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Development of air pollutant deposition, soil water chemistry and soil on Šerlich research plots, and water chemistry in a surface water source

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ABSTRACT: In 1986 (1987) research plots were established in a forest stands on the south-western slope of Šerlich Mt., Orlické hory Mts. (Kristina Colloredo-Mansfeld – Forest Administration Opočno), at the altitude of 950 to 970 m, to study deposition, chemistry of precipitation and soil water and development of soil chemistry. The plots were established on a clear-cut area, in a young stand and a mature stand of spruce, in a mature beech stand, and in an advanced growth of spruce and European mountain ash. The content of solutes in creek water was studied at the same time. Since 1993 the concentration of substances in precipitation water intercepted in the summit part of Šerlich Mt. has been measured. Research on water chemistry in the stands terminated in 1997. Soil analyses were done in 1986 (1987), 1993 and 1999. The load of acid air pollutants in these forest ecosystems was high in the eighties. After 1991 the deposition of H^+, S/SO_4^{2-}, $N/NO_3^- + NH_4^+$, Mn, Zn, Al decreased. Similarly, an increase in pH was observed in soil water, and the concentrations of SO_4^{2-}, and N, Al compounds decreased. But in 1993 the concentrations of SO_4^{2-} and Al increased again under the spruce stand for several months. The concentrations of NO_3^-, Mn, Zn and Al in the stream water also gradually decreased in the nineties. On the contrary, the average values of S-ions increased compared to those of 1987 to 1991. Strongly acid soil reaction developed in deeper layers until 1993. In the second half of the nineties the pH/H_2O value somewhat increased again, however the reserve of K, Mg, Ca available cations in the mineral soil constantly decreased. The saturation of sorption complex by basic cations in the lower layer of rhizosphere did not reach even 10% in 1999. The forest ecosystems of Šerlich Mt. were also loaded by a high fall-out of Pb, and increased fall-out of Cu. The lack of balance of N-compound transformations and consumption in the soil and increased leaching of N in the form of nitrates contribute to soil acidification on the investigated plots.

Keywords: mountain forest stands; deposition; precipitation water chemistry; soil water chemistry; water chemistry in water sources; soil chemistry

In the last decades forests of the Orlické hory Mts. were threatened by air pollutants generated mainly by sources in Eastern, Central and Northern Bohemia, and by some sources across the frontier, mainly in neighbouring Poland. Besides the deposition from precipitation water, aerosols and solid fall-out also play a role in this long-distance transfer.

Forest stands on south-western slopes and in summit parts, exposed to western air currents, also suffered from snow and frost deposit in the past, mainly spruce stands of unsuitable provenance.

Symptoms of great needle damage in spruce stands in the summit parts of the Orlické hory Mts. were observed at the end of the seventies for the first time after a power station in Chvaletice was put into operation.

The damage and decline of stands, mainly in the eastern part, culminated in the first half of the eighties (Matička 2000; Vacek et al. 2000). The spruce stands, damaged by air pollution, were also afflicted by top breakage and biotic harmful factors (bark-beetles and leaf-eating insects). The damage to assimilation organs by air pollution decreased at the end of the eighties and in the early nineties, and the surviving stands revitalised. Successful regeneration by target or transitory species was completed on clear-cut areas resulting from salvage felling (blue spruce, birch and European mountain ash).

Since 1996 damage or decline of individuals and groups started to be observed mainly in young stands of spruce and birch (Husák 2000; Šrámek et al. 2000). No more significant damage was yet observed in the part of the Orlické hory Mts. west of Šerlich Mt.

The air pollution disaster aroused interest to study deposition, impact of forest ecosystem on the chemistry of water running off to surface sources, and the state and development of soil chemistry. Therefore in 1986 and 1987 research plots were established on the slope of Šerlich Mt., in a locality where research on the impact of spruce stands and clear-cuts on the stand microclimate, precipitation interception and snow conditions was conducted already in the sixties (Krečmer et al. 1979). The results of investigations into soil and water chemistry from 1987 to 1991 were already published (LOCHMAN, MAREŠ 1995).

In the ecosystems of the spruce and beech stand within the research object of Opočno Research Station of the Forestry and Game Management Research Institute Jíloviště-Strnady (FGMRI) in Deštné v Orlických horách (KANTOR 1994) established to study the stand water balance, the matter content and its transport was investigated in the vegetation period 1981 (LOCHMAN, KANTOR 1985).

In 1994 to 1999, in the proximity of the research plots of FGMRI, research was subsidised by the Agency for the Nature and Landscape on the deposition with precipitation water in Bukačka nature preserve and Trčkov nature preserve (HÁJEK et al. 2000). The installation of a station by the Czech Hydrometeorological Institute (CHMI) measuring air pollutants (AMS) on the top of Šerlich Mt. in the mid-nineties was another important activity.

Investigations of deposition and its losses through water runoff have been conducted within the GEOMON programme in the eastern part of the Orlické hory Mts., in the basin U Dvou louček since 1994 (FOTTOVÁ, SKOŘEPOVÁ 1998; HRUŠKA et al. 2000).

Investigations of soil properties in forest stands of the Orlické hory Mts. are carried out by the team of researchers from ÚHÚL (VACEK et al. 2000), Forestry Faculty of the University of Agriculture in Brno (PELÍŠEK 1983) and other institutions since the fifties. The interest in the state and development of the basic characteristics has increased since the eighties.

METHOD

Description of research objects

Šerlich research plots are situated on the south-western slope of Šerlich mountain at the altitude of 950 to 970 m (Kristina Colloredo-Mansfeld – Forest Administration Opočno). Detailed specification is given in Table 1.

The plots are situated on the south-western slope of the average gradient 20%. Investigations of soil water chemistry were initiated in five stands at the six localities in 1987:

plot I: clear-cut area reforested by spruce and European mountain ash,
plot II: spruce stand 29 years old (1987),
plot III: open spruce stand 119 years old (1987),
plot IV:
  a) advanced growth of spruce of the 1st age class,
  b) advanced growth of European mountain ash of the 1st age class,
plot V: stand group of beech 119 years old (1987).

Since 1993 the amount of solutes in precipitation water in Šerlich has also been measured (near the automatic station of CHMI) and in Trčkov (by the measuring station of CHMI).

Climatic conditions

In the sixties, average annual precipitation in the open area was 500 mm during the vegetation season and 600 mm in the dormant period (KREČMER et al. 1979). On the plots of the FGMRI, Opočno, at a distance of 2 km and at a similar altitude, the average annual precipitation was 1,170 mm in 1982–1993 (KANTOR 1994). According to the Atlas of the ČSSR (1966), the long-term annual precipitation amount in this region is 1,200–1,400 mm, average annual temperature is 2–4°C, and the climate is characterised as moderately cold – C_1.

Soil conditions

Moderately deep sandy-clay soil developed on the weathered parent rock of mica schist. The humus form in the spruce stand and on the clear-cut area is moder, similarly like in the beech and European mountain ash stand. The soil type is Dystric Cambisol, FAO, partly merging in Haplic Podzols, FAO. The forest site type is acid beech-spruce stand with *Luzulo fagetum* ass. 7K1.

Air pollution

The level of air pollution by toxic gases varies in time and space. Data from a station at Uhřínov, situated on the lower border of the protected area, are available for the Orlické hory Mts. from the past (Orlické hory Protected Landscape Area). According to HÁJEK et al. (2000), after 1980 the average daily concentrations of SO_2 at this station were about 20–30 μg/m^3, with some short-time extremes of about 250 μg/m^3. After 1998, daily concentrations of

Table 1. Position of research objects on Šerlich Mt.

Plot	Gauss-Krieger coordinates		Coordinates		Altitude (m)
	X	Y	Eastern longitude	Northern latitude	
Šerlich I	359810	557885	16°22´40´´	50°19´57´´	960
Šerlich II	359810	557885	16°22´40´´	50°19´57´´	960
Šerlich III	359810	557885	16°22´40´´	50°19´52´´	950
Šerlich IV	359810	557885	16°22´40´´	50°19´52´´	950
Šerlich V	359810	557885	16°22´40´´	50°19´52´´	970
Šerlich AMS	359845	557850	16°22´56´´	50°19´47´´	1,010
Trčkov	360180	557650	16°25´46´´	50°18´45´´	750

SO_2 from November to February were 5–20 $\mu g/m^3$, and from March to October nearly 5 $\mu g/m^3$. During the nineties NOx concentrations also decreased roughly by a half.

Data of the CHMI station from 1996 and 1997 (Zpráva ČHMÚ 1997, 1998) are at disposal. In 1997, the average concentration of SO_2 was 15 $\mu g/m^3$ and of NOx 9 $\mu g/m^3$ at this station (in 1996 lower than 20 $\mu g/m^3$). While in 1997 the average ozone (O_3) concentration in the air was calculated to be 53 $\mu g/m^3$, with the maximum of 131 $\mu g/m^3$, in spring and summer months of 1998 and 1999 the average daily concentrations were about 80–150 $\mu g/m^3$. Dust aerosol did not reach 30 $\mu g/m^3$ in 1996.

Work description

Gutters collecting precipitation water were installed on the plot, and lysimeters for soil water interception under the surface humus layer O and at the depth of 20 (30) cm and 50 cm. Water was collected in containers placed in covered pits. Since the beginning of measurements in 1987 the stream water from the left tribute to the Bělá River by the Šerlišský mlýn locality was also taken.

Snow samples were taken to determine the amount and chemistry of winter precipitation. Soil samples were taken in 1986 (on plot II in 1987), and repeatedly in 1993 and 1999. Water samples were taken in monthly intervals, in winter less frequently, to find the water value of the snow cover before melting.

Laboratory analyses

Analyses of water and soils were done in a laboratory of the FGMRI – Jíloviště-Strnady, using standard methodology. Nitrates, sulphates and ammonium ions were determined colorimetrically in Technicon Auto Analyser II. Chlorides and fluorides were determined by CRYTUR ion-selective electrodes, and phosphorus compound concentrations were determined colorimetrically using ammonium molybdate. To measure cation and metal concentrations, atomic spectrophotometer Varian Techtron AA-1273 was used. Since 1994 concentrations of NO_3^-, Cl^-, F^-, SO_4^{2-} were determined by the chromatograph Thermoseparation Products, and for NH_4^+ colorimeter SAN Plus by Skalar was used. To determine the concentration of cations and metals (Na, K, Mg, Ca, Al, Cu, Fe, Mn, Zn) and total P spectrometer ICP OES LIBERTY 220 by Varian was used since 1994.

In soil sample analyses available nutrients were determined in 1% solution of citric acid, since 1989 available cations were extracted with 1M NH_4Cl. Available phosphorus compounds (PO_4^{3-}) were extracted from the soil with the mixture of 0.05M HCl and 0.025M H_2SO_4. To determine the total element reserve in the organic horizon, in elution of ash after combustion, concentrated HCl was used in 1986 and 1993. In 1999, aqua regia was used to determine the total element reserve. To determine the cations and metals in the solution, the lab used the same instruments as in water analyses. Total reserve of oxidisable carbon (Cox) was determined by the Tjurine method, and nitrogen (Nt) by the Kjeldahl method.

