Development of forest soils in the Krkonoše Mts. in the period 1980–2009

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ABSTRACT: This paper documents the development of soil conditions in the set of 32 permanent research plots in the Krkonoše (Giant) Mts. These plots represent an altitudinal gradient covering the ecosystems of beech, mixed beech-spruce and spruce stands. In all plots, representing the site conditions of the highest areas of the mountain range, standard soil pits were prepared and the soil sampling was performed in autumn of years 1980, 1993, 1998, 2003 and 2009. The results reflect extreme site conditions, soil acidification, large scale surface liming and in minor extent also different tree species composition of the stands. The general type of the soil-genesis is represented by the podzolisation, overlapping the other soil-genetic factors, including the tree species composition. Nevertheless, this development is mostly expressed in the spruce stands. The beech dominance and/or co-dominance are reflected especially by more efficient N-cycling, higher pH, S and V values and fluctuation and lower extractable Al^{3+} content. More efficient cycling in beech ecosystems is insignificantly documented for plant available phosphorus, calcium and magnesium contents; on the contrary higher dynamics for iron ions was registered in the spruce stands. The long-term soil dynamics with a hysteresis (evident on the base of ordination analysis) can be divided into some periods – processes of acidification (typical in the 1980's samples), liming (main effect in 1993 and 1998) and regeneration (2003, 2009). Other features, important for the soil development, are probably related to the vegetation change, but this relation is not statistically significant.

Keywords: acidification; air pollution; Krkonoše Mts.; liming; multidimensional analysis; soil dynamics

State and dynamics of the soils indicate differentiated effects of the human activities in the landscape. Anthropogenic influences are distinguished as one of pedogenic factors (Šály 1978), having big importance also in sub-mountain and mountain conditions of the Krkonoše (Giant) Mts. Intensive human impact can be assumed since 13th century, and is connected with mining and settlement pressure (Lokvenc 1978). The whole region was heavily deforested for the needs of miners in the 16th and 17th century that caused profound change of the species, age and space structure of the forests. Even-aged Norway spruce monocultures became the main form of the forest.

Among other factors, species composition of the forest ecosystem determines the accumulation, transformation and mineralization of the organic matter (humus forms, Green et al. 1993), by the quantity, quality and chemical as well as bio-chemical composition of the litter. The basic knowledge is summarized in many general publications (e.g. Šály 1988; Klimo 1990; McLaren, Cameron 1996; White 1997; Sumner 2000; Boyle, Powers 2001). Heavy load by atmospheric pollution in the Krkonoše Mts. region was documented in the 1970s to 1980s, both direct (air pollution) and indirect (acid and other deposition). High input of acid substances represents qualitatively new factor in the soil dynamics of mountain locations. They are assumed to be more sensitive compared to lower altitudes (Meiwes et al. 1986; Hruška, Cienciala 2001; Purdon et al. 2004; Vacek et al. 2007). Nitrogen depo-

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sition is replacing the main problematic pollutant of the last century – sulphur, causing also acidification, but moreover the nutrient balance disruption resulting in lower ecological stability of stands as well as individual trees (Vacek et al. 2007). This is caused by the climatic factors, pathogen organisms and synergic effects of changed tree species composition, high atmospheric deposition and site acidification (Hruška, Cienciala 2001). Introskeletal erosion represents another site disturbing factor on large stony blockfields covered by thick holorganic horizons since 1980s (Šach 1990), observed especially after heavy logging.

The dolomitic lime was applied in the dose up to 10 t·ha^{-1} at three partial doses from 1982 to 1990. The liming was carried out in the high-mountain locations, approximately above 900 m a.s.l. The waterlogged sites and sites with potential introskeletal erosion have been excluded. Aerial liming was used on large areas, representing not only prevention of further degradation, but also potential risk on large clear-cuts, leading to heavy surface humus mineralization (Míchal et al. 1992; Podrázský 1994).

Aim of the presented study is the evaluation of the state and development of soils in beech, mixed and spruce forests on permanent research plots in the Krkonoše Mts. in the period 1980–2009 and to document ecosystem changes in the respective period.

Two main hypotheses were considered as a basis for more detailed analysis of the data:

- There are differences in the behaviour of Norway spruce (*Picea abies*), beech-spruce-mixed and beech (*Fagus sylvatica*) stands;
- There is dynamics of soil characteristics in the period 1980–2009.

MATERIAL AND METHODS

Permanent plots and soil sampling

In both National Parks (Krkonošský Národní park and Karkonoski Park Narodowy) in total 38 permanent research plots (PRP) were established (Fig. 1; Table 1). Research results presented in this issue are based on the observations and analysis on these plots. On the territory of the Czech part of the Krkonoše Mts., there were established 34 permanent research plots (PRP, numbered 1–34) from 5th to 8th forest altitudinal zone according to the Czech forest typological school. The analysis of soil development presented in this article is based only on results from 32 PRP (PRP 1–32). Major-

