and the mineral soil samples were stored at 2°C prior to analysis.

Foliage (needle and leaves) samples were collected from the upper, south orientated, full lighted third of crown of the young-growth stand on each sampling site. The needles of current year and two-year-old needles of spruce were taken and the leaves of beech were taken as well. Prior to chemical analysis, the needles were dried without previous washing out.

Soil samples

Determination of pH_{H2O}, pH_{CaCl2}, were done in air-dried soil samples according to ISO 10390:2005, which specifies the routine determination of pH using a glass electrode in a 1:5 suspension of soil in water (pH in H₂O) or in 0,01 mol/L calcium chloride solution (pH in CaCl₂). Parameters N_{tot} and C_{tot} were determined by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES).

Determination of extractable volumes (P, K, Ca, Mg, Mn, Al, Fe, Zn, Cu, Pb, Cd, Cr, determined by ICP-OES after mineralization on the dry way and in the react of HNO₃, c = 2mol.

Parameters N_{tot} and C_{tot} by NIRS

Determination of accessible elements P, K, Ca, Mg, Al, Fe, S in the react of Mehlich III determined by ICP-OES

Plant samples

Wet digestion with H₂SO₄, Se and H₂O₂ was used for determination of N, P, K, Ca, Mg, Na followed by methods of detection: titrimetric method for N (Kjeltec, Tecator), spectrophotometry for P (Specol 11), flame emission for K and AAS-Flame for Ca, Mg.

Dry aching and uptake in HNO₃ were used for determination of B, Zn, Mn, Fe, Al, Cu, Cr, Ni, Pb, Cd. The contents of the elements were measured using ICP-AES technique (B, Zn, Mn, Fe, Al, Cu, Cr, Ni) and AAS-flame with HNO₃ and H₂O₂ was used for S followed by ICP-AES as the technique of detection.

3. RESULTS

3.1. Soil

The amounts of organic material on the spruce stand was up 1.4 times that of beech sites with the significantly smallest amounts. The amounts in the mixed stand were close to the spruce ones (Tab. 1).

Table 1. The characteristic selected of the forest floor (median)

	Stand type								
	Forest floor horizon			Organomineral hor. (A _h)			Mineral horizon (B)		
	spruce A	beech B	mixed C	spruce A	beech B	mixed C	spruce A	beech B	mixed C
Org. material [t/ha] *	83,9 ^B	45,3 ^{AC}	77,4 ^B						
pH _{CaCl2}	3,20 ^B	3,62 ^A	3,46	3,26 ^{BC}	3,54 ^A	3,42 ^A	3,65	3,69	3,62
pH _{H2O}	3,98 ^B	4,41 ^A	4,20	4,00 ^{BC}	4,33 ^A	4,19 ^A	4,36 ^B	4,51 ^{AC}	4,37 ^B
N [%]	1,58 ^B	1,47 ^{AC}	1,60 ^B	0,28	0,29	0,30	0,18	0,18	0,20
C _{ox} [%]	33,9 ^B	31,2 ^A	32,5	4,58	4,30	4,31	2,77	2,72	3,01
C/N	21,5	21,3	20,4	16,3 ^{BC}	15,0 ^A	14,7 ^A	14,8	15,3	14,6

*quantity of organic material of forest floor

The values of median of pH_{act} and pH_{exch} inform about the strong acid soil reaction in the (F + H) horizons. The value pH_{H2O} and pH_{CaCl2} were significantly lower on the spruce sites in comparison to the beech sites in all the horizons with the exception of pH_{CaCl2} in (A + B) horizons.

The pH values in the mixed sites were mostly higher than the spruce and smaller than beech ones.

The amount of N_{tot} was similar on the (F + H) horizons of the spruce and mixed sites and significantly higher than on the beech sites. There were no significant differences in the A_h and (A + B).

The percentage of C_{ox} was significantly higher on the (F + H) in spruce sites compared to the beech ones. The slower decomposition on spruce sites corresponds to significantly higher C/N ration in the A_h horizons (Fig 1,2,3).

Figure 1: Contents of C_{ox} in A_h and (A + B) horizons of spruce sites

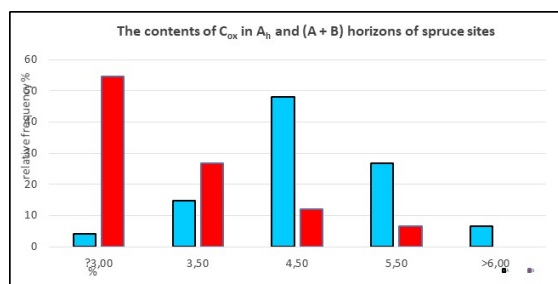


Figure 2: Contents of C_{ox} in A_h and (A + B) horizons of beech sites

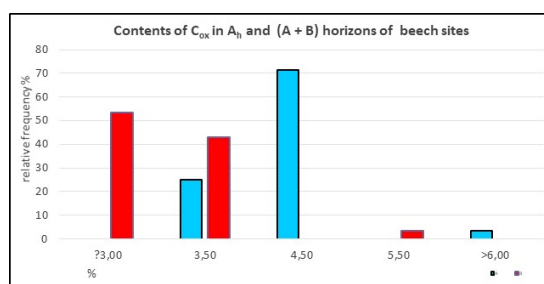
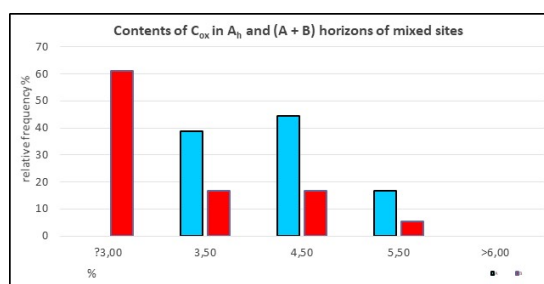