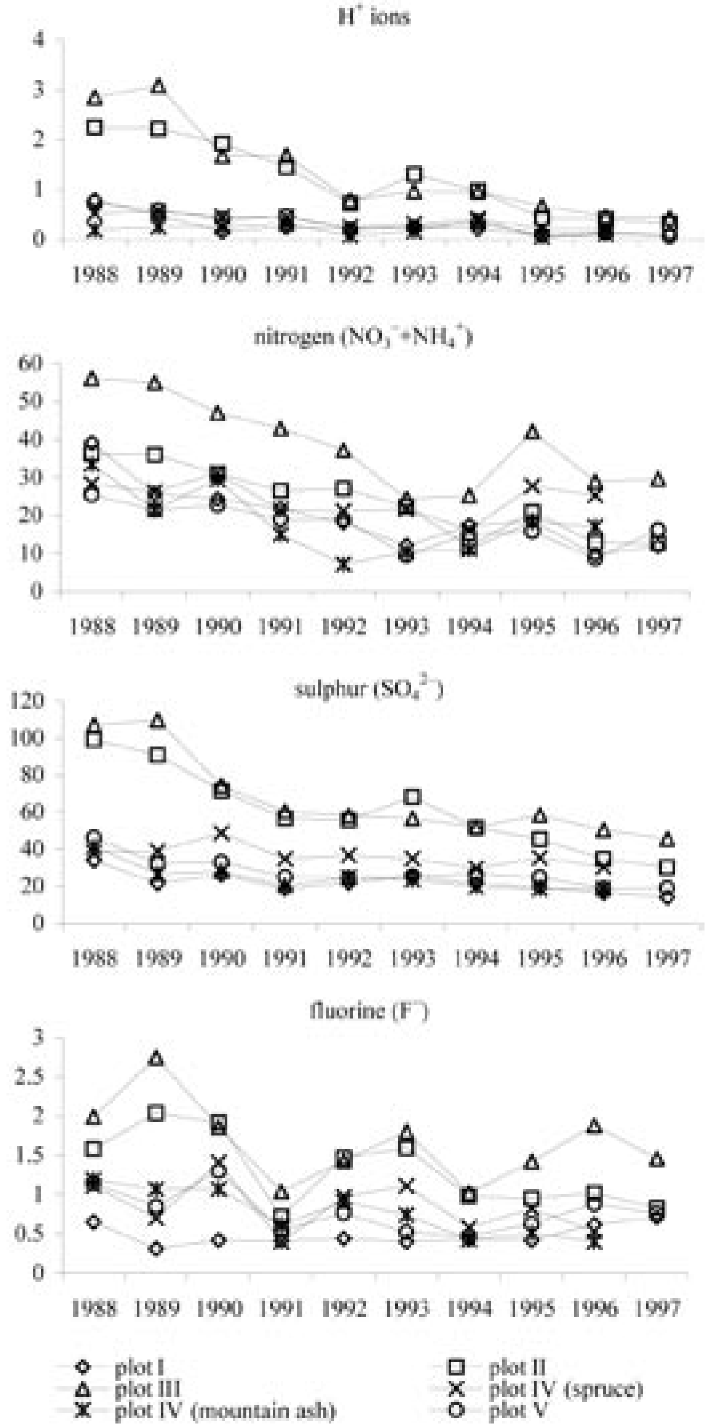
RESULTS

Precipitation water chemistry

Investigations of precipitation water and soil water were initiated in 1987. In that period, great damage to older

Table 2. Chemistry of precipitation water in the open area (bulk) by the AMS in Šerlich

	Year	H	S	N	F	Cl	Zn	Mn
Annual deposition (kg/ha/year)	1993	0.08415	20.54	12.84	0.528	8.98	0.244	0.273
	1994	0.17110	30.45	20.09	0.281	17.40	0.233	0.077
	1995	0.01223	25.03	24.19	1.070	29.82	0.280	0.150
	1996	0.06973	14.89	10.69	0.270	29.12	0.180	0.043
	1997	0.07365	19.77	10.98	0.630	25.25	0.249	0.095
	1998	0.13050	16.87	14.30	0.756	18.14	0.206	0.217
	1999	0.21580	12.08	10.77	0.680	14.42	0.226	0.113
Average concentration (mg/l)	Year	pH	S	N	F	Cl	Zn	Mn
	VII–XI 1987	4.35	2.45	2.100	0.040	1.640	0.058	0.082
	VI–IX 1988	4.35	2.99	2.570	0.069	2.350	0.059	0.029
	1993	5.15	1.68	1.050	0.043	0.735	0.020	0.022
	1994	4.95	1.94	1.270	0.018	1.110	0.015	0.005
	1995	6.14	1.47	1.420	0.063	1.750	0.017	0.009
	1996	5.30	1.04	0.744	0.019	2.030	0.013	0.003
	1997	5.35	1.19	0.662	0.038	1.520	0.015	0.006
	1998	5.10	1.01	0.850	0.046	1.080	0.012	0.013
	1999	4.76	0.98	0.873	0.060	1.160	0.018	0.009



Figs. 1–4. Total deposition with precipitation on Šerlich plots (kg/ha/year)

spruce stands was observed in this part of the Orlické hory Mts. As shown in Fig. 5, the acid atmospheric deposition mainly in spruce stands was enriched by H ions of gas and aerosol emissions (dry deposition) concentrated in tree crowns. On the contrary, in young European mountain ash stands H ions were neutralised by cation leaching from the leaf organs, and throughfall pH increased in some years. After 1991, an increase in average pH values of precipitation water was evident on plots II–V by 1997, both in the open area (bulk) and throughfall.

During the investigations (by 1997), in connection with increasing pH of precipitation water, the proton (H^+) and sulphate deposition (SO_4^{2-}) decreased. This trend was significant mainly in spruce stands on plots II and III, where in the eighties the annual fall-out of H^+ was over 2 kmol/ha (Fig. 1), and after 1995 it decreased below 0.5 kmol/ha, however, its minimum value was still twice higher than on the clear-cut area and in the stand of European mountain ash and beech.

The annual fall-out of S/SO_4^{2-} in spruce stands also decreased gradually, from 100 kg/ha to about a half of this value in 1996 and 1997 (Fig. 2). Similarly, in European mountain ash and beech stands and on the clear-cut area the annual S/SO_4^{2-} deposition with precipitation decreased from about 40 kg to less than 20 kg/ha.

The annual amount of N ($NO_3^- + NH_4^+$) entering the soil with precipitation water had a decreasing trend, with certain misbalance, during the investigations, the decrease was observed mainly in spruce stands. The highest values in the mature spruce stand were over 50 kg/ha, they decreased gradually to 30 kg/ha (Fig. 3). On the other plots, the N deposition ranging between 20 and 40 kg decreased to 10–20 kg/ha/year.

The annual fall-outs of F^- on the clear-cut area were balanced while they varied in the stand. Their decrease in 1988–1997 was insignificant, in 1996–1997 they even increased on the clear-cut area (Fig. 4).

Since 1993 the composition of precipitation was studied in detail on the open area near the automatic measuring station (AMS) in Šerlich. The average annual concentration and total fall-out of H^+, S/SO_4^{2-}, $N(NO_3^- + NH_4^+)$, F^-, Cl^-, Zn, Mn are presented in Table 2. The data confirm fluctuations of precipitation pH (bulk), annual deposition of H^+, F^-, Zn and Mn, and a decrease in S and N deposition in the period 1993 to 1999. Lower contamination of precipitation water by protons, S, N, Mn and Zn was significant, compared to the level in 1987–1988. In February 2000, the concentration of SO_4^{2-} in snow cover was lower than 1 mg/l (0.84 mg/l). Compared to the clear-cut area (plot I), the total S and N fall-out was higher.

In the precipitation water collected nearby the measuring station of CHMI Trčkov, the trend of the annual average development of pH was similar to that at Šerlich (Table 3). Higher average annual concentrations of S and F were most probably influenced by a farm in the close neighbourhood. Before 1996, the total annual deposition of sulphur was higher than 20 kg/ha, and nitrogen 10 kg/ha, since 1996 it was for S between 10 to 20 kg/ha, and for N lower than 10 kg/ha, it means lower than in Šerlich, thanks to lower annual precipitation amounts.

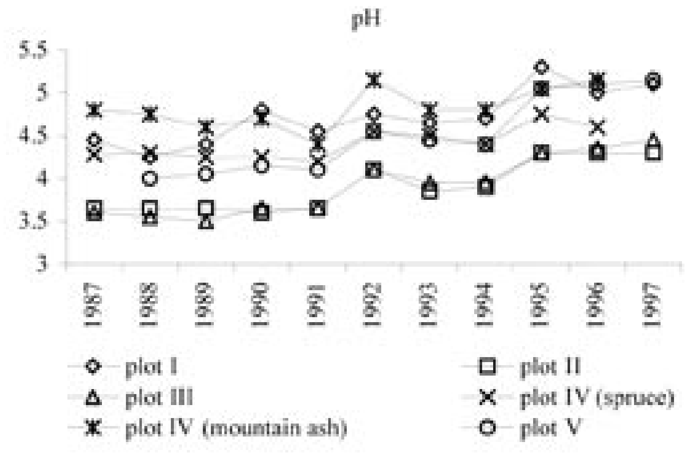


Fig. 5. pH of precipitation water on Šerlich plots

Soil water chemistry

Chemistry of soil water in forest ecosystems is affected by many biological and chemical processes and exchange of matters between soil and vegetation, however, chemistry of precipitation water is crucial for the content of matters mainly in the surface soil horizons. Figs. 6–8 show average pH values of gravitational water collected under the surface humus layer (horizon O), at the depth of 25 to 30 cm and at the depth of 50 cm. That is also why the pH values were the highest in the soil of clear-cut area, and on plots IV (young stand of spruce and European mountain ash) and V (beech stand), and the lowest values were measured in spruce stands. Changes in pH found out in precipitation water since 1992 were recorded also in the soil water.

Table 4 shows average ion concentrations in precipitation and soil water in the period 1987–1991 and 1992–1997.

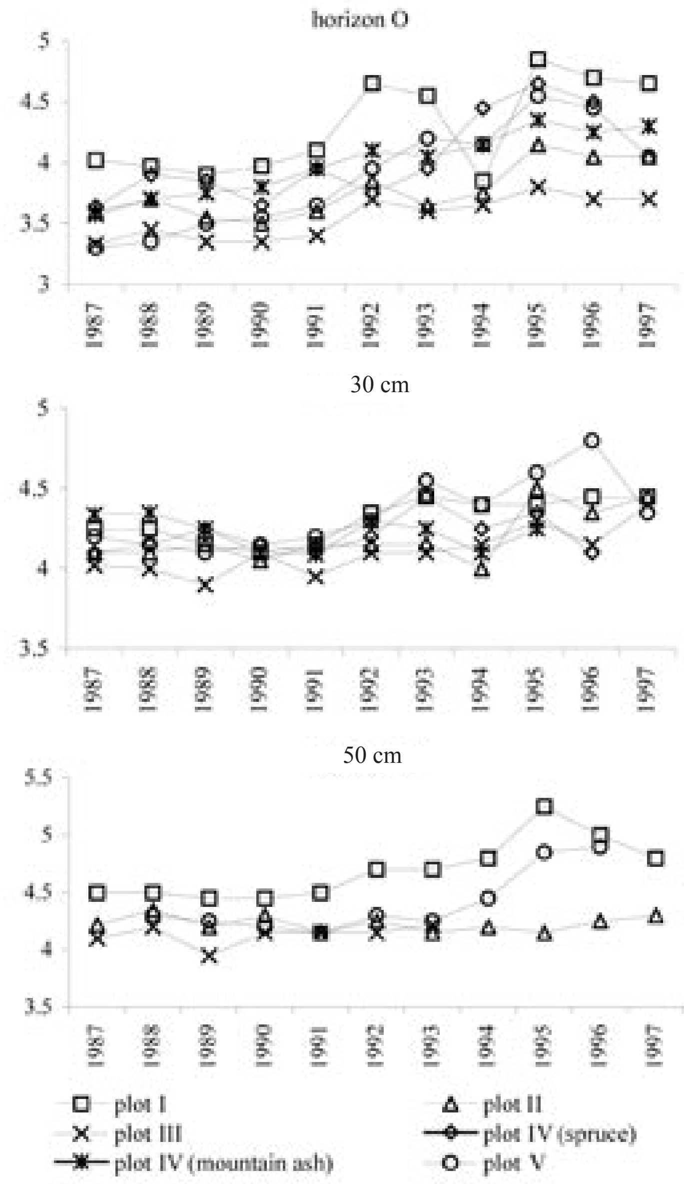
During the first period (1987–1991) the surface humus horizon O on the clear-cut area affected an increase in the concentration of all ions studied in seepage water, with the only exception of N(NO_3^- + NH_4^+). In the stands of spruce and beech, throughfall water in this horizon was enriched by H^+, Ca, Mg, K, Na, Al, S/SO_4^{2-} and N, and, on the contrary, fluorides were isolated (F^-). With K the changes were not unambiguous. In the humus horizon, the cation content of Ca, Mg, K and N in water did not increase in the young stand of European mountain ash. In the mineral horizon, the concentration of protons (H^+), K and N on all the plots decreased, and the content of Na, Al, and on most plots also the content of Mg increased.

In the second period 1992–1997, the surface humus layer of the stands also affected an increase in the ion concentrations of H, Mg, Al in percolating water, and with the exception of spruce stand (II and III), also an increase in Ca, S/SO_4^{2-} and N. On the clear-cut area, the surface humus layer and ground vegetation enriched the precipitation water by all studied matters, with the exception of N. In water percolating the mineral soil, pH increased (H^+ decrease), K concentration decreased, and in all stands the concentration of Mg, Na, Al increased. The changes in Ca and SO_4^{2-} and N(NO_3^- + NH_4^+) concentrations were not unambiguous.

Besides a decrease in proton concentrations in precipitation and soil water during the investigations in 1987–1997 (Fig. 5), the average concentrations of other geo-biogens were also different (Table 4). In the period since1992 the concentrations of K, Al, N, SO_4^{2-}, F^- decreased, both in precipitation and soil water, on the clear-cut area and in the spruce and beech stands (plots I, II, III, V). On the contrary, a visible increase was determined in Mg, and at least in deeper soil horizons (in 50 cm) also in Ca and Na.