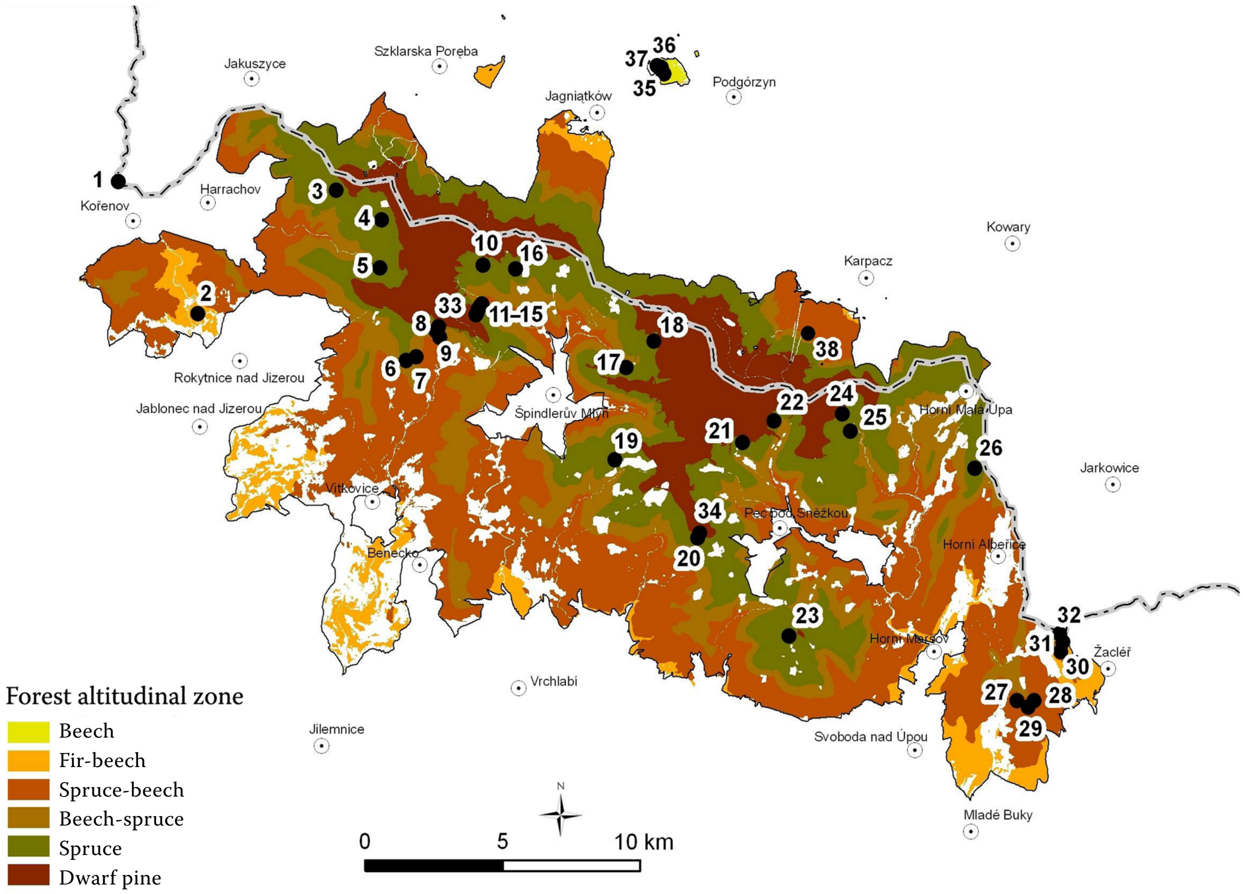

Fig.1. Location of permanent plots in the Krkonoše Mts.

Table 1. Basic characteristics of the permanent research plots (by forest management plan, state to 2003)

Plot		Forest administration[1]/ Forest district[2]	Stand	Tree species[3]	Age at 2009	Height (m)	dbh (cm)	Site class	Growing stock ($m^3 \cdot ha^{-1}$)	Altitude (m)	Exposition	Inclination (°)	Site type[4]	Air pollution threat zone[5]	Geology	Soil type
1+	U Tunelu	H/H	$221A_{13/2a}$	BK SM	132/22	27 26	48 43	26 26	382 45	730	SW	26	6N4	D	biotite granite	Cambisols
2	Vilémov	H/Ro	415B17/2	SM BK MD	173/19	28 27 33	36 40 42	26 24 30	198 128 22	600	SW	22	5Y0	C	mica phyllites schists	Leptosols
3++	U Lubošské bystřiny	H/H	514A2a/1a	KOS SMP SM	23/17	1 2 2	–	0 14 16	–	1,150	SW	22	8Y0	B	biotite granite	Haplic Podzols
4	Pod Voseckou boudou	H/H	511A17/4/1	SM	224/47/11	18	35	16	178	1,180	SW	12	8G3 8R1	A	biotite granite	Histosols, Gleysols
5	Pod Lysou horou	H/H	508B17/1a	SM	243/11	22	40	20	237	1,130	N	17	8G3	B	biotite granite	Gleysols
6	Bažinky 2	H/R	311A17/4/1a	BK SM	223/39/17	30 31	40 45	26 28	260 280	1,060	E	22	7S1	C	gneiss, phyllites	Entic Podzols
7	Bažinky 1	H/R	311A17/4/1a	SM BK	223/39/17	30 31	40 45	26 28	255 39	940	E	24	6S1	C	gneiss	Cambisols
8	Nad Benzínou 2	H/R	306C16/1a	BK SM	158/10	20 26	31 42	20 26	220 35	1,190	SW	24	7K1	B	biotite granite	Entic Podzols
9	Nad Benzínou 1	H/R	306C17/3b/1a	SM BK	186/30/10	23 22	40 38	22 20	20 240	1,170	SW	17	7K1	B	biotite granite	Entic Podzols
10+	Pod Vysokým Kolem	V/ŠM	103E17/1d	SM	188/12	20	39	18	172	1,240	S	16	8N1	B	biotite granite	podzol, Gleysols
11	Strmá stráň A	V/ŠM	117B17/1	SM KOS	226/16	17	33	16 0	162	1,220	NE	29	8Z4	B	biotite granite	Haplic Podzols
12	Strmá stráň B	V/ŠM	117B17/1	SM KOS	226/16	17	30	16 0	162	1,170	NE	26	8Z4	B	biotite granite	Haplic Podzols
13+	Strmá stráň C	V/ŠM	117C17/1b	SM	233/10	22	39	20	197	1,120	NE	23	8F1	B	biotite granite	Haplic Podzols