Figure 3: Contents of C_{ox} in A_h and (A + B) horizons of mixed sites



The distribution of C_{ox} proportion in mineral phase of soil profiles was significantly different. There was an equal distribution in the A_h horizons of the spruce stands. The decreasing distribution in (A + B) horizons expressed slower movement of recalcitrant organic material of the spruce stands while organic material of the beech stands with higher rate of easily dissoluble part stabilized in two classes with some outliers. The distribution in the mixed stand was closer to the spruce ones. A higher amount in the classes 4.5 % and 5.5 % represents admixture of more recalcitrant organic material and slower decomposition rates.

Tab. 2a: Comparison of mean values of macronutrients (ANOVA*)

	Stand type								
	Forest floor horizon (F + H)			Organomineral hor. (A_h)			Mineral horizon (A+B)		
	spruce A	beech B	mixed C	spruce A	beech B	mixed C	spruce A	beech B	mixed C
P_{dus} [mg/kg]	829	902	935	80,1 ^{BC}	129 ^A	134 ^A	67,3	80,5	88,5
K_{dus} [mg/kg]	1247 ^B	1591 ^A	1505	96,2 ^{BC}	160 ^A	137 ^A	83,5 ^{BC}	107 ^A	110 ^A
Ca_{dus} [mg/kg]	1842 ^B	3890 ^A	2880	104	781	337	76,0 ^B	182 ^A	142
Mg_{dus} [mg/kg]	718	1102	937	163 ^B	357 ^A	277	175 ^C	225	253 ^A
P_{MIII} [mg/kg]				< 3,5 ^B	8,63 ^A	4,53	< 3,5	5,17	< 3,5
K_{MIII} [mg/kg]				55,1 ^{BC}	85,2 ^A	78,3 ^A	38,4 ^B	50,5 ^A	51,8
Ca_{MIII} [mg/kg]				75,0 ^B	264 ^A	230	53,8 ^B	145 ^A	104
Mg_{MIII} [mg/kg]				28,7	50,7	51,4	16,7	21,7	24,6
P_{AR} [mg/kg]				364 ^{BC}	533 ^A	518 ^A	317 ^C	404	437 ^A
K_{AR} [mg/kg]				1638 ^B	2153 ^A	2086	1902	2282	2266
Ca_{AR} [mg/kg]				199	898	433	185 ^B	296 ^A	249
Mg_{AR} [mg/kg]				1747 ^B	2406 ^A	2331	2215	2666	2730

* statistically significant difference ($p < 0,05$), letters A, B, C express statistically significant difference from the value listed in this column

The contents extractable of phosphorus (P_{ext}) in the (F + H) horizons of spruce sites were very low (Fig 4). The significantly smallest contents of all investigated forms appeared in the A_h horizons of the spruce sites. The pseudototal contents (P_{AR}) of (A + B) horizons were significantly higher on the mixed stand in comparison with the spruce ones (Table 2a).

The contents of K_{ext} were statistically different in all the horizons with the smallest values in the spruce sites. The K_{MIII} contents were significantly smaller in the A_h and (A + B) horizons and pseudototal K_{AR} in the A_h horizons of the spruce sites. There were no significant differences in the (A + B) horizons in pseudototal contents.

The Ca_{ext} contents were significantly higher in the (F + H) and A_h horizons of the beech sites in comparison with the spruce ones. The contents accessible a (Ca_{MIII}) were significantly smaller in the A_h and (A + B) horizons of the spruce sites compared to the beech ones and this is valid for the pseudototal contents in the (A + B) horizons as well.

Figure 4: Extractable P

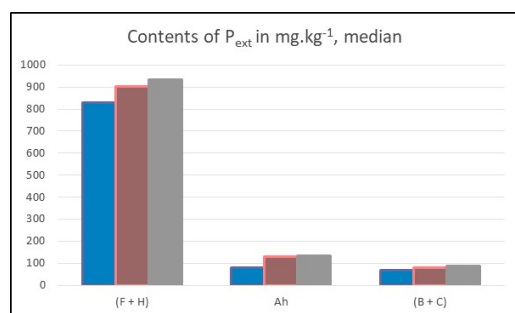
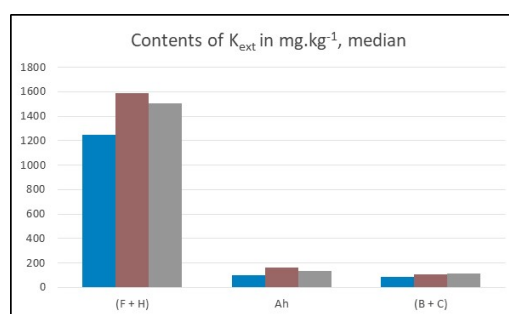


Figure 5: Extractable K



The Mg_{ext} contents were the lowest on the spruce sites. The differences between the spruce and beech sites were significant in the A_h and between the spruce and mixed sites in the (A + B) horizons. The accessible contents were not significantly different and the pseudototal contents are significantly smaller in the A_h horizons of the spruce sites in comparison with the beech ones. There are no significant differences in the (A + B) horizons.