Table 3. Chemistry of precipitation water nearby the station of CHMI Trčkov

	Year	H	S	N	F	Cl	Zn	Mn
Total annual fall-out (kg/ha/year)	1993	0.08	30.87	20.97	0.994	13.43	0.277	0.213
	1994	0.21	26.00	10.16	0.480	15.42	0.757	0.606
	1995	0.01	27.35	17.56	0.940	34.76	0.244	0.122
	1996	0.03	11.42	6.30	0.420	20.90	0.121	0.033
	1997	0.09	15.11	6.41	0.700	18.09	0.337	0.119
	1998	0.08	13.72	9.46	0.621	21.14	0.100	0.043
	1999	0.22	11.86	6.84	0.570		0.213	0.120
	Year	pH	S	N	F	Cl	Zn	Mn
Average concentration (mg/l)	1993	5.15	2.92	1.840	0.088	1.19	0.025	0.019
	1994	4.75	2.13	0.832	0.059	1.26	0.062	0.003
	1995	6.05	1.80	1.160	0.062	2.29	0.016	0.008
	1996	5.50	1.48	0.818	0.055	2.71	0.016	0.004
	1997	5.15	1.16	0.492	0.054	1.39	0.026	0.009
	1998	5.15	1.33	0.920	0.060	3.06	0.012	0.005
	1999	4.61	1.18	0.723	0.060	2.08		0.011



Figs. 6–8. pH of soil water sampled at different depths on Šerlich plots

Under the closing canopy of young spruce and European mountain ash stand (plots IVa and IVb) the decrease in concentrations of the ions studied during the second period was not unambiguous.

The trend of Al, SO_4^{2-} and F^- decrease in the soil water was interrupted in autumn 1993 by a sharp increase in concentrations of these ions at the depth of 50 cm on plot II (Table 5). The concentrations of Al in individual samples increased up to16.8 mg/l and SO_4^{2-} to 151 mg/l. This increase can be explained by a release of these ions from the compound complex in the upper soil horizons, after sudden soil acidification caused by opening the crown canopy due to snow calamity.

Development of average concentrations of Al and the ratio of mol Ca/mol Al in the soil water on all plots is shown in Figs. 9–11. Average annual Al concentration in water taken from the mineral soil under the spruce stand on plots II and III overreached 5 mg/l and the ratio mol Ca/mol Al at the depth of 30 to 50 cm was lower than 1 and often even under 0.5 in some years. Minimum values were measured on plot II at a depth of 50 cm.

Causes of an increase in average Al concentrations in 1994 to 10.95 mg/l were already mentioned above (Table 5).

On the clear-cut area, in beech stand (plot V) and in the young spruce and European mountain ash stand (plots IVa, IVb) the ratios of average annual concentrations of Ca and Al were mostly above 1, even in mineral soil.

Water in a surface source

Samples were taken in a stream running from Bukačka Nature Preserve, in the basin of which the plots are situated, above the confluence with Bělá by Šerlišský mlýn. During the years 1987 to 1999, the pH values of individual samples ranged from 4.85 to 7.0. Average annual pH was 6.05 (1996) to 6.85 (1999), as shown in Fig. 12. In 1996 and 1997, a significant decrease in average annual pH values occurred. A visible decrease in the concentration was observed in NO_3^- (Fig. 13), K and metals Al, Fe, Mn, Zn (Table 6). Differences in average values in 1987–1991 and 1992–1999 for F^-, Na, Mg, Ca were not significant. Table 6 and Fig. 14 show a certain increase in SO_4^{2-} ions.

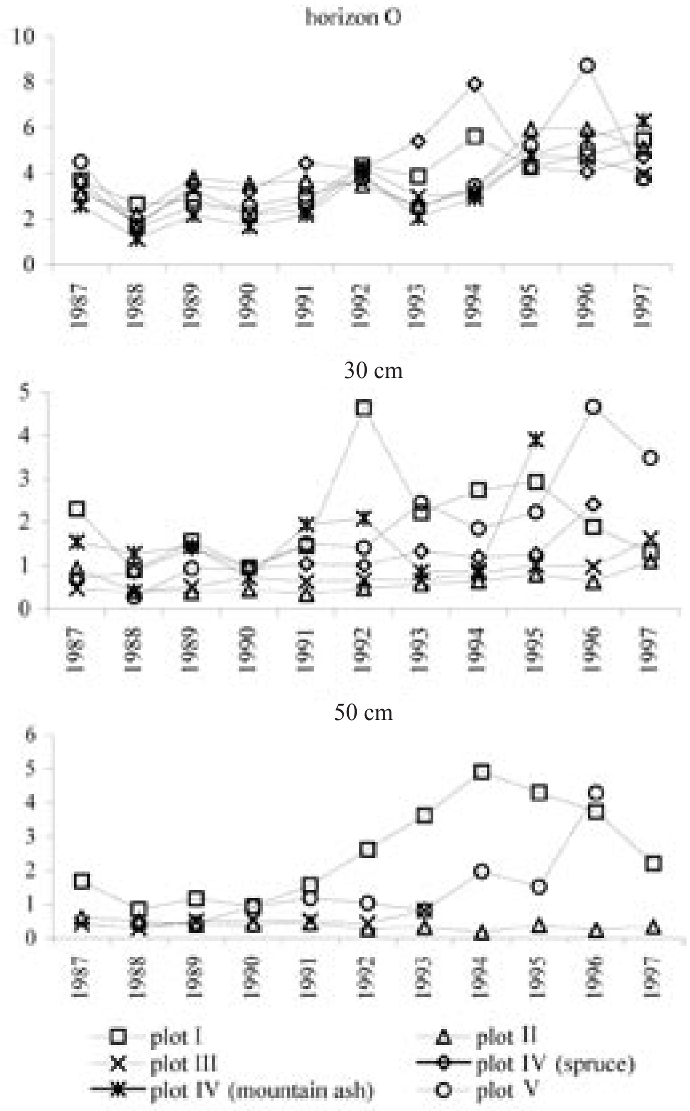
To evaluate the balance of ions studied within the basin, besides deposition the losses with runoff water are also to be known. In a small stream below Šerlich no flow rate was measured, and the annual runoff cannot be determined directly. Rough calculation can be done using the stand water balance values in mature spruce and beech stands on the clear-cut area, and in young spruce and beech stands on the plots according to KANTOR (1994). The author reported that the annual runoff within the above-mentioned ecosystems in 1976 to 1993 was about 773 mm (spruce stand) to 909 mm (beech stand). If we take the annual runoff 800 mm for the calculation, in the given SO_4^{2-} in the stream water of 15.32 mg/l (1988–1991) and 16.78 mg/l (1992–1997) the annual loss of S/SO_4^{2-} with runoff was 40.9 and 44.8 kg/ha. In the average concentration of NO_3^- 12.21 mg/l (1988–1991) and 8.5 mg/l (1992 to 1997) and of NH_4^+ 1.04 and 0.318 mg/l, the annual loss of N in 1988 to 1991 was 28.0 kg/ha and in 1992–1997 it was16.15 kg/ha. Lower nitrogen loss in the second period would be 11.85 kg/ha/year (Table 11).

The difference in total fall-out of N in the two evaluated periods, both in the stands and on the clear-cut area, was about 13 kg/ha, with the exception of young spruce stand (Table 11). It is obvious that the lower load of nitrogen compounds in the studied forest ecosystems in the nine-

Table 4. Average ion concentrations in precipitation water and soil water on Šerlich plots

Location of samplings	Period*	H^+	Ca	Mg	K	Na	Al	N	SO_4^{2-}	F^-
		(µg/l)	(mg/l)							
Plot I – clearcut area										
Precipitation water	1	37	2.26	0.29	0.33	0.41	0.170	2.49	6.77	0.040
	2	13.4	1.94	0.46	0.26	0.48	0.076	1.20	4.87	0.042
Soil water under O horizon	1	103	2.73	0.99	2.85	0.56	0.650	2.46	16.39	0.070
	2	42	2.33	0.68	1.38	0.61	0.420	0.88	8.07	0.051
Soil water at 30 cm	1	63	2.12	0.65	0.69	0.61	0.990	1.57	10.62	0.090
	2	38	2.40	0.78	0.55	0.65	0.690	1.19	8.72	0.088
Soil water at 50 cm	1	32	2.04	0.50	1.27	0.56	1.150	2.00	9.92	0.050
	2	14.7	2.01	0.68	1.20	0.64	0.420	0.77	6.97	0.038
Plot II – spruce										
Precipitation water	1	219	3.03	0.65	2.94	0.76	0.490	3.65	26.16	0.180
	2	80	2.49	0.72	2.17	0.66	0.138	2.07	14.90	0.119
Soil water under O horizon	1	263	4.20	1.00	3.80	0.68	0.840	6.57	30.97	0.150
	2	133	2.36	0.83	0.84	0.60	0.420	1.62	13.02	0.055
Soil water at 30 cm	1	65	2.67	0.89	0.93	0.75	4.500	3.05	36.53	0.130
	2	53	2.33	0.97	0.53	0.87	2.470	2.36	20.92	0.114
Soil water at 50 cm	1	84	2.23	0.58	1.25	0.65	3.300	3.52	25.29	0.110
	2	62	2.83	1.23	0.66	1.21	6.700	1.09	30.82	0.132
Plot III – spruce stand										
Precipitation water	1	257	3.28	0.63	3.06	0.85	0.600	5.64	29.30	0.220
	2	75	3.40	0.84	2.27	0.83	0.227	3.28	16.80	0.158
Soil water under O horizon	1	384	3.73	0.81	2.99	1.02	1.230	7.89	32.80	0.190
	2	212	3.16	0.96	1.58	0.84	0.550	2.64	18.45	0.120
Soil water at 30 cm	1	99	3.46	1.24	1.03	1.11	3.130	4.97	34.15	0.260
	2	66	3.03	1.32	0.40	0.98	2.280	3.35	19.52	0.147
Soil water at 50 cm	1	91	3.54	1.30	1.21	0.99	5.460	4.91	34.84	0.240
	2	67	3.91	2.02	1.20	1.59	4.410	5.06	35.14	0.237
Plot IV – young spruce stand										
Precipitation water	1	55	2.33	0.61	3.30	0.56	0.230	3.02	13.64	0.120
	2	30.2	2.49	0.86	2.89	0.74	0.210	2.44	10.85	0.087
Soil water under O horizon	1	136	2.56	0.58	2.53	0.81	0.620	4.34	17.58	0.100
	2	75	3.53	1.22	3.40	1.01	0.480	4.85	14.48	0.097
Soil water at 25 cm	1	64	2.64	0.97	0.63	0.62	1.550	2.73	15.54	0.150
	2	57	2.99	1.32	0.55	0.71	1.490	3.05	12.44	0.109
Plot IV – young ash stand										
Precipitation water	1	25	2.06	0.50	2.66	0.47	0.140	2.49	8.50	0.390
	2	15.8	2.07	0.69	1.99	0.62	0.190	1.33	6.54	0.062
Soil water under O horizon	1	157	1.92	0.52	1.56	0.67	0.670	1.91	15.59	0.070
	2	66	2.68	0.93	1.72	0.61	0.480	2.29	8.76	0.064
Soil water at 25 cm	1	56	2.58	0.70	0.66	0.93	1.250	1.54	12.76	0.160
	2	6	2.52	0.96	0.78	0.85	1.110	3.13	11.74	0.244
Plot V – beech stand										
Precipitation water	1	79	2.35	0.49	2.47	0.60	0.290	4.54	15.09	0.160
	2	22.6	2.08	0.63	1.44	0.71	0.142	1.84	9.06	0.088
Soil water under O horizon	1	259	2.87	0.74	2.91	0.70	0.820	5.39	18.98	0.100
	2	66	2.72	0.84	2.36	0.67	0.470	2.42	11.35	0.074
Soil water at 30 cm	1	71	2.70	0.76	1.68	0.92	2.070	4.69	18.21	0.090
	2	27.8	2.60	0.96	1.26	0.76	0.770	3.13	10.89	0.076
Soil water at 50 cm	1	60	2.44	0.80	0.54	0.82	3.300	3.93	21.48	0.120
	2	34.4	3.31	0.99	0.73	0.83	1.270	1.72	14.77	0.073

*Period 1: 1987–1991; period 2: 1992–1997



Figs. 9–11. Ca/Al ratio in soil water sampled at different depths on Šerlich plots

ties also resulted in corresponding lower leaching of this element in the basin.

With sulphur, however, in spite of a significant lowering of deposition in all stands and on the clear-cut area, no lower losses in stream water runoff were observed. As shown in Table 11, total annual fall-out of mineral nitrogen and sulphur (SO_4^{2-}) varies according to the tree species and its age. In the spruce stands it was higher than the losses in runoff water, expressing the average of all stands, including broadleaved stand and clear cuts.