Table 1 to be continued

Plot		Forest administration[1]/ Forest district[2]	Stand	Tree species[3]	Age at 2009	Height (m)	dbh (cm)	Site class	Growing stock ($m^3 \cdot ha^{-1}$)	Altitude (m)	Exposition	Inclination (°)	Site type[4]	Air pollution threat zone[5]	Geology	Soil type
14[++]	Strmá stráň D	V/ŠM	117C1a	SM BK JR BRP KL OLZ	11	–	–	24 18 12 12 18 16	–	1,050	NE	24	8F1	B	biotite granite	Haplic Podzols
15[++]	Strmá stráň E	V/ŠM	117C1a	SM BK JR BRP KL OLZ	11	–	–	24 18 12 12 18 16	–	990	NE	22	8N1	B	biotite granite	Haplic Podzols
16[++]	Pod Martinovkou	V/ŠM	105D3/2	SM SMP BRP JR	32/18	2 2 1 1	–	16 16 12 12	–	1,170	SE	16	8K2	B	biotite granite	Haplic Podzols
17[++]	U Bílého Labe	V/ŠM	219A2/1a	SM JR BR	22/14	2 2 2	–	14 12 16	–	1,070	NE	29	8N0	B	biotite granite	Haplic Podzols
18[++]	U Čertovy strouhy	V/ŠM	213A1a	SM	12	1	–	18	–	1,200	SW	23	8N0	B	biotite granite	Haplic Podzols
19[++]	U Klínové boudy	V/V	310A1	SM BRP JR	10	–	–	20 20 20	–	1,170	SE	22	8K2	B	mica schists, phyllites	Haplic Podzols
20	Pod Liščí horou	V/Č	407A17c/1c	SM	228/10	20	38	18	241	1,260	SW	19	8Z4	B	mica schists, phyllites	Haplic Podzols
21	Modrý důl	M/P	233A14	SM	139	20	32	20	275	1,230	S	21	8Z4	B	mica schists, phyllites	Haplic Podzols

Table 1 to be continued

Plot		Forest administration[1]/ Forest district[2]	Stand	Tree species[3]	Age at 2009	Height (m)	dbh (cm)	Site class	Growing stock ($m^3·ha^{-1}$)	Altitude (m)	Exposition	Inclination (°)	Site type[4]	Air pollution threat zone[5]	Geology	Soil type
22	Obří důl	M/P	233B17/1c	SM JR	178/9	23 9	35 15	22 12	292	1,160	E	32	8Y0	B	mica schists, phyllites	Haplic Podzols
23	Václavák	M/S	101B17/1b	SM	192/11	17	40	16	165	1,190	NE	4	8R1	B	orthogneisses	Histosols
24+	Střední hora	M/P	330D17a/1a	SM	183/15	21	38	20	258	1,250	SE	20	8Z4	B	mica schists, phyllites	Haplic Podzols
25++	Pod Koulí	M/P	331A1a	SM BK KL JR BR	11	–	–	22 20 20 18 18	–	1,140	NE	28	8K9	B	mica schists, phyllites	Haplic Podzols
26++	Lysečinský hřeben	M/P	303D2	SM KOS BR JR OLZ	23	2 – 1 1 –	18	16 0 14 14 16	248	1,170	W	3	8Z4	A	orthogneisses	Haplic Podzols
27	U Bukového pralesa A	M/S	525C17/3/1	BK SM JR	171/28/15	15 18 15	30 32 30	16 18 14	82 42 2	1,030	SW	3	6Z0	C	phyllites	Cambisols
28	U Bukového pralesa C	M/S	536B15/1e	BK	152/15	24	34	22	235	940	SE	15	6K5	C	phyllites	Cambisols
29	U Bukového pralesa B	M/S	536A17/2/1b	BK SM	173/ 23/9	25 27	47 45	22 26	210 23	950	SE	16	6S1	C	phyllites	Cambisols
30	U Hadí cesty D	M/S	542D17/1c	BK KL	173/13	31 28	49 40	28 26	420 38	790	NE	24	6D5	D	metadiabase	Cambisols
31	U Hadí cesty F	M/S	542C15/1b	BK KL SM	156/14	29 27 31	43 39 40	26 24 28	398 40 20	740	NE	23	6B9	D	metadiabase	Cambisols

Table 1 to be continued

Plot		Forest administration[1]/ Forest district[2]	Stand	Tree species[3]	Age at 2009	Height (m)	dbh (cm)	Site class	Growing stock ($m^3 \cdot ha^{-1}$)	Altitude (m)	Exposition	Inclination (°)	Site type[4]	Air pollution threat zone[5]	Geology	Soil type
32	U Hadí cesty E	M/S	542B14/6a/1c	BK KL	140/62/15	26 26	41 35	24 24	313 34	760	NE	35	5B9 (5A1)	D	metadiabase	Cambisols
33	Nad Benzínou 3	R	306 B12	KOS SM JRO	124	1 7 5	– 16 9	0 14 12	– 2 –	1,310	SW	21	9K2	A	biotite granite	Cambisols
34	Liščí hora	Č	405 B15a/4	SM	149/43	7	15	16	15	1,310	SW	16	9K2	A	mica schists, phyllites	Haplic Podzols
35	Chojnik – beech	KPN	213j	BK SM	171/22/10	28 25	51 31	28 26	420 45	580	NW	15	4B1	D	biotite granite	Cambisols
36	Chojnik – fir-beech	KPN	213f	SM JD BK BO	118/27/10	28 26 28 26	39 38 35 65	28 28 28 24	207 157 106 50	520	N	16	4S1	D	biotite granite	Cambisols
37	Chojnik – relict pine	KPNP	213g	BO BK	191/22/11	19 23	42 45	20 22	179 22	470	NE	22	0Z0	D	biotite granite	Ranker
38	Lomniczka – beech acidophylous	KPN	38k	BK SM	120/94/3	22 20	36 24	20 24	213 22	1,040	W	25	6K1	B	mica schists, phyllites	Entic Podzols