Figure 6: Extractable Ca

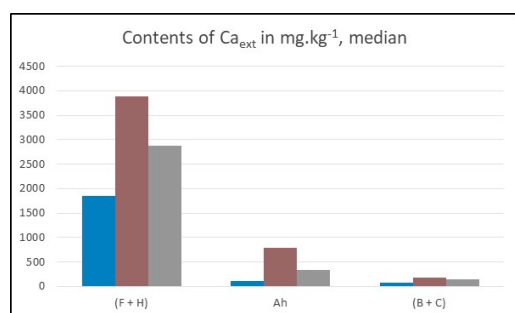
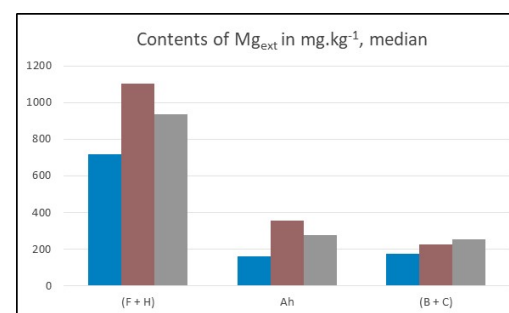


Figure 7: Extractable Mg



Significantly higher contents of Al_{ext} and Al_{AR} in the beech and mixed sites were only found in the A_h horizons (Table 2b). The iron contents were smallest on the spruce sites in the (F + H) horizons (Fe_{ext}) and in the A_h horizons (Fe_{AR}). The contents of Fe_{MIII} were significantly higher in the A_h horizons of the spruce sites.

The contents of Mn_{ext} were significantly smaller in the (F + H) and A_h horizons of the spruce sites in comparison with the beech sites. There were both the extractable and pseudototal contents similar in the bottom of the soil profile (A + B horizons). The manganese contents raised from 29 to 1,440 mg.kg⁻¹ in the (F + H) horizons of the spruce sites, from 103 to 2,900 mg.kg⁻¹ in the beech sites and from 91 to 2,020 mg.kg⁻¹ in the mixed ones. The local extraordinary high contents were determined both in the soils and foliage on the same sites.

A special place in this survey was given to the available contents of sulphur (S_{MIII}) determined by the Mehlich method (Table 7). The only significant higher contents on the spruce sites in comparison with the beech ones were found in the (A + H) horizons. The contents seem to have an increased tendency by the depth of soil.

The contents of Cd_{ext} and Cr_{ext} (Table 5c) were the highest in the forest (F + H) horizons of all the stands. The smallest values were under spruce trees in comparison with mixed plants. The contents of Cu_{ext} a Fe_{ext} were the smallest on the spruce sites in (F + H) horizons and a significant difference was found between the beech and mixed stands for Cu_{ext} and between the spruce and mixed stands for Fe_{ext} . The contents of lead (Pb_{ext}) are similar in this horizon and the contents of Zn_{ext} were the smallest in spruce plants.

Tab. 2b: Comparison of mean values of micronutrients (ANOVA*)

	Stand type								
	Forest floor horizon (F + H)			Organomineral hor. (A_h)			Mineral horizon (A+B)		
	spruce A	beech B	mixed C	spruce A	beech B	mixed C	spruce A	beech B	mixed C
Al_{dus} [mg/kg]	5114	5592	5476	3551 ^B	4326 ^A	3967	4713	4989	4670
B_{dus} [mg/kg]	2,52 ^B	3,41 ^A	2,92						
Cd_{dus} [mg/kg]	0,54 ^C	0,62	0,77 ^A	< 0,2 ^{BC}	0,28 ^A	0,25 ^A	< 0,2 ^B	0,22 ^A	< 0,2
Cr_{dus} [mg/kg]	9,20 ^C	10,9	12,5 ^A	3,18 ^B	3,96 ^A	3,92	3,89	3,80	3,94
Cu_{dus} [mg/kg]	11,4	10,0 ^C	14,5 ^B	5,61 ^{BC}	7,03 ^A	7,37 ^A	3,61	4,05	4,05
Fe_{dus} [mg/kg]	6825 ^C	8121	8709 ^A	5388	5936	5572	7099	6234	6198
Mn_{dus} [mg/kg]	241 ^{BC}	612 ^A	568 ^A	165 ^B	335 ^A	329	271	358	391
Pb_{dus} [mg/kg]	130	114	166	58,6 ^{BC}	92,7 ^A	87,5 ^A	24,0 ^{BC}	31,2 ^A	34,2 ^A
Zn_{dus} [mg/kg]	62,9 ^{BC}	85,5 ^A	97,8 ^A	11,7 ^{BC}	21,3 ^A	19,1 ^A	10,9 ^{BC}	17,9 ^A	16,2 ^A
Vym. acid. [mekv./kg]				156	146	149	105	105	114
Al_{MIII} [mg/kg]				1832	1948	1926	2107	2091	2079
Fe_{MIII} [mg/kg]				628 ^B	571 ^A	586	451	415	447
S_{MIII} [mg/kg]				25,8	24,2	26,2	35,0 ^B	26,9 ^A	30,5
Al_{AR} [mg/kg]				14041 ^B	16974 ^A	16066	17779	20328	19122
Cd_{AR} [mg/kg]				0,16 ^{BC}	0,34 ^A	0,31 ^A	< 0,15 ^{BC}	0,25 ^A	0,20 ^A