In the beech stand no stem flow was measured, the proportion of which is quite important in the stand precipitation in mountain forests (25–30% of throughfall) (KANTOR 1985), and in contaminated water the concentrations of H^+, SO_4^{2-}, NO_3^-, NH_4^+, F^- in stemflow water are also much higher than in the throughfall (LOCHMAN, KANTOR 1985; LOCHMAN, MAREŠ 1995).

The NO_3^- deposition with precipitation in the studied stands and the losses with runoff water can also be observed. As shown in Table 11, the annual loss of 1.575 kmol/ha in 1988–1991 and 1.040 kmol/ha in 1992–1997 was not compensated through deposition in any of the studied sample plots. So it is obvious that the nitrification of ammonium ions in forest soils and their leaching was the source of NO_3^- ions in the stream. Ammonium nitrogen accounted for more than 60% of total mineral N coming to the ecosystem with precipitation. As shown in Table 4, the highest increase in NO_3^- was measured in the soil water, in the surface humus layer of spruce stand and beech stand, where an increase in H ions was observed at the same time. In these stands the highest nitrogen fall-out ($N/NO_3^- + NH_4^+$) was also observed that limited the herbaceous vegetation.

Soil chemistry and its development

Soil and humus samples for analyses were taken on the research plots in 1986, 1987 and again in 1993 and 1999. The results of sample analyses carried out in 1959 are also at disposal for plots II, III and IV.

The data in Table 7 show that surface horizons in the given locality in the Orlické hory Mts. were mostly acid,

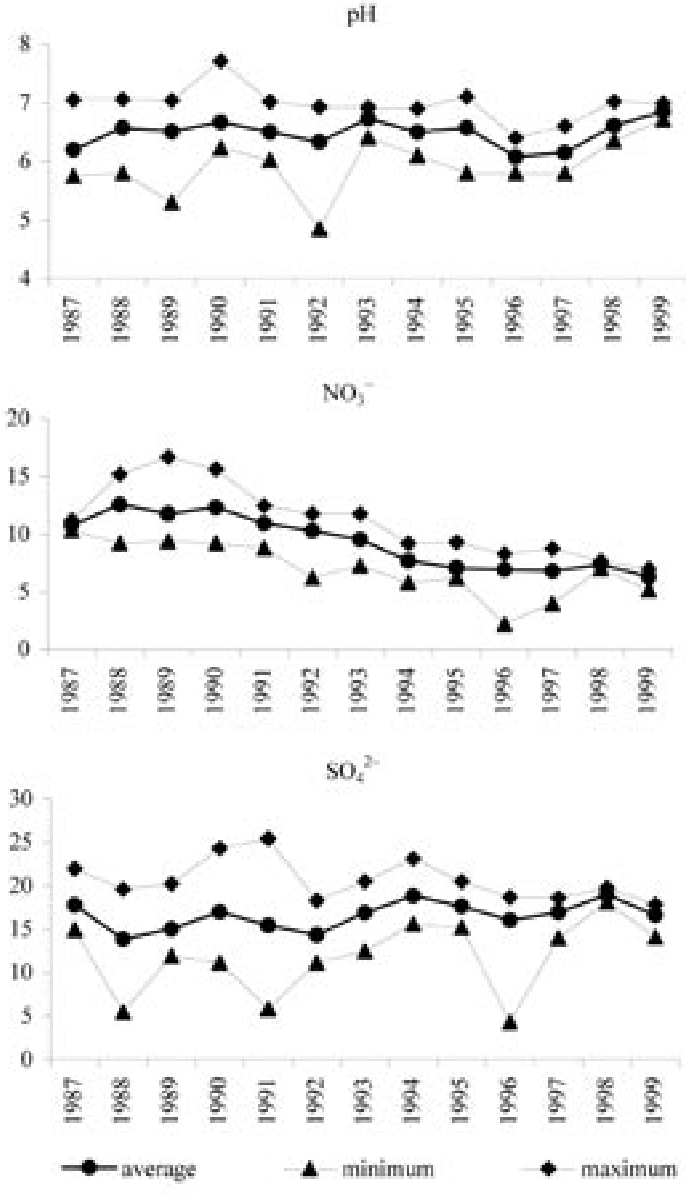
Table 5. Ion concentrations in soil water, plot II, depth 50 cm in the period of increased Al concentrations

Sampling	pH	K	Mg	Ca	Al	SO_4^{2-}	NO_3^-	Ca/Al	Mg/Al	PO_4^{3-}
				(mg/l)				(mol)	(mol)	
27. 10. 1993	3.89	4.52	1.28	2.87	6.65	53.41	30.78	0.290	0.213	0.952
3. 2. 1994	3.90	1.60	1.49	2.81	16.80	123.17	6.54	0.112	0.098	0.406
15. 3. 1994	4.10	0.45	2.05	4.12	12.89	100.70	0.65	0.215	0.176	0.053
7. 6. 1994	4.26	0.42	1.21	2.67	10.84	102.15	1.14	0.165	0.123	0.072
1. 9. 1994	3.78	4.50	0.84	4.24	2.66	29.75	20.28	1.073	0.350	0.600
13. 12. 1994	4.14	0.74	1.98	4.73	15.33	150.84	0.65	0.207	0.143	
27. 1. 1995	4.26	0.14	1.49	2.72	7.56	61.56	1.45	0.242	0.219	
26. 7. 1996	4.10	0.22	1.12	2.62	6.14	44.51	2.75	0.288	0.203	0.010
23. 4. 1997	4.20	0.42	1.14	2.68	7.19	50.49	2.23	0.251	0.176	0.010

even before the intensive air pollution load. The water extract of humus horizons had pH(H_2O) lower than 4.2 and exchangeable pH(KCl) did not reach the value 3. By 1986 (1987) strong acidification penetrated into deeper layers. On the former clear-cut area (plot II) there grew a closed spruce stand, and in the place of open spruce stand (plot IV) there grew a natural spruce and ash young stand. In 1999, in the young, broken spruce stand (plot II) the pH has increased slightly (mainly pH/H_2O). In the open mature stand the pH(H_2O) increased slightly, and pH(KCl) decreased moderately. In the young stand after thinning (plot IVb) pH(H_2O) increased more significantly, and also an increase in exchangeable pH(KCl) was observed, compared to the state in 1987 (Table 7). However, the available cation reserve decreased in time, and today also in the deeper soil layers does not exceed 50 ppm for Ca, 10 ppm for Mg and 40 ppm for K. The difference between the plots is small. The content of P available (PO_4^{3-}) also decreased.

Table 8 shows a decrease in basic cations (BCE) in the soil in 1986 to 1999. In the soil samples from the lower part of the profile taken in 1986 and 1987, the sum of basic cations (BCE) in the sorption complex was affected mainly by higher Ca reserve. Favourable molar ratio of basic cations Na, K, Mg, Ca and the sum of acid cations of the metals Al, Fe, Mn (ACE) was found only in the humus horizons under the stands of European mountain ash and beech. The valence value of basic cations (BCE) in the sorption complex of mineral soil on plots II, III and V did not mostly reach 10% of the valence value of metals (ACE), as shown in Table 8.

The reserve of exchangeable cations in the extract of 1M NH_4Cl decreased with the profile depth, on the contrary, total reserve determined after decomposition of the soil material by aqua regia increased. The state of 1999 for potassium



Figs. 12–14. pH values and nitrate and sulphate concentrations (mg/l) in the stream water near Šerlišský mlýn

Table 6. Average annual concentrations of elements (mg/l) in the stream water near Šerlišský mlýn

Year	pH	N	NO_3^-	F	S/SO_4^{2-}	Al	Fe	Mn	Zn
1987	6.43	2.85	10.8	0.06	5.93	0.380	0.05	0.02	0.03
1988	6.57	3.32	12.6	0.09	4.62	0.180	0.03	0.03	0.02
1989	6.51	3.50	11.8	0.10	5.02	0.036	0.03	0.03	0.03
1990	6.67	4.24	15.0	0.09	5.67	0.101	0.02	0.03	0.01
1991	6.50	3.57	10.9	0.07	5.15	0.144	0.02	0.02	0.02
1992	6.33	3.00	10.3	0.09	4.79	0.190	0.01	0.02	0.01
1993	6.73	2.17	9.55	0.11	5.64	0.220	0.01	0.01	0.01
1994	6.51	–	7.69	0.07	6.29	0.102	0.01	0.01	0.01
1995	6.40	1.66	7.08	0.08	5.89	0.037	0.01	0.01	0.02
1996	6.05	1.80	7.72	0.08	6.00	0.014	0.01	< 0.01	0.01
1997	6.10	1.60	6.79	0.06	5.66	0.051	0.02	0.01	0.01
1998	6.70	1.71	7.37	0.08	6.34	0.014	< 0.01	< 0.01	0.01

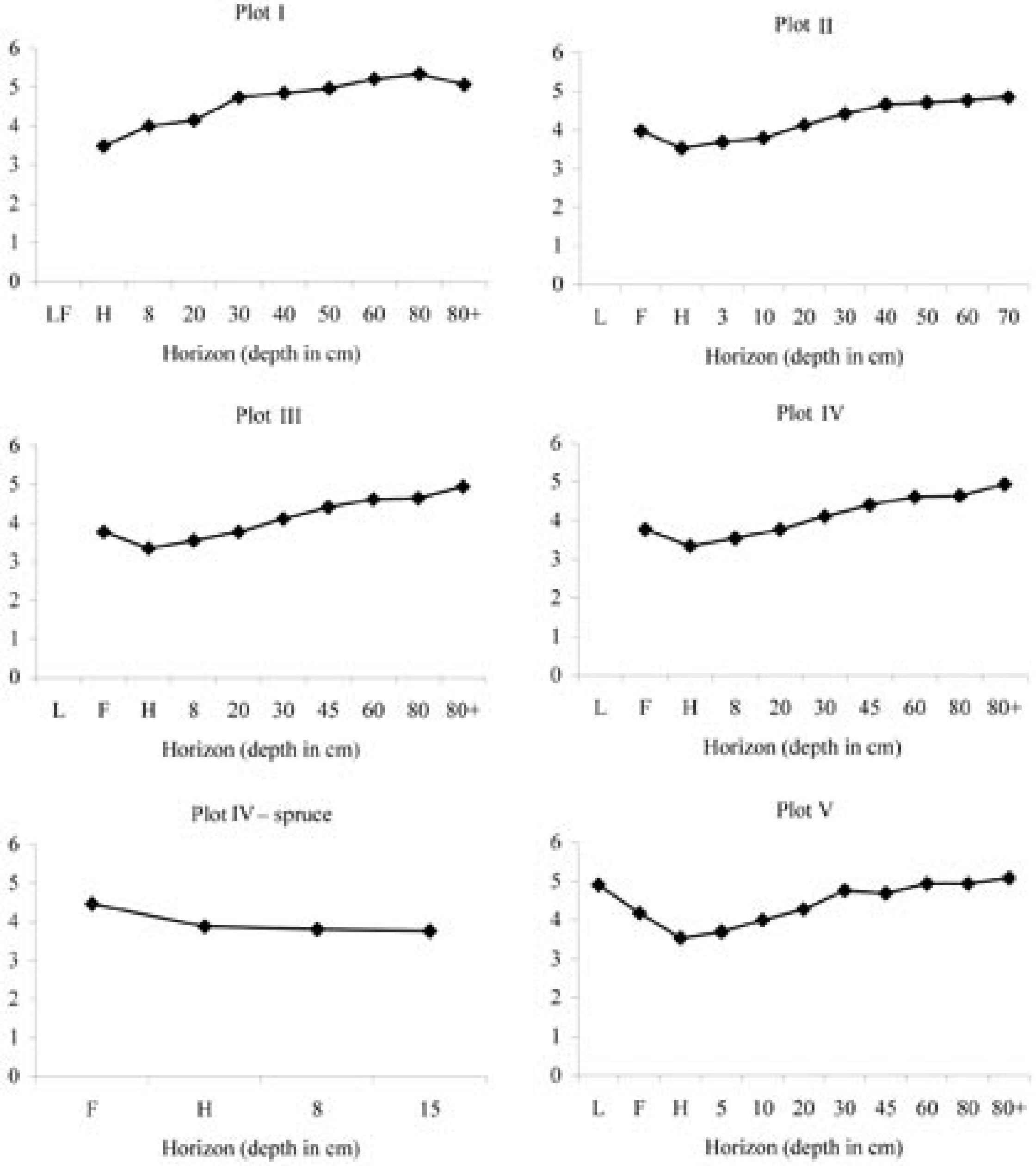


Fig. 15. Values of recent pH(H_2O) in the soil profile on Šerlich plots (samples taken in October 1999)

is shown in Fig. 16, calcium Fig. 17 and magnesium Fig. 18. The two forms are closest in the surface humus layer, they start to differ significantly with the increasing proportion of mineral grains of the weathered parent rock, most significantly for Mg, showing the lowest values of the form available, and the highest reserve in the extract by aqua regia. In a deeper part of rhizosphere (over 50 cm) the ratio of the forms is 1:100–500 for Ca and 1:1,000–2,000 for Mg. During the observations, the reserve of available cations increased in the humus horizons of broad-leaved species (beech and European mountain ash) (Tables 7 and 8).