[1]Forest administration: H – Harrachov; V – Vrchlabí; M – Horní Maršov; [2]Forest district: H – Harrachov; Ro – Rokytnice; R – Rezek; ŠM – Špindlerův Mlýn; V – Vrchlabí; Č – Černý Důl; P – Pec pod Sněžkou; S – Svoboda nad Úpou, KPN – Karkonoski Park Narodowy; [3]BK – *Fagus sylvatica*, BR – *Betula pendula*, BRP – *Betula pubescens*, JD – *Abies alba*, JR – *Sorbus aucuparia*, KL – *Acer pseudoplatanus*, KOS – *Pinus mugo*, MD – *Larix decidua*, OLZ – *Alnus alnobetula*, SM – *Picea abies*, SMP – *Picea pungens*; [4]See Viewegh et al. (2003); [5]According to Forestry Management Institute, Brandýs nad Labem. A – the highest level of threat, D - without any threat; [+]partial harvest (PRP 1 in 1991, PRP 10 since 2008, PRP 13 since 1998, PRP 24 since 2008); [++]total harvest of the stand (PRP 3 in 1983, PRP 14 in 1999, PRP 15 in 1996, PRP 16 in 1997, PRP 17 in 1989, PRP 18 in 1998, PRP 19 in 2000, PRP 25 in 1998, PRP 26 in 1984)

ity of them was initiated in year 1980, PRP 11 to 15 in 1976. The plots were established as part of the projects, which were solved by Research Station Opočno of the Forestry and Game Management Research Institute (FGMRI 2009). The plots represent European beech (*Fagus sylvatica*, plot group Fa), mixed (beech-spruce, plot group Fa-Pi) and Norway spruce (*Picea abies*, plot group Pi) stands and respective forest ecosystems. The plot size is mainly regular 50 × 50 m (0.25 ha) (Vacek, Matějka 1999). Excemption from this size are listed in Vacek et al. (2010).

The basic soil survey was done in autumn 1980, when soil pits were prepared. Repeated soil sampling and analyses were performed in autumns 1993, 1998, 2003 and 2009 (Podrázský, Vacek 1994; Vacek, Podrázský 1994, 1995, 1999; Podrázský 1996; Vacek et al. 2000; Podrázský et al. 2007). The soil pit was always restored within the same place. Standard soil survey methods were applied. Soil samples were taken from particular soil genetic horizons. Particular horizons (L, F and H) were sampled quantitatively by iron frame 25 × 25 cm in 1993 only.

Soil analyses

Soil samples were analyzed in the accredited laboratory of FGMRI (later privatized, using the same methods – detailed description see e.g. Podrázský 1995) in Opočno. From the analyses performed, results of the following ones are presented in this paper:
- total organic carbon (C_{ox}) and nitrogen (N) contents by the Springer-Klee method;
- soil reaction as pH in water (pH_{H_2O}) and in 1 mol · l^{-1} solution of KCl (pH_{KCl}), using 1:2.5 ratio of soil:solution, pH-meter with calomel and glass electrode;
- extractable aluminium (Al^{3+}) and hydrogen (H^+) in 1N KCl solution, titration by 0.05 mol·l^{-1} solution of NaOH to pH 8.2, second sample managed by 3% NaF, difference gives content of Al-ions;
- soil adsorption complex characteristics by Kappen: S – exchangeable base content, T – cation exchange capacity, H – hydrolytical acidity, V – base saturation. S-value is determined in the solution of soil by 0.1 mol·l^{-1} HCl (soil:solution equal to 1:10–1:5 according to humus content) and after titration by 0.1 mol·l^{-1} NaOH to pH 4.95, H value in the solution of 1 mol·l^{-1} CH_3COONa (2–5 g of soil in 25 ml) after titration 0.1 mol·l^{-1} NaOH to pH 8.2. T values calculated as S + H and V = S/T;
- plant available elements (P, K, Ca, Mg, Fe) content in the 1% citric acid solution. P was determined spectrometrically, potassium by flame photometry, calcium and magnesium by AAS.

Some methods are used very seldom at present, their application was conditioned by the necessity to keep comparable methods of soil-chemical analyses since 1980s.

Data processing

Database of the analytical results within the SoilExplorer software (Matějka 2005) was completed by soil-chemistry analytical results and horizon identification parameters. This program is useful to compare selected pair of soil profiles (e.g. two plots or the same plot in two sampling periods).

Some ratios (Al^{3+}/T, C_{ox}/N, Ca/Mg and Fe/C_{ox}) were calculated to indicate important relations in the soil chemical state.

The PCA ordination of all samples was calculated on the basis of following soil features: C_{ox}, total N, pH_{H_2O}, pH_{KCl}, S, T-S, T, V, available P, K, Ca, Mg and Fe. All horizons and subsets representing five sampling periods were processed together. The ordination results were visualized by the PlotOA program (Matějka 2009).

The PCA ordination of the top mineral horizons (A) or comparable samples was used to evaluate basic differences among plots and to describe changes during whole period of investigation (1980–2009).

Hierarchical classification based on result of PCA ordination was selected as basic method to reveal differences between samples because PCA is based on correlation matrix among descriptors to be used. No data standardization is necessary in this case. All ordination coordinates were used as input data. Dynamics of soil changes in the plot were quantified as sum of variances for all ordination coordinates over all periods of sampling and from 1993 to 2009 separately, because first sampling year (1980) appeared to be slightly different in the horizon specification.