Significantly smaller contents of hazardous elements in the A_h horizons of the spruce stands were found in case of Cr, Cu, Pb a Zn, too. In case of Pb_{ext} and Zn_{ext} , the contents were significantly smaller in the bottom of soil profiles (A + B). The diagram described for extractable contents was in effect in case of pseudototal contents. Considering the highest contents of hazardous elements in the (F + H) horizons we assume an airborne origin of these elements. The contents of hazardous elements were higher at the edge of a forest complex, along roads and near the source of pollutants, for instance near the Třinec industrial complex.

Tab.3: Means of contents of element in foliage (N v %, others in mg.kg⁻¹).

Norway spruce														
Age	N	P	K	Ca	Mg	Al	Fe	S	B	Cu	Pb	Zn	Cd	Cr
C*	1,4	1452	6959	4002	956	63	77	1022	18	3,3	0,4	36	0,18	0,31
C+1	1,4	1211	5696	5348	831	87	96	1044	15	3	0,5*	32*	0,15	0,30
Beech														
c	2,34	1445	9973	8805	1332	80	173	1658	25	7	1	36	0,17	0,46

*c = current year needles; c + 1 = current + + year needles

The contents of macronutrient in the needles of current year reached 70 % of the level of the class indicated as adequate to optimum (FÜRST A. 2009). The contents of Mg were sufficient. The accumulation of Al, Ca, Fe was found in older needles and the translocation of K, Mg, P, Zn, B from older needles.

The nutrition of the beech by the macronutrients was at a sufficient and locally a luxury level.

The sufficient level of nutrition by Fe was found in the spruce and the beech, the contents of Mn and hazardous elements (Cd, Cr, Cu, Pb) were out of sphere of pertinent toxicity.

3.4. Development of chemical properties in 2001 – 2015 years

102 sites were investigated repeatedly after 13 and 14 years. The development of chemical properties was done by comparison of these data.

Tab.4: Soil chemical reaction, nitrogen total (%) carbon oxidizable (%) – mean values

	Forest floor horizons (F + H)											
	Spruce stands				Beech stands				Mixed stands			
	Forest floor horizons (F + H)											
	pH _{H2O}	pH _{CaCl2}	N _{tot}	C _{ox}	pH _{H2O}	pH _{CaCl2}	N _{tot}	C _{ox}	pH _{H2O}	pH _{CaCl2}	N _{tot}	C _{ox}
2004	4,20	3,36	1,28	34,5	4,48	3,81	1,47	36,2	4,27	3,57	1,33	31,5
2018	3,93	3,14	1,58	34,0	4,46	3,67	1,45	31,7	4,19	3,44	1,62	33,2
	Organomineral horizons (A _h)											
	spruce				beech				mixed			
2004	3,99	3,30	0,43	8,64	4,15	3,47	0,48	9,21	4,11	3,50	0,42	8,55
2018	3,99	3,26	0,29	4,65	4,36	3,57	0,29	4,29	4,19	3,43	0,30	4,27
	Mineral horizons (A + B)											
	spruce				beech				mixed			
2004	4,32	3,74	0,17	3,36	4,36	3,73	0,20	3,01	4,48	3,83	0,24	3,78
2018	4,36	3,65	0,18	2,94	4,50	3,70	0,17	2,70	4,37	3,58	0,23	3,33

The pH_{H2O} and pH_{CaCl2} values in the (F + H) horizons decreased significantly in the spruce horizons. There was no significant change of pH detected in the A_h horizons of the spruce and the beech sites. The value of pH_{H2O} increased significantly in the (A + B) horizons of the beech sites.

The contents of N_{tot} increased significantly in the (F+H) horizons of the spruce and the mixed sites. The decrease in the A_h horizons of the spruce and the beech sites could be connected by significantly smaller contents of C_{ox} noted in 2018.

Tab.5a: Contents extractable of P, K, Ca, Mg (mg.kg⁻¹) – mean values

	Spruce stands				Beech stands				Mixed stands			
	Forest floor horizons (F + H)											
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg
2004	910	1329	2720	686	899	1416	5801	870	1126	1362	4419	1030
2018	837	1528	1519	587	908	1542	4417	1171	978	1511	2961	959
	Organomineral horizons (A _h)											
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg
2004	106	268	271	150	154	360	490	242	185	304	464	256
2018	85,2	96,7	93,9	159	131	162	910	393	153	144	384	292
	Mineral horizons (A + B)											
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg
2004	68,1	189	113	152	72,0	207	165	232	140	245	273	312
2018	72,4	80,9	70,0	171	83,8	103	167	218	113	131	190	310