Not only the ratio of total C:N but also C:P ratio is of importance for the micro-organism development. On Šerlich plots, in the humus horizons C:N was determined as lower than 20, it means favourable, but the ratio of C:P was unsatisfactory, it was over 200 on all the plots (UN-ECE, EC) 1998.

In humus samples taken in 1986 (87) and 1993 total content of heavy metals was determined in the humus material after mineralisation in the ash extract by concentrated HCl, and in the samples of humus and soil from 1999 in the extract by aqua regia. In Table 9 the contents of Cr, Cu, Mn, Ni, Pb, Zn, Cd (only in 1993) and As (only in 1999) are shown.

Increased contents of Cd, Cu, Cr, Mn, Ni, Pb and Zn correspond to the levels found in forest soils in other areas exposed to fall-out of air pollutants (dry deposition). In the surface horizons an increase in concentrations of As and Cr with the depth was obvious while minimum content of Mn was measured in Oh layer. The lowest content of Cu, Ni and Zn was found at the depth of 0–10 cm. The highest

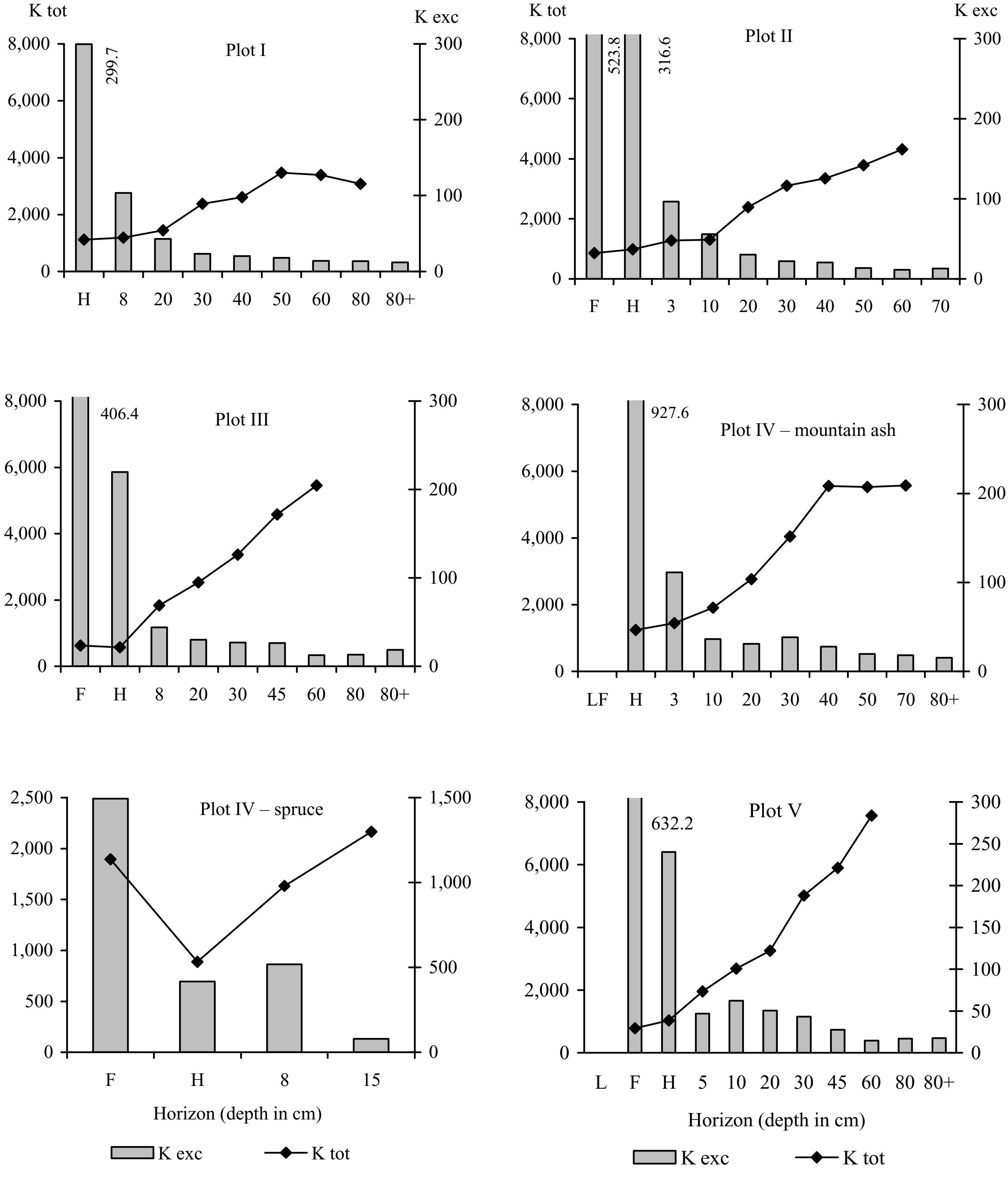


Fig. 16. Reserve of available potassium (K exchangeable) and total potential reserve of potassium (K tot) in the soil on Šerlich plots (mg/kg)

accumulation of Pb was in the layer Oh, it penetrates with humic matters to the mineral soil. Table 9 shows the total reserve of metals in the soil at the depth of 60 cm, where a significant proportion of the parent rock grains is present. It is higher for Cr, Cu, Mn, Ni and Zn than in the surface horizons, only for Pb it is significantly lower, and more or less balanced on individual plots (20.5 to 29.0 ppm). The reserve of heavy metals was lowest in the surface humus layer of the young European mountain ash stand (Cr – 2.8; Ni – 4.2; Pb – 29.3 ppm), the highest Pb content was in the H horizons of the clear-cut area – 338 ppm.

DISCUSSION

The ambience and deposition of pollutants in forest ecosystems of the Orlické hory Mts. are studied also by other institutions, and their results can be compared with our data. Based on data on pollutant concentrations in the

Table 7. Long-term pH development, content of available cations and phosphorus in humus and soil in Šerlich (mg/kg)

Depth (cm)	pH		K	Mg	Ca	P	pH		K	Mg	Ca	P	pH		K	Mg	Ca	P
	(H_2O)	(KCl)					(H_2O)	(KCl)					(H_2O)	(KCl)				
Plot II	1959 – reforested clearcut area						1987 – spruce stand						1999 – spruce stand after thinning					
Oh	4.2	2.8	106	45	437	100	3.7	2.8	145	55	236	88	3.5	2.7	317	97	419	32
0–5	3.6	2.7	48	13	309	161	3.3	2.7	41	17	54	230	3.7	2.7	96	30	56	41
10–20	4.2	3.3	54	6	330	247	3.7	3.2	16	15	52	410	4.1	3.2	30	15	45	77
20–30	4.5	3.8	41	13	373	256	4.1	3.7	20	11	54	89	4.4	3.6	22	10	34	64
40–50	4.7	4.3	25	13	437	215	4.3	4.0	15	8	115	150	4.7	4.1	13	6	27	132
80–95	4.8	4.5	29	6	224	215	4.6	4.2	11	6	507	165	4.9	4.2	13	6	23	207
Plot III	1959 – spruce stand						1986 – spruce stand						1999 – open spruce stand					
Oh	3.6	2.4	136	78	442	80	3.1	2.5	121	66	511	92	3.3	2.5	220	94	326	22
0–10	3.8	2.7	90	6	85	221	3.3	2.6	37	24	58	610	3.5	2.5	44	26	72	54
10–20							3.5	2.9	29	33	68	640	3.8	2.9	30	19	43	23
20–30	4.3	3.8	49	6	139	102	4.1	3.7	29	20	55	68	4.1	3.5	27	20	52	42
30–45	4.7	4.2	40	19	384	224	4.3	4.0	20	16	94	105	4.4	3.9	26	11	33	73
80–90	4.8	4.2	43	45	651	407	4.5	4.1	20	11	576	590	4.9	4.5	19	8	24	155
Plot IV	1959 – open spruce stand						1987 – naturally regenerated ash stand						1999 – natural ash stand after thinning					
Oh	3.6	2.9	319	90	309	83	3.7	2.9	241	160	751	126	4.4	3.5	928	556	3,414	73
0–10	4.2	3.0	56	6	64	133	3.3	2.7	42	26	77	114	3.7	2.8	61	42	224	36
10–20	4.0	3.4					3.5	3.0	30	23	47	114	4.2	3.1	31	15	54	36
20–30	4.6	4.0	33	6	106	134	4.0	3.8	21	11	93	107	4.8	3.9	38	13	51	43
40–50	4.6	4.3	27	13	245	192	4.4	4.0	17	8	174	165	5.2	4.3	20	7	29	142
60–70	4.6	4.4	28	13	181	262	4.4	4.1	15	10	306	300	4.9	4.3	15	5	26	144

1959 and 1986 – determination in citric acid extract, 1999 – determination in NH_4Cl extract

air as measured by the station of CHMI (Czech Hydrometeorological Institute) on Šerlich, and using some other hydrometeorological values, in 1996 the potential annual deposition of sulphur was calculated to be 10–20 kg/ha, and deposition of nitrogen 5–10 kg/ha in the oxide form.

Wet deposition of H^+ is calculated to be 0.3 to 0.4 kg, and dry deposition 0.5 to 1.0 kg/ha/year (CHMI Report, 1997). Annual fall-out of $N(NH_4^+)$ with precipitation should reach about 4–8 kg and F^- fall-out 0.3–0.5 kg per ha. The deposition of sulphur and nitrogen ($NO_3^- + NH_4^+$) as measured by our staff corresponded to these calculations. For the H-ions in precipitation (bulk) on Šerlich Mt., the fall-out was lower (Table 2). On the contrary, calculated wet deposition of F^- was lower than the fall-out (bulk), in which also dry deposition was included as measured by our staff.

Since 1994 throughfall precipitation was measured in the mature mixed stand of spruce and beech in Bukačka Nature Preserve, and in the open older stand of fir, spruce and beech in Trčkov NNR. The results of this action by AOPK are presented by HÁJEK et al. (2000). The data in Table 10 confirm that in 1996–1998 the annual fall-out (12 months) of S and N in Bukačka Nature Preserve was between the values found in Šerlich in the mature spruce stand (plot III) and mature beech stand (plot V), as shown in Table 11. Average pH was also higher there than in the spruce stand, and lower than in the beech stand (Fig. 5). In both cases it was throughfall precipitation with no stem flow measured. The higher S fall-out under the stand in Trčkov, compared to that in Bukačka, also corresponds to the higher concentration of S/SO_4^{2-} in precipitation water (bulk) at the station of Trčkov than in precipitation in Šerlich (Tables 2 and 3).

Atmospheric deposition of pollutants in the forest basin U Dvou louček, eastern part of the Orlické hory Mts., has been measured by the Czech Geological Survey since 1994. The survey data are published in Annual Reports by CHMI. The S and N balance within the basin, with respect to the critical load of forest ecosystems was calculated by FOTTOVÁ and SKOŘEPOVÁ (1998). The annual fall-out of S and N within this basin was presented by HRUŠKA et al. (2000).

According to these authors, in 1994–1999 the annual deposition in the open area (bulk) was between 15.1 and 32.2 kg for sulphur, between 9.1 and 22.3 kg for nitrogen ($NO_3^- + NH_4^+$), and between 0.1 and 0.9 kg per ha for protons (H^+). Under the spruce stand of age class IV the annual fall-out of sulphur was 49.6 to 91.0 kg, nitrogen 25.9 to 47.3 kg, and H-ions 0.7 to 1.9 kg/ha. The presented values are higher than the annual deposition measured on the clear-cut area in the same period (plot I) and on spruce stand plots II and III on the slope of Šerlich Mt.