The soil data variances were compared with vegetation state and dynamics. Data on phytocoenology was processed in Vacek et al. (2007). Indices dS and dH on the community dynamics were calculated similarly to Matějka and Málková (2010).

RESULTS AND DISCUSSION

Basic general description of variability in soil characteristics

General survey of basic soil-chemistry characteristics is presented in Table 2. Consistency in the maintenance, sampling, and analyses of soil samples is the main problem in the turbulent research

Table 2. Basic soil features – averages over horizons (L-F-H, A, B, C) stand types and years of sampling

Horizon	Stand type	Year	No. of plots	C_{ox} (%)	N (%)	pH_{H_2O}	pH_{KCl}	Extractable Al^{3+}	Extractable H^+	Sorption complex S	Sorption complex T	V (%)	Citric acid extractable P	Ca	Mg	K	Fe	Ratio Al^+/T	C/N	Ca/Mg
								H^{+*}					(mg·kg^{-1})							
L-F-H	Fa	1980	6	27.9	1.46	3.6	3.0	–	–	122	354	34.0	139	433	166	118	567	–	19.1	2.61
		1998	6	55.7	1.96	5.1	3.8	30.3	16.1	371	721	52.3	298	7,694	1,127	1,101	220	0.042	28.4	6.82
		2003	6	54.5	1.89	4.5	3.6	24.7	15.7	380	710	53.2	392	4,322	599	815	181	0.035	28.8	7.22
		2009	6	38.5	1.82	4.1	3.5	63.5	11.6	263	675	37.9	162	2,685	381	383	801	0.094	21.2	7.05
	Fa-Pi	1980	6	35.4	1.42	3.5	2.7	–	–	197	531	33.6	123	614	154	188	516	–	24.9	3.98
		1998	6	50.4	1.62	4.8	3.4	57.6	10.5	159	597	30.0	186	5,869	496	1,004	250	0.096	31.1	11.83
		2003	6	54.5	1.59	3.8	3.2	62.9	4.1	167	605	27.3	121	1,789	223	587	411	0.104	34.4	8.02
		2009	6	38.0	1.66	4.1	3.5	58.4	7.5	219	658	34.6	132	2,229	255	401	937	0.089	22.8	8.75
	Pi	1980	19	32.4	1.43	3.4	2.7	–	–	80	543	17.8	115	149	44	98	715		22.7	3.40
		1998	20	58.9	1.80	4.7	3.0	106.2	11.5	125	609	21.4	127	1241	212	535	430	0.174	32.7	5.85
		2003	20	48.4	1.58	3.7	3.0	116.2	7.9	126	675	18.9	110	682	113	233	785	0.172	30.6	6.01
		2009	20	35.7	1.81	3.9	3.3	111.8	4.9	146	690	21.2	113	1154	185	345	783	0.162	19.7	6.23
A	Fa	1980	6	4.6	0.29	3.9	3.1	–	–	38	122	26.6	51	125	37	31	948	–	15.9	3.39
		1993	6	8.1	0.56	4.1	3.3	–	–	44	214	20.4	87	235	77	40	1,948	–	14.3	3.04
		1998	6	16.5	0.64	4.3	2.9	82.0	2.2	74	267	29.3	85	356	97	47	1,349	0.307	25.9	3.66
		2003	6	16.8	0.65	3.8	2.9	80.3	5.1	59	266	22.7	110	339	83	87	2,239	0.302	25.8	4.09
		2009	6	10.7	0.63	4.2	3.2	71.7	4.6	44	255	16.5	112	428	86	51	2,000	0.281	16.9	5.00
	Fa-Pi	1980	6	19.2	1.03	3.7	3.0	–	–	115	343	31.6	86	307	90	102	703	–	18.7	3.40
		1993	6	7.8	0.47	3.9	3.3	–	–	32	182	18.4	87	114	35	45	2,637	–	16.7	3.23
		1998	6	16.0	0.43	4.7	2.8	75.1	3.6	20	194	10.0	68	233	55	71	1,770	0.388	37.4	4.24
		2003	6	15.7	0.51	3.6	3.1	78.7	0.7	30	228	16.8	71	177	48	89	2,395	0.346	30.6	3.70
		2009	6	10.8	0.43	4.1	3.2	71.4	0.8	35	218	15.7	75	250	40	67	2,501	0.328	25.2	6.23
	Pi	1980	19	12.2	0.80	3.7	3.1	–	–	53	281	17.9	72	94	26	55	758	–	15.3	3.65
		1993	14	10.3	0.62	3.8	3.2	–	–	29	188	14.2	81	91	32	39	1,416	–	16.6	2.84
		1998	19	11.3	0.41	4.9	3.0	71.5	3.5	19	121	15.7	95	193	40	71	922	0.589	27.7	4.81
		2003	19	10.4	0.37	4.0	3.3	74.0	2.2	30	183	14.9	76	96	26	42	1,446	0.405	28.3	3.67
		2009	19	7.4	0.37	4.3	3.5	59.7	1.7	36	180	17.5	74	179	33	52	1,448	0.331	19.8	5.45
B	Fa	1980	6	2.6	0.16	4.3	3.7	–	–	37	179	29.5	38	105	24	13	575	–	16.5	4.42
		1993	6	4.5	0.33	4.5	3.9	–	–	37	130	29.0	64	323	40	27	943	–	13.4	8.00
		1998	6	4.3	0.19	4.6	3.3	53.3	1.0	53	134	42.2	81	451	71	37	884	0.398	23.2	6.33
		2003	6	4.3	0.18	4.3	3.7	41.9	1.6	49	128	35.3	75	183	31	30	1,263	0.328	24.0	5.95
		2009	6	4.1	0.24	4.6	3.6	49.1	1.7	29	127	20.9	76	177	34	19	1,276	0.387	17.3	5.17
	Fa-Pi	1980	6	4.3	0.26	4.1	3.8	–	–	49	164	29.5	47	74	9	33	921	–	16.6	7.90
		1993	6	5.5	0.48	4.4	4.0	–	–	44	163	26.4	88	69	13	30	1681	–	11.4	5.41
		1998	6	9.3	0.26	5.2	3.5	41.2	3.1	31	159	21.0	73	190	22	31	1,119	0.259	36.1	8.65
		2003	6	6.6	0.21	4.1	3.7	38.7	1.0	25	135	28.2	76	111	16	29	1,080	0.286	32.1	7.06
		2009	6	5.7	0.23	4.8	4.0	42.5	0.1	55	168	32.4	81	228	26	38	2,498	0.253	24.4	8.89
	Pi	1980	18	4.1	0.24	4.0	3.5	–	–	33	141	22.8	35	40	9	21	1,269	–	17.1	4.45
		1993	13	7.0	0.44	4.2	3.8	–	–	36	165	22.2	77	59	17	23	2,530	–	16.0	3.53
		1998	19	7.7	0.24	5.0	3.3	67.4	1.7	17	88	15.7	74	120	21	32	966	0.766	31.8	5.80
		2003	19	6.7	0.22	4.2	3.6	56.6	1.2	32	157	18.7	71	86	21	31	1,771	0.361	31.0	4.16
		2009	18	4.0	0.19	4.7	3.9	43.6	0.5	32	136	19.7	77	161	28	36	2,014	0.321	21.7	5.84