The contents of P_{ext}, Ca_{ext} and Mg_{ext} were significantly smaller in the (F+H) horizons of the spruce stand (Table 5a). The similarity was seen in the decrease of this nutrient on the mixed sites even though with significance just in the case of P_{ext}. On the contrary, the significant increase was noted in P_{ext} and Mg_{ext} on the beech sites. A significant decrease of P_{ext} K_{ext} and Ca_{ext} was found in the A_h horizons of the spruce sites. The increase of nutrient of the (F + H) horizons of the beech sites was projected to the A_h horizons by contents rather

higher in Ca_{ext} and Mg_{ext} and by stable contents of P_{ext} . The contents of K_{ext} were significantly smaller. A decreasing tendency of the contents in the A_h horizons on spruce sites was not observed on the mixed sites with stability of contents of P_{ext} and Mg_{ext} and only insignificantly decreased contents of K_{ext} and Ca_{ext} . A significant decrease of K_{ext} and stable contents of P_{ext} were observed in the (A + B) horizons of all the sites. The contents of Ca_{ext} decreased and Mg_{ext} increased significantly on the spruce sites. There was no significant change at the beech stands with exception of K_{ext} decreased. This is observed on the mixed sites, too.

Table 5b: Contents extractable of Fe, Mn, Pb, Zn (mg.kg^{-1}) – mean values

	Spruce stands				Beech stands				Mixed stands			
	Forest floor horizons (F + H)											
	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn
2004	4321	6335	393	75,7	3745	5461	988	102	5020	9600	653	118
2018	5100	6952	224	63,4	5540	7947	699	87,8	5377	9049	492	106
	Organomineral horizons A _h											
	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn
2004	3259	4539	101	14,7	3833	4578	215	27,8	3880	4861	162	24,1
2018	3570	5624	148	11,8	4465	6007	381	21,8	4032	5657	362	20,8
	Mineral horizons (A + B)											
	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn	Al	Fe	Mn	Zn
2004	4093	6167	205	9,93	4105	7853	228	15,4	5379	7853	341	22,7
2018	4716	7369	250	10,5	5006	7234	389	17,1	5228	7234	480	19,8

The contents of Al_{ext} increased significantly in all investigated horizons both the spruce and the beech sites (Table 5b). This applies for Fe_{ext} on the spruce sites (without significance in (F + H)) and on the beech sites for (F + H) and in the A_h horizons. Mn_{ext} in all the sites decreased in the (F + H) horizons (on the spruce stand significantly) and increased in the A_h and (A + B) horizons particularly on the beech sites. Zn_{ext} has decreased on all the sites in the (F + H) horizons, increased in the A_h horizons. In the (A + B) horizons, there were only neglected changes.

Table 5c: Contents extractable of Cd, Cr, Cu, Pb (mg.kg^{-1}) – mean values

type	Spruce stands				Beech stands				Mixed stands			
	Forest floor horizons (F + H)											
	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb
2004	0,76	8,20	15,4	118	1,00	7,97	14,4	89,7	1,14	11,3	22,8	165
2018	0,54	9,38	11,6	133	0,64	11,0	10,0	103	0,84	13,0	15,5	177
	Organomineral horizons A _h											
	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb
2004	0,19	3,56	7,61	99,3	0,45	4,25	10,3	168	0,27	4,78	9,76	126
2018	<0,2	3,27	5,84	60,2	--	4,04	7,14	94,8	--	3,99	7,88	95,3
	Mineral horizons (A + B)											
	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb	Cd	Cr	Cu	Pb
2004	0,20	3,56	7,61	25,3	0,24	3,23	0,24	30,7	0,32	5,70	9,0	38,1
2018	<0,2	3,27	5,84	24,5	--	3,73	---	31,6	<0,2	4,50	4,92	40,1

The contents of hazardous Cd_{ext} generally decreased during the period of 2005 – 2018 (Table 5c), in contrast of Cr_{ext} with a significant increase in the (F + H) horizons of the spruce and beech sites and insignificantly on the mixed sites. A reverse tendency was observed in the A_h horizons with smaller contents particularly on the mixed sites. Cu_{ext} decreased on all the sites, significantly on the spruce sites. Pb_{ext} increased in the (F + H) horizons and decreased in the A_h horizons of all the sites.

Table 6: Contents accessible of P, K, Ca, Mg (mg.kg⁻¹) – mean values

	Spruce stands				Beech stands				Mixed stands			
	Organomineral horizons A _h											
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg
2004	7.07	89,0	176	32,9	13,7	129	350	54,5	18,3	95,9	318	45,1
2018	<3,5	55.6	---	23,5	---	86,4	291	55,3	---	81,5	260	56,9
	Mineral horizons (A + B)											
	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	Mg
2004	3,57	51,2	74,0	14,8	5,50	66,9	125	25,4	7,00	74,6	196	32,0
2018	<3,5	36.9	---	---	---	49,3	---	20,5	---	61,7	140	32,0

The P_{MIII} contents significantly decreased in the A_h and (A + B) horizons of all the sites. The K_{MIII}, Ca_{MIII} and Mg_{MIII} contents decreased significantly in the A_h horizon and K_{MIII}, Ca_{MIII} in the (A + B) horizons on the spruce sites.

On the beech sites, there was observed significant decreasing of K_{MIII}, and Ca_{MIII}. Mg_{MIII} kept its level in the (A + B) horizons. There was no significant change in the contents of accessible nutrients in the (A + B) horizons of the beech and mixed sites (Table 6).