(Figs. 1–3). The differences can be explained by different air currents in the two localities. Their role was also confirmed by investigations of fresh snow and frost deposit in the locality Šerlich (1,000 m above sea level) conducted by the staff of the Protected Landscape Area Orlické hory – HÁJEK et al. (2000). They revealed the impact of the air current direction from the atmosphere loaded by pollutants, and the impact before snow fall-out and formation

Table 8. Cation reserve in the soil sorption complex (mmol⁺/kg) and pH(H_2O), BCE-exchangeable basic cations, ACE-exchangeable acid cations

	Depth	pH(H_2O)	BCE	ACE	(cm)	pH(H_2O)	BCE	ACE	(cm)	pH(H_2O)	BCE	ACE
Plot I		1986				1993				1999		
	H	3.5	28.88		F	3.8	65.76	103.24	H	3.5	35.87	109.48
	10	3.3	10.66		H	3.5	43.34	127.02	10	4.0	13.34	64.75
	20	3.6	9.18		10	3.6	14.40	56.14	20	4.6	7.81	64.31
	30	4.0	6.17		20	3.9	7.79	88.24	30	4.7	4.52	51.47
	40	4.2	6.83		30	4.1	5.57	83.87	40	4.9	4.06	40.24
	60	4.3	4.50		40	4.5	3.76	58.34	50	5.0	3.13	32.07
	80	4.6	15.18		60	4.6	4.27	59.26	60	5.2	2.74	21.99
	80+	4.6	18.88		80	4.7	3.19	32.51	70	5.3	2.53	12.01
									80	5.1	2.25	11.70
Plot II		1987				1993				1999		
	H	3.7	22.70		H	3.6	28.97	101.21	F	4.0	101.28	33.66
	5	3.4	7.60		10	3.6	7.72	70.98	H	3.5	37.98	100.31
	10	3.3	4.54		20	4.0	5.13	85.23	3	3.7	8.08	64.23
	20	3.7	5.86		30	4.4	7.84	45.34	10	3.8	4.91	62.81
	30	4.1	5.49		40	4.6	7.04	33.28	20	4.1	4.86	79.25
	40	4.2	5.47		50	4.6	6.36	22.30	30	4.4	3.25	63.37
	50	4.3	7.29		60	4.6	6.53	23.75	40	4.7	2.72	37.86
	60	4.4	12.01		70	4.6	6.05	19.34	50	4.7	2.30	26.38
	80	4.4	17.43		70+	4.7	6.05	16.60	60	4.8	2.38	20.94
	80+	4.6	13.19						70	4.9	2.16	17.49
Plot III		1986				1993				1999		
	H	3.1	23.93		H	3.7	32.26	84.44	F	3.8	105.31	37.32
	10	3.3	6.00		10	3.5	11.82	58.56	H	3.3	30.54	111.91
	20	3.5	7.29		20	3.7	10.58	77.80	10	3.5	7.17	63.85
	30	4.1	5.33		30	3.9	9.07	88.41	20	3.8	4.82	77.82
	45	4.3	6.95		45	4.2	7.38	51.92	30	4.1	5.16	82.08
	60	4.6	21.75		60	4.5	6.45	28.89	45	4.4	3.49	48.97
	80	4.4	28.26		80	4.8	5.32	22.19	60	4.6	2.61	25.32
	80+	4.5	30.32						80	4.6	2.21	20.12
									80+	4.9	2.74	19.29
Plot IV*		1987				1993				1999		
	H	3.7	49.22		H	3.9	230.42	55.42	H	4.4	242.03	34.06
	10	3.3	7.58		10	3.8	11.01	71.76	3	3.5	34.81	77.31
	20	3.5	5.61		20	4.2	8.03	59.64	10	3.9	7.82	69.48
	30	4.0	6.27		30	4.4	8.51	47.93	20	4.2	5.37	74.30
	40	4.3	8.61		40	4.5	9.27	36.98	30	4.8	4.73	50.54
	50	4.4	10.01		50	4.6	8.05	35.83	40	5.0	3.71	39.88
	80	4.4	16.65		70	4.6	3.10	30.42	50	5.2	2.88	29.29
	80+	4.6	23.40		70+	4.6	2.57	22.14	80	5.0	2.57	19.41
									80+	4.9	2.25	17.25

Table 8. to be continued

	Depth	pH(H_2O)	BCE	ACE	(cm)	pH(H_2O)	BCE	ACE	(cm)	pH(H_2O)	BCE	ACE
	1986				1993				1999			
Plot V	H	3.3	24.53		H	3.6	34.75	46.66	F	4.2	124.80	29.76
	10	3.8	8.52		10	3.8	21.88	128.75	H	3.6	70.28	98.52
	20	4.0	8.63		20	4.2	5.37	61.93	5	3.7	16.88	65.48
	45	4.3	9.43		30	4.3	4.62	48.34	10	4.0	7.72	56.34
	60	4.4	12.90		45	4.5	6.42	42.88	20	4.3	5.14	72.57
	80	4.5	25.14		60	4.5	3.18	44.54	30	4.8	4.16	53.73
	80+	4.5	27.14		80	5.0	6.11	42.32	45	4.7	3.42	43.27
									60	4.9	2.58	45.77
									80	4.9	2.50	35.23
									80+	5.1	2.58	36.46

1986 – determination in extract of 1% citric acid, 1993, 1999 – determination in 0.1M NH_4Cl
* Plot IV – European mountain ash stand

Table 9. Heavy metal reserve in surface horizons in ppm (mg/kg)

Horizon	Year of sampling		As	Cd	Cr	Cu	Mn	Ni	Pb	Zn
Ol	1986 (7)*	range			3.0	17.0	97.0	3.0	37.0	23.0
					7.0	45.0	585.0	8.0	101.0	91.0
Of	1986 (7)	range			3.0	15.0	74.0	5.0	110.0	29.0
					13.0	46.0	558.0	15.0	303.0	84.0
Oh	1986				17.0	43.0	171.0	19.0	350.0	92.0
Of	1993*	range		0.36	1.5	9.8	101.0		17.4	27.8
				0.53	11.8	23.2	733.0		91.8	51.3
Oh	1993	range		0.47	10.7	9.1	72.3		115.0	22.6
				0.65	12.2	25.0	212.0		225.0	73.2
Of	1999	range	< 5.0		2.8	14.6	159.0	4.2	29.3	35.4
			7.0		16.6	24.7	718.0	14.5	179.0	63.9
Oh	1999	range	7.5		9.5	27.0	71.6	9.4	106.0	39.0
			21.5		15.5	34.9	238.0	16.4	338.0	72.1
0–10 cm	1999	range	30.1		14.4	8.7	131.0	6.1	63.1	20.6
			90.0		20.6	27.8	1,336.0	12.1	185.0	40.5
10–20 cm	1999	range			26.6	11.5	363.0	11.7	81.1	32.1
					50.6	33.0	2,636.0	21.6	100.0	79.8
60 cm	1999	range			59.7	46.0	1,248.0	62.6	20.5	109.0
					87.7	105.0	2,098.0	81.7	29.0	143.0

* In samples taken in 1986 (7) and 1993 the element content was determined in the extract of ash by concentrated HCl, in samples taken in 1999 in the extract by aqua regia

of frost deposit. Preliminary "washing-out" influences a decrease in the content of acid air pollutants, causing pH decrease in snow water. Precipitation and frost deposit, formed and coming from the north, northeast and east, but also northwest were of more favourable (higher) pH value than the precipitation coming from W, SW, S, and SE. In 1994–2000, the pH values of fresh snow cover were of average annual values 4.5–5.5, in the frost deposit it was by one order lower, 3.5–4.5. By 1998 the water of frost deposit was of higher pH than that of snow, however.

Evaluating the deposition of air pollutants within the plots and basin of the FGMRI in the eighties and nineties (LOCHMAN 1993, 1997; LOCHMAN, MAREŠ 1995; LOCHMAN et al. 1998; LOCHMAN, ŠEBKOVÁ 1998; LOCHMAN et al. 2000) we can state that the forests of the Orlické hory Mts. have been among the most loaded ecosystems in the CR. Similar conclusions were presented by FOTTOVÁ and SKOŘEPOVÁ (1998) as a result of monitoring of the fall-out and matter balance in the basins investigated within the GEOMON programme.

A significant difference is obvious in the chemistry of precipitation water taken on the plot of Zdíkov (water basin U Lizu) in the foothills of the Šumava Mts. The annual average values of precipitation water pH in the mature spruce stand in Šerlich were 3.65–4.65 in 1990–1997. In the same time, under the spruce stand in Zdíkov, they were 4.0–5.0. In the beech stand in Šerlich the average annual value of pH was between 4.10 and 5.20, and in Zdíkov it was 4.45–5.40.

In 1990–1997 the annual sulphur (S/SO_4^{2-}) fall out with precipitation in the spruce stand in Šerlich was 45.5–74.3 kg per ha and in the spruce stand in Zdíkov 12.6–23.7 kg/ha. In the same period the annual sulphur deposition under the beech stand was 18.8–33.0 kg/ha in Šerlich and in Zdíkov 6.5–15.0 kg/ha. There were large differences in the annual nitrogen ($NO_3^- + NH_4^+$) deposition: 25.2–47.0 kg/ha in the mature spruce stand in Šerlich and 6.4–16.0 kg/ha in Zdíkov. The differences in N deposition with precipitation under the crowns of mature beech trees were not so high as in the spruce stand. In Šerlich the annual sums were 8.7–22.7 kg/ha, in Zdíkov 5.7–12.3 kg/ha. Forest ecosystems and the weathered mother rock mantel in the basins of the investigated streams affected an increased pH value of runoff water to similar values. In the no-name stream by Šerlich, the annual average pH values were 6.05–6.85, and in the stream in Zdíkov (basin U Lizu) they were 6.20–6.78 (1990–1997). The differences in average NO_3^- concentrations were higher, 6.31–12.32 mg/l in Šerlich compared to 2.34–4.84 mg/l in the basin U Lizu. Even with much higher sulphur deposition in Šerlich, the average sulphate concentrations in the water of the stream were about 14.1–19.0 mg/l, and in the stream U Lizu they were between 10.6 and 14.1 mg/l.

The data in Table 11 show that in 1988–1991 accumulation of sulphates occurred in the soil of the spruce stands (weathered mantel) in connection with Al (Fe) oxides, by forming the complex reversible aluminium-sulphate compounds (MATZNER, ULRICH 1990; ULRICH 1981; ULRICH et al. 1981). As a result of the change in the soil environment (pH, SO_4^{2-} concentration, temperature) the bonds are disturbed and sulphate ions, together with the Al compounds, get to the soil solution. That is why an increased leaching of these ions and negative sulphur balance can be observed in the basins loaded for a long-time after the capacity of SO_4^{2-} valence was used and pH of the soil environment changed (ALLEWEL, MATZNER 1993; MANDERSCHEID et al. 1995). Similar bonds to metal oxides like sulphates can be created by fluorides (F^-), and consequently their concentrations in the water of the sources are much lower than in the soil water (HERRNSTADT 1995).

Not only the acid fall-out is the source of forest soil acidification but also changes and losses of individual forms of nitrogen, supposing that the production and uptake of NH_4^+ and NO_3^- are not synchronised in time and space. When mineralisation occurs together with the formation of NH_4^+, the H ions are consumed in equivalent, when NO_3^- is formed, two H ions are released. In ammonium ion uptake, the H^+ ions are released in the same quantity (in mol), and in NO_3^- uptake, for each ion two H ions are taken out of the environment. When nitrates are leached with runoff water from the rhizosphere, the production balance and proton consumption in the system (soil) are disturbed and acidification occurs. The loss of 14 kg N in the form of NO_3^- causes its loading by 1 kmol H^+ in case that the organic nitrogen is the source, or the load is 2 kmol H^+ when NH_4^+ of deposition is the source (KHANNA, ULRICH 1985; ULRICH et al. 1981). The data in Table 11 confirm that the proton production by the change in nitrogen forms and their leaching can reach the same level as the deposition with precipitation (Fig. 1), mainly in the second half of the nineties.

With pH of the stream water higher than 6.0 and runoff 800 mm, the annual loss of H ions with the runoff is lower than 0.008 kmol/ha. Nearly the whole fall-out is consumed in the forest ecosystems and weathered rock mantel. Neutralisation of soil water in the runoff is connected with cation leaching and also with Al ions in the rhizosphere (Table 4). In SO_4^{2-} bond with Al oxides in the lower soil layer and weathered mantel, H ions are bound (KHANNA, ULRICH 1985) and mainly the release of Ca, Mg plays a role in proton consumption (Table 6), so the water pH in the surface source was on average over 6. Based on the difference in the sum of valence values of cations and anions of strong acid in the stream water, it is evident that the weathered rock mantel in the basin is able to neutralise the H ions in favour of cations. The difference between the sum of Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+ and H^+ and the sum of NO_3^-, F^-, Cl^-, SO_4^{2-} was 166.4 μmol/l in 1987–1991 and 175.0 μmol/l in 1995–1997. It means that carbon compounds are also dissociated in the stream water.