Table 2 to be continued

Horizon	Stand type	Year	No. of plots	C_{ox} (%)	N (%)	pH_{H_2O}	pH_{KCl}	Extractable Al^{3+} (H^{+*})	Extractable H^+ (H^{+*})	Sorption complex S (H^{+*})	Sorption complex T (H^{+*})	V (%)	Citric acid extractable P (mg·kg⁻¹)	Ca (mg·kg⁻¹)	Mg (mg·kg⁻¹)	K (mg·kg⁻¹)	Fe (mg·kg⁻¹)	Ratio Al^+/T	C/N	Ca/Mg
C	Fa	1980	6	1.3	0.10	4.5	4.0	–	–	35	94	38.4	34	196	21	14	318	–	12.5	9.35
		1993	6	3.3	0.21	4.5	3.9	–	–	45	129	36.9	89	497	52	24	719	–	16.1	9.47
		1998	5	2.7	0.11	4.8	3.4	29.8	1.6	56	108	52.8	109	777	64	19	423	0.276	23.5	12.07
		2003	5	3.1	0.12	4.4	3.9	26.6	1.2	43	99	41.3	79	261	30	28	711	0.268	25.1	8.63
		2009	6	3.3	0.12	4.8	4.0	31.7	0.8	21	93	23.9	85	188	30	22	808	0.339	27.9	6.36
	Fa-Pi	1980	5	2.6	0.20	4.4	4.1	–	–	51	145	36.3	63	79	13	24	364	–	12.8	6.12
		1993	4	8.1	0.22	3.8	4.3	–	–	38	95	35.4	107	197	14	25	509	–	36.4	14.41
		1998	4	6.6	0.17	5.0	3.5	11.0	2.9	39	155	32.4	77	264	18	17	314	0.071	37.9	14.87
		2003	4	6.4	0.21	4.5	4.1	27.1	–	42	132	45.9	91	100	11	24	358	0.206	30.6	8.73
		2009	4	3.7	0.12	5.1	4.3	49.4	0.1	40	110	41.7	80	256	28	39	1,582	0.449	30.0	9.14
	Pi	1980	17	2.0	0.66	4.4	4.0	–	–	29	102	28.4	30	51	5	15	589	–	3.1	10.72
		1993	12	6.3	0.14	4.4	4.0	–	–	20	89	26.0	71	76	8	17	1,199	–	44.1	9.12
		1998	15	2.7	0.10	5.2	3.5	28.6	1.3	12	63	18.4	57	143	14	32	579	0.455	26.9	10.12
		2003	16	5.5	0.18	4.4	4.0	39.1	0.6	34	123	24.2	74	99	18	27	929	0.319	29.8	5.51
		2009	12	3.5	0.12	5.0	4.1	23.7	0.2	18	75	21.0	67	153	21	23	997	0.316	29.9	7.47

*eq. mol·kg⁻¹

environment of the Czech Republic. This is also the reason for neglecting soil holorganic horizons in the year 1993 for purposes of this presentation.

Total organic carbon content

In the beech stands, high fluctuations of the total C content were observed in the upper soil horizons, probably also due to sampling effects in particular terms. This is valid especially for the O (L-F-H, holorganic) horizons. In the A horizons, the stable increase between 1980 and 2003 is observed. The total C content increased in B and C horizons in the period 1980–1993 as possible result of ageing and decaying stands. The state is deviating in stable limits in the period 1993–2009 in the B and C horizons.

In the mixed stands, the dynamics was comparable, as well as the value range in O and A horizons, with decrease in A horizon in 1993. In the lower B and C horizons the contents are higher compared to beech stands, almost double, with an increase in 1980s–1990s and then decrease to the year 2009.

In the spruce stands, the total C content showed similar tendencies, as well as values in the O horizons. The A horizons show relatively stable state in the period 1980–2003, with decrease in the last period. The values are lower compared to stands with beech dominance or significant admixture – this trend is species specific. On the contrary, the total C contents in the B horizons are higher than in pure beech stands, reflecting probably podzolisation processes. Relatively high fluctuations are observed in the C horizon, values are higher compared to beech stands, but lower compared to mixed ones.