Table 7: Contents accessible of sulphur (mg.kg⁻¹) – values of median

	S (mg.kg ⁻¹)		
Horizon	Spruce stands	Beech stands	Mixed stands
Organomineral	26,3	23,5	24,7
Mineral	30,6	22,2	28,2

The content of accessible form of sulphur (S_{MIII}) was determined in the A_h and (A + B) horizons (Tab. 7). There were found out no significant differences between the sites. The highest contents were found under the spruce trees and the smallest ones under the beech trees.

Table 8a: Contents of elements in the current year's needles of spruce (N %, others in mg.kg⁻¹)

	N	P	K	Ca	Mg	Al	Fe	S	B	Cu	Pb	Zn
	Current year's needles											
2004	1,53	1589	8228	3999	946	82	64	1170	18	3,8	0,7	39
2018	1,40*	1452*	6959*	4002	956	63*	77*	1022*	18	3,3*	0,4*	36*
	Previous year's needles											
2004	1,43	1258	6308	5355	838	106	81	1157	18	3	1,0	37
2018	1,40	1211	5696*	5348	831	87*	96*	1044*	15*	3	0,5*	32*

* statistically significant difference

Statistically significant differences in the contents of elements in the tissue of spruce needles of current year were found in N, P, K, Al, S, Cu, Pb and Zn (Tab 8a). The contents were significantly smaller in 2018. Significantly smaller contents in the previous year's needles we found in the K, Al, S, B, Pb and Zn. The increased contents were found for Fe in both the current and previous year's needles.

Table 8b: Contents of elements in beech leaves – mean values (N in %, others in mg.kg⁻¹)

	N	P	K	Ca	Mg	Al	Fe	S	B	Cu	Pb	Zn
2004	1,96	1276	9677	9673	1582	104	156	1570	21	8	3	47
2018	2,34*	1445*	9973	8805	1332*	80*	173*	1658	25	7	1*	36*

* statistically significant difference

A significantly higher nutrition level of the beech in accordance with the leaves chemistry was found for N, P and Fe, while a lower level for Mg (Table 8b). The contents of Al, Pb and Zn were significantly lower in 2018.

The research of the assimilatory tissue chemistry development revealed a lesser level of spruce nutrition in N, P, K, Ca, and S. The content of Mg kept its level. Increased contents of Fe and a stable level of B in the current year's needles were favourable.

Since 2004, the nutrition of the beech has been improved considering N, P and Fe. A significantly decrease was registered for the Mg level.

Discussion

The accumulation of organic material in the (F + H) horizons is typical of the spruce sites (Table 1) with a higher number of recalcitrant compounds (higher content of lignin, tannin agents, resins and waxes, lower pH etc. (PRESCOTT et al. (2000, AUGUSTO et al. 2002), and with a slower decomposition rate due to the acid environment, a low stock of potassium (GANJEGUNTE et al. 2005) and phosphorus (BELYAZID, BELYAZID, 2012, LANG et al. 2016) as the limiting factors of microbial decomposition (Table 2a). A significantly lower amount of C_{ox} in mineral horizons of the beech sites resulted from a higher portion of easily biodegradable compounds in beech litter. The approximately even amount of C_{ox} on the spruce and mixed sites expresses a significant influence of spruce litter on chemical properties of the soil environment. A lower forest floor C_{ox} content of the beech stands corresponds to a faster turnover on these sites with a higher soil fertility as indicated by a significantly higher pH value (VESTERDAL L., RAULUND-RASMUSSEN K., 1998).

Low values of pH on the spruce sites compared with the beech stands, as is observed in our work (Tab. 1), are postulated above all by (ULRICH 1991, PICHLER et al. (2006), OOSTRA et al., (2006), BERG (1986), VESTERDAL, RAULUND-RASMUSSEN (1998).

Some of these authors referred about the continuing acidification induced by a high input of atmospheric N and followed by nitrification as an acidification factor (ROTHER A. et al. 2002, KRUPOVÁ et al. (2018), VRIES DE et al. (2014), FISCHER et al. (2007) or by the reoxidation of S deposited before that (Table 7). The acidification effect of spruce trees on the flysch is reported by BERGER et al. (2014).

The pauperization - lower contents of macronutrients in soils (Table 2a, 2b) under the moder horizons of the spruce stands, is referred by (HAGEN-THORN and all. 2004).

Another factor of acidification is a nutrient uptake by the growth of trees. Mean annual increment of the main stand of management set of fertile spruce sites this NFR is higher ($5,0 \text{ m}^3 \cdot \text{year}^{-1}$) in comparison with the beech sites ($3,1 \text{ m}^3 \cdot \text{year}^{-1}$). Even if the coniferous forest nitrogen requirement is only 50% compared with that of a deciduous forest having the same level of production, a shorter time of rotation period, a different roots architecture and nutrients uptake leads to higher rates of acidification of spruce sites. (MATZNER AND ULRICH (1983) estimated a higher number of protons released in the soil, following the uptake of acidification under the spruce in comparison with the beech.

The distribution of C_{ox} proportion in mineral phase of soil profiles shows a considerable difference in the A_h horizons, where the difference of the soil chemistry due to differences in aboveground litter quality will be more pronounced (HAGEN-THORN et al. 2004, LANGENBRUCH et al. 2012).

The proportion of C_{ox} shows an equitable distribution in the spruce sites, whereas the organic material of the beech sites is concentrated and stabilized in two classes with some outliers. The distribution in the mixed stands is closer to the spruce ones, particularly by larger expansion

with a higher amount in the classes 5,5 % probably representing admixture of more recalcitrant organic material.