The chemistry of forest soils in the Orlické hory Mts. and its development in the last decades were investigated mainly by the staff of the FGMRI Research Station in Opočno, and of FMI (Forestry Management Institute). VACEK et al. (2000) presented the results of investigations in selected spruce and beech stands in the Orlické hory Mts. in 1973–1992. Even at the beginning of the seventies the soils there were strongly acid in the surface horizons O and Ah, of pH(H_2O) between 3.5 and 4.00 and pH(KCl) ranging between 2.7 and 3.4. In 1983, another decrease was observed – pH(H_2O) was 3.3–3.7, and pH(KCl) was 2.6–2.9. In the samples taken in 1992 pH/H_2O was slightly increased, and the pH(KCl) exchangeable did not show an unambiguous trend of changes. The same authors (VACEK et al. 2000) presented the results of regionwide soil investigations carried out in 1982–1985 by FMI (210 plots). In the samples of surface horizons of the mineral soil taken in the stands of vegetation zone 7, the pH(H_2O) range was between 2.93 and 4.34 (on average 3.58), and pH(KCl) was 2.42–4.03 (on average 2.90). For the samples taken in 1985–1987 in Ah and Al horizons (5.37% Cox) the average reserve of available Ca was calculated to be 116 ppm, Mg 18.1 ppm, K 34 ppm, P 48 ppm, and the C:N ratio 15.3. The average soil pH decreased with the altitude (vegetation zone 6 to 8), and also the reserve of available P, Ca,

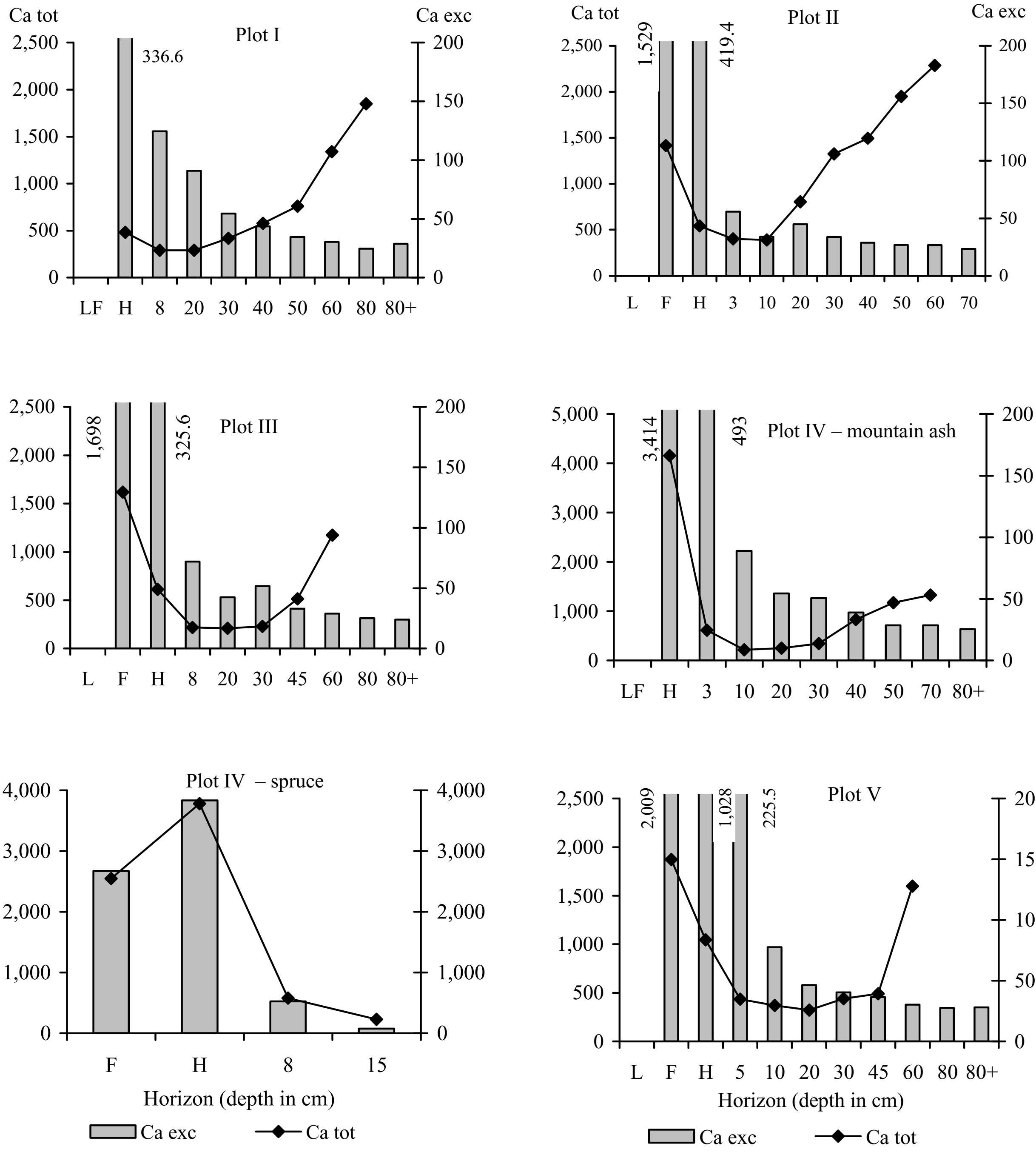


Fig. 17. Reserve of available calcium (Ca exchangeable) and total potential reserve of calcium (Ca tot) in the soil on Šerlich plots (mg/kg)

Mg. At the same time, in these organic-mineral horizons the total C and N reserve increased with the altitude.

The pH values of the humus horizons within the FGMRI plots, as presented by VACEK et al. (2000), corresponded to pH(H_2O) of the samples taken in 1986 (1987) on the plots of Šerlich (Tables 7 and 8), for pH(KCl) they were slightly higher.

The higher number of plots investigated by FMI provides a wider range of pH values than that determined in the soil of our plots. The reserve of available cations was at the same level as the reserve in the soils of Šerlich plots.

In surface horizons of the mineral soil pH exchangeable does not reach the value 3.5 and in deeper horizons the saturation of the sorption complex with basic cations is lower than 10%. The ratio of basic cations (BCE) to the sum of acid metal cations (ACE) is 1:10. If the level of saturation with bases is so low, Al ions can be easily released to the soil solution, and they can be a stress for the roots of tree species. A dangerous increase in Al concentrations can cause a sudden disturbance of reversible compounds of Al and sulphates (ULRICH 1995; ULRICH et al. 1981; EC, UN/ECE 1997).

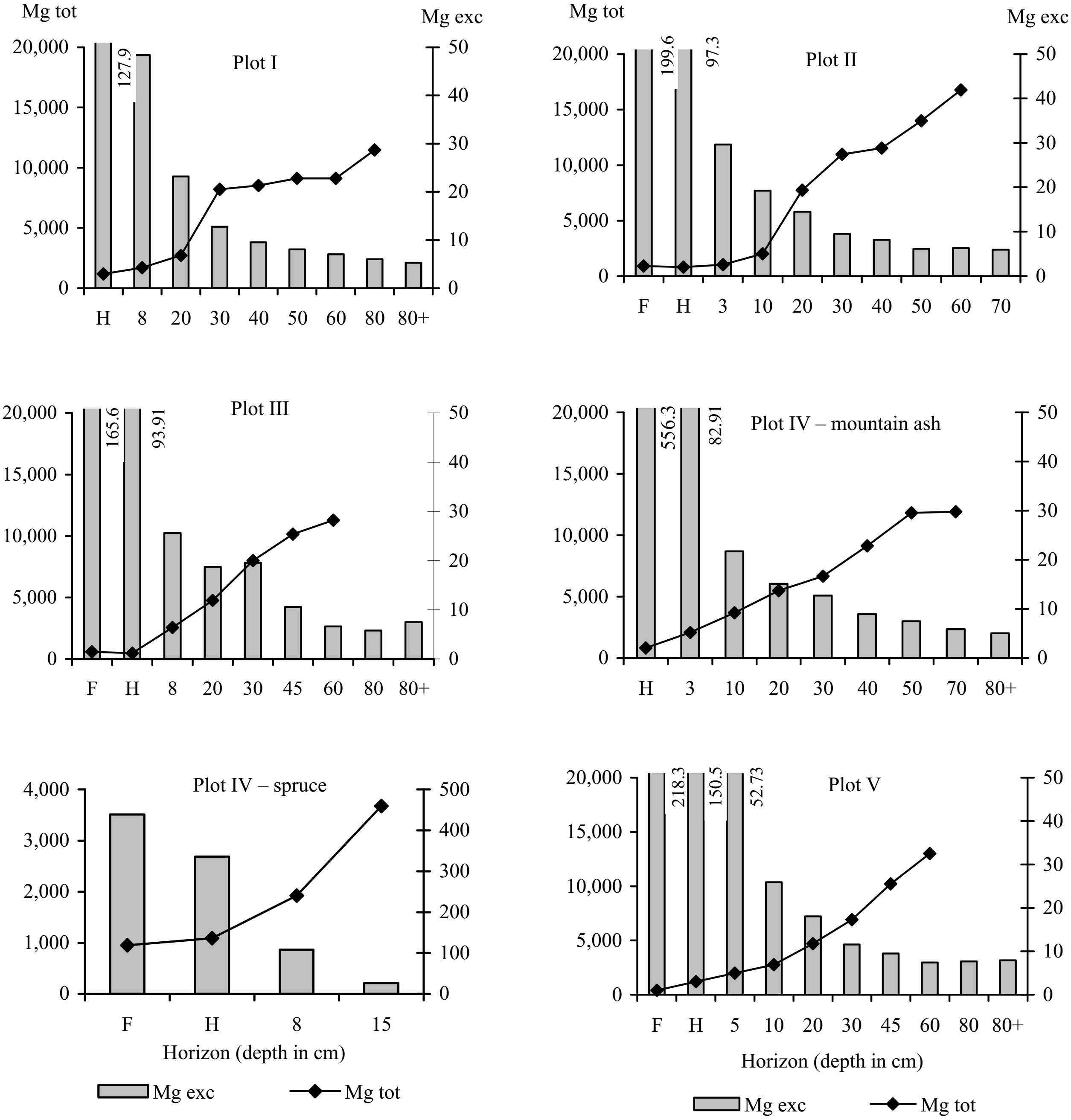


Fig. 18. Reserve of available magnesium (Mg exchangeable) and total potential reserve of magnesium (Mg tot) in the soil on Šerlich plots (mg/kg)

The low reserve of available cations in mineral soils, mainly of Mg, causes a threat of their possible deficiency in the stand nutrition. The uptake by the roots could be influenced negatively by a high relative concentration of other cations (BARBER 1995). This case was not proved on Šerlich plots. The reserve of available Ca is 50–70%, K 20–40%, Mg 10–20% of the total reserve of these cations in the sorption complex. In the soil water of individual sampling places in spruce and beech stands the concentrations of Ca ranged between 45 and 65%, K 14–28%, Mg 14–30%. Circulation of K in the soil is fast; it is taken up by the roots preferentially and intensively leached from the leaves and humus material. Its concentrations decrease with depth in the soil water in the rhizosphere of mineral profile. In the leaf organs the K reserve is at the second position after N, and the reserve of Mg often follows that of Ca and P.

According to the report by the European Commission (EC, UN/ECE 1997) average relative concentrations of the main cations in organic horizons (H) of European forest soils are 64% for Ca, 15% for Mg and 21% for K.

The deficiency of available magnesium in forest stands of the Orlické hory Mts. can be caused by a high reserve of available forms of nitrogen that under favourable cli-

Table 10. Deposition of air pollutants with precipitation in Bukačka and Trčkov in kg/ha (HÁJEK et al. 2000)

Locality	Period	pH	N	S	Cl^-
Bukačka	10/1996–9/1997	4.7	24.30	24.00	9.4
	10/1997–9/1998	4.6	17.23	23.35	9.2
Trčkov	10/1996–9/1997	4.2	25.30	47.00	12.3
	10/1997–9/1998	4.4	16.82	35.43	13.3

Table 11. Deposition of sulphur and nitrogen on Šerlich plots, losses with the stream water (kg(kmol)/ha/year)

Plot	S (kg/ha)		S (kg/ha)	N/NO_3 + NH_4^- (kg/ha)		N (kg/ha)	NO_3^- (kmol/ha)		NO_3^- (kmol/ha)
	1988–1991	1992–1999	Difference	1988–1991	1992–1997	Difference	1988–1991	1992–1997	Difference
I	25.05	19.69	5.36	27.59	14.57	13.02	0.68	0.45	0.23
II	79.47	47.15	32.32	32.26	17.90	14.36	0.92	0.40	0.52
III	87.80	53.46	34.34	54.49	41.53	12.96	1.53	0.84	0.69
IV spruce	40.15	33.37	6.78	26.78	22.48	4.30	0.71	0.78	–0.07
IV ash	28.95	20.94	8.81	24.88	12.76	12.12	0.62	0.51	0.11
V	34.10	23.16	10.94	27.41	14.04	13.37	0.70	0.50	0.20
Loss – stream	40.93	44.84	–3.91	28.00	16.15	11.85	1.58	1.04	0.54

matic conditions (warm and dry weather) supports higher increments and escalates the nutrient uptake from the soil. Above-average warm weather during the vegetation season supports nitrification, and in combination with high precipitation it leads to higher leaching of NO_3^- and cations. Together with growing demands of stands (vegetation) for nutrition it supports forest soil acidification and decreases the reserve of available nutrients (REHFUESS 1990).