Total nitrogen content and C/N ratio

The total N content is highly dependent on the soil organic matter content (Podrázský 1995; Šály 1988), this was confirmed in general trend also in the presented study. Exception is represented by the year 2009, when the N-content is increasing despite the general trend of total C decrease in O horizons. This can be related to long-term changes in humus quality and to probable consequences of the effects of large-scale liming in the last decades of the 20th century (Podrázský 2006a, b).

In the holorganic horizons, the contents of the total N are the highest and C_{ox}/N values the lowest in the beech stands, other groups are comparable. Tendency of the highest N (and lowest C_{ox}/N) contents in the beech stands is obvious also in the A horizon, the spruce forests show the lowest values. C_{ox}/N values in the spruce stands are intermedial.

Dominance or co-dominance of spruce increases also the contents of N and C_{ox}/N values in the

B and C horizons, in the year 1993 highly. These trends are related to general mineralization and humus transformation processes in the stands with more opened canopy.

Soil reaction and adsorption complex

Soil reaction shows also considerable variation during the study period. In the holorganic horizons, there is insignificant tendency of decrease in the order: beech, mixed, spruce stands and increase in 1980s–1990s and decrease in 1990s and 2000s. This can be related to large scale liming in the late 1980s, despite the fact, that research plots were not an object of direct measures. In the A horizons, the situation (with variations) is very stable during the whole study period. Only in the spruce stand slow increase is more visible, due to more probable liming effects and ground vegetation change related to lower canopy cover. Very similar tendencies are observed also in the B horizons and not distinct trends can be assumed in the C horizons.

During the observation period the extractable Al content is slightly increasing in the O horizons of the beech stands, in other stand sets is stable. In this soil layer, the absolute values are in this order (from the highest to the lowest Al^{3+} content): spruce, mixed and beech stands, which corresponds to generally accepted assumption. In the A horizons, in beech and mixed stands the situation is similar, beech stands show lower contents, decrease of the Al ions content is observed in the last period in all investigated stand types. Contrary situation is documented in the B horizons, which can be connected with more pronounced podzolisation in the spruce stands (litter, more extreme sites). In the C horizons, the variation is high, highest values recorded in the year 2009 were in the mixed stands. Extractable H shows continuous decrease; this phenomenon should be studied more in detail.

Content of exchangeable bases (S-values) in the holorganic horizons is the highest in the beech stands, lower in the mixed and the lowest in the pure spruce stands. There is evident decrease in beech stands in the last period of the study, in contrast with stable increase in other forest types. Similar trend was observed in the A and B horizons, despite values lower by one order. Stable state or high variation was documented in the C horizons without obvious trend.

High variation was observed also for the cation exchange capacity (T-value), without visible trends. Certain exception from this general tendency is represented by higher values in holorganic and A horizons of the beech stands, increase of values in the surface humus during the study period.

Dynamics of the base saturation (V-values) can be considered as the most complex indication of the adsorption complex development. Also in this case, the obvious tendencies can not be easily described. In the holorganic horizons, the values are decreasing in order beech, mixed, spruce stands, without changes in the period 1980–2009. Stable state can be considered. In the mineral horizons, the base saturation is supposed to decrease especially in the beech stands, the final state is similar in all forest types, with the exception of higher values in the mixed stands in B and C horizons.

Higher acidity of the spruce sites is documented by higher values of the Al^{3+}/T ratio. The values are increasing, going from holorganic to A and B horizons, decreasing again in the C layers. This corresponds with the general pedogenetic trend at all sites – podzolisation.

Plant available nutrients

Plant available phosphorus content increased in the period 1980–1993, which may be caused by the methods of laboratory analyses, despite the fact that the conservation of the analytical procedures was insisted. The values did not show visible time trends later. They were higher in the beech stands in the holorganic horizons and slightly in the horizons A. The P contents were lower in the spruce stands in the C horizons.

Calcium content showed clear effects of the surface liming in the Krkonoše Mts. in the late 1980s. The values increased in the period 1980–1998, later they decreased again, their size decreased from beech through mixed to spruce stands. Very similar trend was documented for the plant available magnesium content. Also the ratio Ca/Mg shows probable effects of the liming of the whole area. There is a peak around the year 1998, quite high variation is observed in other periods.

Clear differences were not observed for the extractable potassium content. Only in the holorganic horizons, the contents were the lowest in the spruce stands, in the mineral horizons, sometimes the tendency of lower contents in the beech stands was obvious. This trend can reflect more pronounced demands of beech (broad-leaved species in general) for bases (Podrázský, Remeš 2008).

The content of plant extractable iron documents only the most general trend in the soil development. According to the main soil-genetic process, podzolisation and its clearer pattern in the spruce forests, the contents of this element are higher in the hologanic horizons in the stands with spruce dominance. The A horizons are the mostly leached ones, on the contrary, showing lower Fe contents there, increasing again in the illuviation horizons.

Despite a large number of plots, large time scale and very detailed research, the clear trends in the soil development were not detected. In extreme sites, also under beech, there are quite extreme soils. Only some very general and weekly supported trends were documented, in contrast with other sites and authors (Hruška, Cienciala 2001; Podrázský, Remeš 2007). Podzolisation is the main soil-genetic trend (Šály 1988; Klimo 1990), the species composition has less important position. Higher shifts in the soils of beech stands can be ascribed to lower acidity and higher sensitivity of these soils to changes of their characteristics (Meiwes et al. 1986).