A decreasing frequency distribution of C_{ox} in the A_h horizons of the spruce sites reflects a slower C turnover along a significantly higher C/N ratio in the A_h horizons of the spruce sites. On the other hand, on the beech sites, a higher content of C_{ox} in both the A_h and (A + B) horizons resulted from a faster turnover of SOM and a higher proportion of stable fraction of SOC, stabilized through a Ca-mediated processes (ROWLEY et al. 2018) in eutric cambisols, as was postulated by SOUCÉMARIANADIN et al. (2018) and WIESMEIER et al. (2014). In our survey, we can see it on the beech and partly on the mixed sites. A frequency distribution of C_{ox} in A_h on the mixed stand seems to be more influenced by spruce litter.

Higher contents of macronutrient (N, K, Ca, and Mg) under the deciduous trees are referred by AUGUSTO et al. (2002). The nutrient input via litterfall is 10 to 50% higher for N and P and 100 to 400% higher for Ca, Mg and K in broadleaves than in conifers. Those results are confirmed by our investigation (Table 2a, 2b.). Similar results are referred by LEGOUT et al. (2007), KACÁLEK et al. (2010). The beech called “mother of the forest” is said to counteract soil degradation by faster litter decomposition and higher contents of basic cations in the foliage (BERGER, 2014).

The accessibility of N as a growth limiting factor (VITOUSEK et al. 2010, VITOUSEK et al. 1982) influenced a higher level of macronutrients in beech foliage (Table 8) on the mul-moder beech sites with a higher turnover of nutrients in comparison with N blocked on the moder spruce and mixed sites (Table 1).

The cycle of P is classified as a recycling system which enables forest ecosystems to sustain a sufficient P supply over many generations (LANG et al. 2016). The Mehlich method gives accessible contents of nutrient. In case of P_{MIII} , the insufficient content (Table 2a) does not correspond to a high level of P nutrition, expressed by the contents in the foliage (Table 8a, 8b). Higher extractable (P_{extr}) and pseudototal (P_{AR}) contents reveal the storages of phosphorus which could be accepted by the plant with an altered strategy of nutrient acquiring as is described by LAMBERS et al. (2008), LANG et al. (2016). This information refers to a weaker suitability of Mehlich extract to express the ability of spruce to extract phosphorus. The assumption of increased local availability of P under the condition of a higher amount of N_{tot} in the spruce and mixed stands (Table 4) (VITOUSEK et al. 2010) do not correspond with decreasing contents of P_{extr} in the soil of the spruce and mixed stands (Table 5a) and in the spruce needles (Table 8a). This decrease suggests rather a suppressive effect of N_{tot} to the microbial activity (SPOHN M., 2015, BERG B. 1986) and a fall of P concentration in the soil solution with the aging of soil LAMBERS et al. (2008). On the other hand, a beneficial effect of N on P plants takings by enzyme release of ester-P bound in soil organic matter (VITOUSEK et al. 2010) may cause an increase of P_{extr} content in soils (Table 4) and foliage on the beech sites (Table 8b).

The increase of K in the (F + H) horizons of all the sites due to biological cycling is in line with good contents of K in the foliage of both the spruce and beech. The insignificant increase of K_{ext} in the (F + H) horizons may reflect a significant decrease of antagonist Ca_{ext} and Mg_{ext} in those horizons.

The second reason may be more intensive pumping from mineral soil which results in the depletion of soil environment by shallow-rooted spruce trees (GÖRANSSON et al. 2008). This depletion may be compensated by more intense recycling and weathering of K. Possible sources of K weathering are illite and orthoclase (MANNING, 2010) determined by our mineral composition researches.

A significant decrease of K_{ext} in the A_h and (A + B) horizons may result from a weakening soil weathering potential, a decisive factor for the K availability (HELMISAARI H-S., 1995).

The differences in Ca contents are caused by nutrient cycles with higher contents of Ca in the beech foliage and the ability of beech to use weathering pools of Ca from deeper soils,

as may be seen in higher Ca_{MIII} contents in the A_h ($\text{Ca}_{\text{MIII}Ah} > \text{Ca}_{\text{MIII}(A+B)}$) and $\text{Ca}_{\text{AR}Ah} > \text{Ca}_{\text{AR}(A+B)}$), while K_{AR} and Mg_{AR} contents increase with the soil depth (Table 2a). Even if these differences of means contents in upper horizons are not statistically significant and influenced by the outlay values, the pump effect of beech as described on Flysch by BERGER et al. (2004) can not be excluded.

There were significantly lower contents of Mg_{ext} found in the A_h horizons of spruce sites compared with the beech sites, and in the (A + B) horizons compared with the mixed sites. These differences may be a result of a higher amount on the mixed sites as is postulated by BOLTE et al. (2004). This author shows a higher representation of $\text{C}_{\text{ox}} > 3,0 \%$ in mineral horizons. This observation corresponds to median values of C_{ox} determined in our survey (Table 1). Higher contents of Mg raised from both the enrichment of decaying roots and the influence of exudates of living roots, releasing nutrients from soil. The lignin-derived phenols released from the beech deadwood at „mul-silicate“ and „moder-silicate“ sites (edaphic category „B“ and „S“) help increasing the availability of nutrient (STUTZ et al. 2019), as is confirmed by higher contents of accessible nutrient on the beech and mixed sites of our survey (Table 2a).