The situation when there is a deficiency of some nutrients (Mg, K) in the soil (soil water) can last for several weeks or months, similarly like the increased concentration of H and Al, and the state need not be necessarily revealed by analyses of soil samples taken after the first symptoms of damage were observed in the trees. Sampling and analyses of the soil water in damaged forest stands are not done regularly, and the chemical composition changes faster than the reserve of available biogens in the soil.

CONCLUSION

The load of air pollutants in forests of the Orlické hory Mts., coming both from Czech sources and from abroad, has been long-term. Concentrations of sulphur compounds in the air and the fall-out decreased significantly in the nineties, together with the proton fall-out (H^+). On the plots situated on the slope of Šerlich Mt. the fall-out of nitrogen compounds also decreased, but they are still much higher than their consumption by vegetation. Nitrogen comes mainly in the form of NH_4^+, and it runs off with the stream water mainly in the form of nitrates (NO_3^-), in a higher amount than the deposition with precipitation. The process of nitrification and leaching of NO_3^- can cause acidification of the soil environment on the studied plots, similarly like the direct proton fall-out.

A reduction in air pollutant deposition into the forest ecosystems in the stream basin resulted in a decrease in concentrations of NO_3^-, Al and heavy metals in water. Average sulphate concentration increased in the nineties, however. It was probably caused by the release of unstable compounds with Al oxides in which their were bound in the period of high air pollutants fall-out.

The soils on the research plots were strongly acid in surface horizons even at end of the fifties, acidification penetrated gradually downwards by the end of the eighties. In the nineties soil pH(H_2O) increased, the trend of pH(KCl) exchangeable was not unambiguous. The reserve of available basic cations in the mineral soil decreased during the period of investigations, mainly in deeper horizons. It increased in the humus and organic-mineral horizons (O, A). While the basic cation reserve in the sorption complex (BCE) decreased, the reserve of acid metal cations increased, mainly of Al (ACE), so their valence ratio in the B and B/Cd horizons under the stands was lower than 1:10. Also the available P forms were leached.

Since 1992 the average pH value in the soil water of all plots increased and the concentrations of SO_4^{2-}, N (NO_3^- + NH_4^+), Al and K decreased. Under the spruce stands, a temporary increase in concentrations of Al, SO_4^{2-} and also F^- was observed in the lower part of the rhizosphere, however. This may be caused by decomposition of reversible compounds of Al and SO_4^{2-}, or Al and F^-. Even in the conditions of decreasing acid deposition (H, SO_4^{2-}, NO_3^-) the biological and chemical processes in the soil, evoked also by climatic factors, can cause its acidification and create conditions unsuitable for the tree growth.

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Vývoj depozice imisních látek, chemismu půdní vody a půdy na výzkumných plochách Šerlich a chemismu vody v povrchovém zdroji

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ABSTRAKT: Na jihozápadním svahu Šerlichu v Orlických horách (Kristina Colloredo-Mansfeldová – Správa lesů Opočno) v nadmořské výšce 950–970 m byly v roce 1986 (1987) zřízeny výzkumné plochy pro sledování depozice látek, chemismu srážkové a půdní vody a vývoje chemismu půdy. Plochy byly založeny na seči, v mladším a dospělém porostu smrku a dospělém buku a v nárostu smrku a jeřábu. Současně probíhalo sledování obsahu rozpuštěných látek ve vodě potoka. Od roku 1993 je zjišťována koncentrace látek ve srážkové vodě zachycované na vrcholové části Šerlichu. Výzkum chemismu vody v porostech byl ukončen v roce 1997. Analýzy půdy se uskutečnily v roce 1986 (1987), 1993 a 1999. V osmdesátých letech zde probíhalo silné zatížení lesních ekosystémů kyselými imisními látkami. Po roce 1991 nastalo snížení depozice H^+, S/SO_4^{2-}, $N/NO_3^- + NH_4^+$, Mn, Zn, Al. Podobně i v půdní vodě probíhalo zvýšení pH a poklesly koncentrace SO_4^{2-}, sloučenin N a Al. V roce 1993 se však po několik měsíců v půdní vodě pod porosty smrku opět navýšily koncentrace SO_4^{2-} a Al. Také ve vodě potoka se v devadesátých letech postupně snižovaly koncentrace NO_3^-, Mn, Zn a Al. Naopak u síranových iontů se v těchto letech průměrné hodnoty proti období let 1987 až 1991 zvyšovaly. Velmi kyselé pH půdy postupovalo až do roku 1993 do větší hloubky. V druhé polovině devadesátých let se pH/H_2O spíše zvyšovalo, ale zásoba přístupných kationtů K, Mg, Ca v minerální půdě nadále klesala. Nasycení sorpčního komplexu půdy bazickými kationty ve spodní části rizosféry nedosahovala v roce 1999 ani 10 %. Lesní ekosystémy na Šerlichu byly zatěžovány i vysokým spadem Pb a zvýšeným spadem Cu. K okyselování půdy na sledovaných plochách přispívá nevyvážená bilance přeměn a spotřeby sloučenin dusíku v půdním prostředí a zvýšené vymývání N v nitrátové formě.

Klíčová slova: horské lesy; depozice; chemismus srážkové vody; chemismus půdní vody; chemismus vody ve vodních zdrojích; chemismus půdy

Na jihozápadním svahu Šerlichu v Orlických horách byly v roce 1986 (1987) založeny výzkumné plochy pro sledování depozice látek, chemismu srážkové a půdní vody a pro periodické sledování vývoje chemismu půdy v lesních ekosystémech. Plochy leží v nadmořské výšce 950–970 m na zalesněné seči (plocha I), v porostech smrku II. a VI. věkové třídy (plochy II a III) v porostní skupině buku VI. věkové třídy (plocha V) a v nárostu smrku a jeřábu (plocha IV). Od roku 1987 probíhalo zjišťování chemismu vody v bezejmenném přítoku Bělé. Od roku 1993 je také sledována koncentrace látek ve vodě srážek zachycovaných na vrcholové části Šerlichu (u stanice ČHMÚ). Měření na výzkumných plochách bylo ukončeno roku 1997.

Výsledky výzkumu ukazují, že po roce 1991 narůstaly průměrné hodnoty pH srážkové vody zachycované na seči i pod korunami porostů. V souladu s nárůstem pH klesala i depozice protonů (H^+) a síranů (SO_4^{2-}) zejména v porostech smrku, kde v osmdesátých letech minulého století roční spad H^+ překračoval 2 kmol/ha a po roce 1995 se snížil na méně než 0,5 kmol/ha. Také roční spad S (SO_4^{2-}) v porostech smrku postupně klesal ze 100 kg/ha na méně než poloviční hodnoty v letech 1996 a 1997. Nejvyšší roční depozice N ($NO_3^- + NH_4^+$) v porostu smrku na počátku měření překračovaly 50 kg/ha a ke konci sledovaného období se pohybovaly okolo 30 kg/ha. Spad těchto imisních látek se srážkami na seči a s podkorunovými srážkami v porostech buku a jeřábu se pohyboval zhruba na poloviční úrovni.

Ve vodě protékající horizontem pokryvného humusu se zvyšovala koncentrace téměř všech sledovaných látek. Při průtoku minerálním půdním profilem se v odtékající gravitační vodě snižovaly koncentrace protonů (zvyšování pH), K, anorganického N ($NO_3^- + NH_4^+$) a naopak se v ní zvyšovaly koncentrace Na, Mg a Al.

Při hodnocení koncentrací iontů ve srážkové a půdní vodě v letech 1987–1991 a 1992–1997 je od roku 1992 zřejmé jejich snížení u K, Al, N ($NO_3^- + NH_4^+$), SO_4^{2-}

a F^- na seči a v porostech smrku a buku. Naopak nárůst je patrný u Mg a alespoň v hlubších horizontech půdy (v 50 cm) u Ca a Na. V podzimních měsících roku 1993 proběhlo přechodné zvýšení koncentrací Al, SO_4^{2-} a F^- v půdní vodě na ploše II v hloubce 50 cm. V jednotlivých odběrech dosahovaly koncentrace Al až 16,8 mg/l. Tento jev je možné vysvětlit uvolněním uvedených iontů z komplexních nestálých sloučenin v nadložním horizontu při náhlém okyselení půdního prostředí. Při průměrných ročních koncentracích Al v půdní vodě zachycované v porostech smrku v hloubce 50 cm (plocha II a III) překračujících 5 mg/l byly poměry mol Ca/mol Al nižší než 1 a často nižší než 0,5. Při již zmíněném přechodném výskytu vysokých koncentrací Al a SO_4^{2-} v zimě roku 1994 poklesl molární poměr Ca a Al na 0,112.

Ve vodě sledovaného potoka tekoucího od SPR Bukačka kolísaly hodnoty pH jednotlivých vzorků mezi roky 1987–1999 v rozmezí 4,85–7,0. Během sledovaného období se průměrné roční hodnoty pH podstatně nezměnily. Ke zjevnému snížení koncentrací došlo u NO_3^-, K a kovů (Al, Fe, Mn, Zn).

Výsledky rozborů vzorků půdy odebraných v roce 1959 ukazují, že na sledované lokalitě byly povrchové půdní horizonty silně kyselé již před intenzivní imisní zátěží – s pH (H_2O) < 4,2 a pH (KCl) < 3,0. Do roku 1986 (1987) postoupilo silné okyselení do větší hloubky. Mezi lety 1987 a 1999 se v půdě prolámaného porostu smrku (plocha II) poněkud zvýšilo pH (H_2O). V uvolněném mýtném porostu smrku (plocha III) se mírně zvýšilo pH (H_2O) a mírně pokleslo pH (KCl). V nárostu jeřábu (plocha IVb) v roce 1999 narostlo půdní pH (H_2O) i pH (KCl) proti stavu z roku 1987. Poměr uhlíku a dusíku (Cox : Nt) v půdním materiálu byl během sledovaného období příznivý, v pokryvném humusu pod 20 a v minerální půdě pod 15.

Zásoba přístupných kationtů postupně klesala od povrchových horizontů a v současnosti klesá i v horizontech B a C. Na jednotlivých plochách se podstatně neliší a u Ca nepřekračuje v hlubších horizontech minerální půdy 50 ppm, u Mg 10 ppm a u K 40 ppm. Poklesla i zásoba přístupného P (PO_4^{3-}). Sorpční komplex minerální půdy je silně nenasycený bazickými kationty (zpravidla < 10 %). Příznivější poměr mezi molární hodnotou bazických kationtů Ca, K, Mg, Na (BCE) a kyselých kationtů Al, Fe, Mn (ACE) byl stanoven jen v humusových horizontech pod porosty jeřábu a buku.

Zvýšené obsahy Cd, Cu, Cr, Mn, Ni, Pb a Zn odpovídají úrovni zjišťované v lesních půdách jiných oblastí intenzivněji zasažených imisními spady. Nejmenší zásoba těžkých kovů byla v pokryvném humusu nárostu jeřábu (plocha IV) a nejvíce Pb obsahoval horizont H na zalesněné seči.

Při bilancování spadu síry (SO_4^{2-}) a její ztráty s odtékající vodou je zřejmé, že v letech 1987–1991 probíhala její akumulace v půdě, kdežto v letech 1992–1997 (v období poklesu spadu) nastávalo její uvolňování z nestálých sloučenin s oxidy Al. Ve stejném období se proti předchozímu snížily ztráty dusíku ($NO_3^- + NH_4^+$) s odtékající vodou o 11,85 kg/ha/rok (z 28,00 na 16,15 kg/ha/rok).

Z bilancí spadu a ztrát anorganického N a jeho forem ($NO_3^- + NH_4^+$) vyplývá, že nitrifikace amonných iontů a jejich vymývání z půdy sledovaných lesních ekosystémů odtékající vodou způsobuje vyšší produkci protonů než jejich spotřebu a tím přispívá i k okyselování půdního prostředí. Při průměrném pH potoční vody vyšším než 6 je roční ztráta H iontů s odtokem vody nižší než 0,008 kmol/ha. Téměř celý spad protonů je tedy „spotřebováván“ v lesních půdách a ve zvětralinovém plášti.

I při snižování depozice H^+, SO_4^{2-}, N ($NO_3^- + NH_4^+$) mohou biologické a chemické procesy v půdě, vyvolané i klimatickými faktory, způsobovat její acidifikaci a ovlivňovat chemismus vody ve zdrojích a tím vytvářet nepříznivé podmínky pro růst dřevin a pro zajišťování pitné vody.

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