A special role is played by a higher rate of weathering described by JONARD et al. (2014) and confirmed with the representativity of chlorits in the soil investigated.

Higher contents of Al_{ext} in the A_h horizons (Table 2b) of the beech sites may be related to the location of Al within the roots, absorption of Al on mucilage or mycorrhizas and a high level of Al in the root cortical apoplast (JENTSCHKE et al., 2001). From this point of view, a high density of coarse roots on the spruce sites may incorporate a big amount of Al and Fe compared with a deeper displacement of roots on the beech and mixed sites.

Significantly smaller contents of Mn (Table 2b) in the (F + H) and A_h horizons of the spruce sites are explicated by BERGER et al. (2004). The soils under trees, especially on the flysch, are cemented by wind vibrations and have become impermeable and more waterlogged. The manganese oxides in wet soils are converted to a mobile Mn^{2+} and taken by roots. Manganese on those sites is stored in spruce boles in contrast to the beech where it is stored on the leaves, and after a leaf fall, it is stored in the (H + F) and A_h horizons (Table 2b).

The sulphur was deposited in the soil in the 70s and the 80s of the 20th century. The highest amounts were found in the (A + B) horizons with the highest adsorption capacity due to higher iron and aluminium contents which are strongly related to SO_4^{2-} adsorption. On the contrary, organic matter may block adsorption sites (EDWARDS, 1998).

Lesser contents of available S (S_{MIII}) in the beech site may be explained by a more mobile ester form of organic sulphur which is stored in the stem of the beech as a protein, in contrast to the spruce where a reduced sulphur is stored in needles as glutathione (EDWARDS, 1998, KAISER and GUGGENBERGER, 2005, RENNENBERG and HERSCHBACH, 1995).

High atmospheric inputs to forest ecosystems caused the increase of plant uptake rates of relatively mobile hazardous metals: zinc (Zn) and manganese (Mn), and a top soil accumulation of less mobile metals: copper (Cu) and lead (Pb) (Table 5c) (TÜRSTCHER et al., 2017). Increasing contents of Pb were found in the (F + H) horizons of all the sites. The significance of this increase was only affirmed in the spruce sites. The significantly decreased contents of Cu in the horizons (F + H) of all the sites reflect the trends of a declining pollution of forest ecosystems in Europe in recent decades (HARMENS et al. 2008).

Significantly higher contents of Cd_{ext} , Cr_{ext} , Cu_{ext} , Fe_{ext} and Zn_{ext} (Table 2a) and noticeably higher contents of Pb_{ext} in the (F + H) horizons of the mixed sites may result from higher contents in the assimilatory tissue (Cu, Fe) (Table 8a) and maybe from a pumpkin effect of deeper situated beech roots in the mixed site (Cd, Zn) (BOLTE et al., 2004). Cd is more mobile in acid soils of the spruce sites and, similarly to Mn, Al, Zn and C, is washed out from the rhizosphere (BERGKVIST, 1987). The opposite is true for Pb, Cu and Fe which are washed out from the A_h horizons and precipitated in the bottom (A + H) horizons (BERGKVIST, 1987).

This accumulation is confirmed in our survey just in case of Fe (Table 2b). The contents of Pb and Cu decreased from the (F + H) to the (A + B). Less mobile Cu and Pb are strongly related to the biomass of mushrooms (Cu) and strongly bound to the organic matter (Pb) (STEINNES, 1995).

The equal or even improved level of P and Mg nutrition is connected with a phenomenon of faster weathering in the acid condition (VADENBONCOEUR et al., 2014) and with a changed plant strategy consisting in stronger excavating of nutrients as is referred today in the forest of Central Europe (JONNARD et al. 2014, FERNÁNDEZ-MARTÍNEZ et al. 2014). This assumption is supported by a large amount of chlorite derived by biotite weathering, as was declared in our survey. Moreover, on the beech sites, we suppose a higher contribution of macronutrient released from organic material and from dead roots of deciduous trees (GORDON W. S., JACKSON R. B. 2000).

(JONARD et al. 2015) referred about the decreasing concentration of N in the leaves of *Fagus sylvatica* and in 1-year-old needles of *Picea abies*. This is not consistent with our finding for the spruce. The decrease of P contents in current-year needles of the spruce is in line with our work but the contents of P in beech leaves are higher. In our survey, decreased contents of S are observed just in the spruce. Nonsignificant decrease of deficient contents of calcium is observed in beech leaves. A magnesium decrease in beech leaves is observed in our survey, while the content in the spruce needles keeps its deficient level. A decrease of the contents of K is confirmed by our survey for the spruce.

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Conclusion

The results of the periodical survey of forest nutrition brought the findings about the soil chemistry of the soil environment in the most expanded tree management set of stands in the NRF Moravian-Silesian Beskids. The forest sites described are the results of management in a commercial forest after several centuries and especially the result of the influence of pollution in the late 20th century. The actual state of forest ecosystems and the development of the last fifteen years confirmed a carrying on acidification and deterioration of forest ecosystems. The findings are in line with the declarations of other authors pointing out changed behaviours of woody plants excavating the nutrients from more recalcitrant sources and exhausting the soil environment. The information is largely applicable in the forest management planning.

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