Multidimensional analyse of data set

Two first axis of the principal component analysis (PCA) describe 47.7% and 20.8% of the total data variability. Approximately three groups of soil variables can be revealed - first group is represented by both active and exchangeable pH, second one contains available nutrients Ca, Mg, K, P and exchangeable base content. The last group with C_{ox}, N and total exchange capacity corresponds to content of organic matter in the sample. Iron shows a different position in the ordination space (Fig. 2). The ordination space of such distribution of basic soil parameters contains corresponding distribution of individual soil samples. Because the ordination space of all individual samples is not well transparent for high number of samples, position of averages according to the main horizon and stand type was visualized (Fig. 3). The most varying features of the soils during all periods of sampling are visible in organic horizons (O = L+F+H). The proximity of first (1980) and last (2009) sampling points to possible regeneration processes in soils. The most important changes in the O horizons of soils in the beech dominated ecosystems were present in 1998 and 2003. Changes under stands with Norway spruce (both Fa-Pi and Pi stand types) were smaller. The most distinct second points (1993) of both trajectories are omissible because they were calculated on the base of one or two plots only.

Ordination of the A-horizon soil samples

The PCA ordination was processed with data subset describing upper part of the A horizon (or corresponding horizon below the H horizon). The goal of this analysis is to describe similarities among plots and soil dynamics during observation period. Several samples can not be included

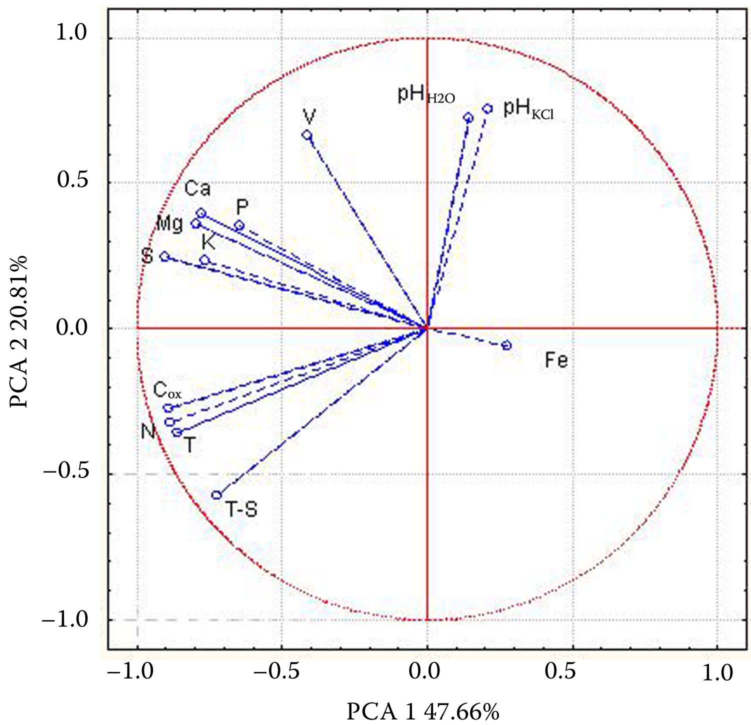

Fig. 2. Principal component analysis for all samples at all sampling years

Ordination coordinates of sample features are plotted

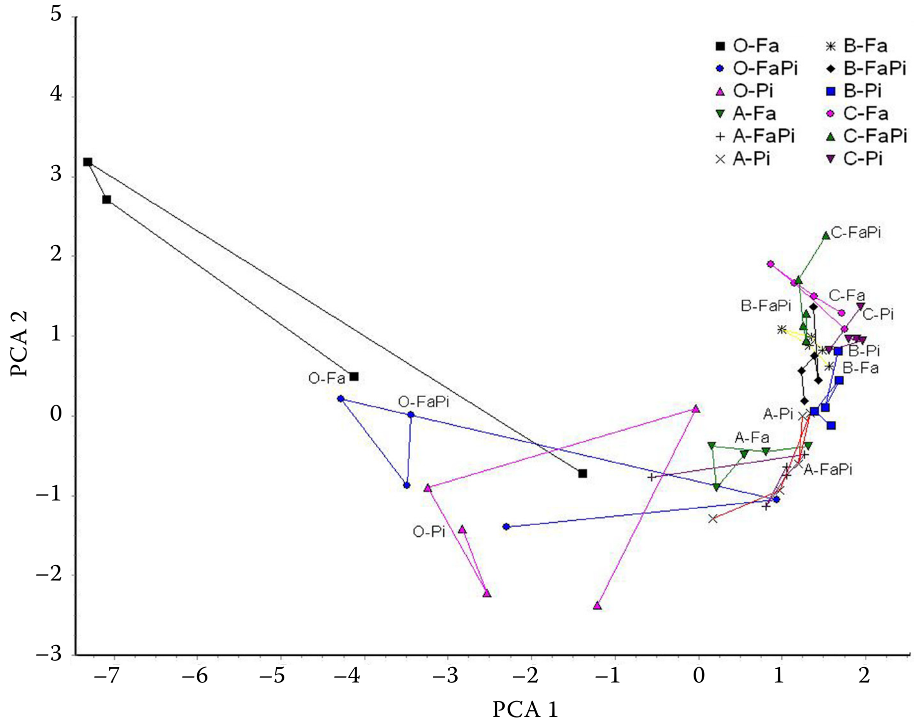

Fig. 3. Average factor coordinates of soil samples grouped according to the main horizon and stand type. The trajectory displays changes in different years of sampling. Point corresponding to the last year (2009) is marked by the group label

into the set because one or more variables were not known. First axis describe 36.3% of the total data variance, second axis corresponds to 15.8% of data variance. The soil variables are not correlated into groups so tightly as in the case of analysis of all-horizon data (Fig. 4).

The samples from ecosystems with spruce, mixed and beech stands are only partly differentiated (Fig. 5). There are lot of soil samples from all ecosystem types which are very similar in studied soil features.

A shift of soils in the ordination space was well observable in 1993. The confidence ellipses for samples taken in 1980, 2003 and 2009 are closely localized (Fig. 6). We can speak about a hysteresis in soils during the processes of acidification (1980) – liming (main effect in 1993 and 1998) – regeneration (2003, 2009).

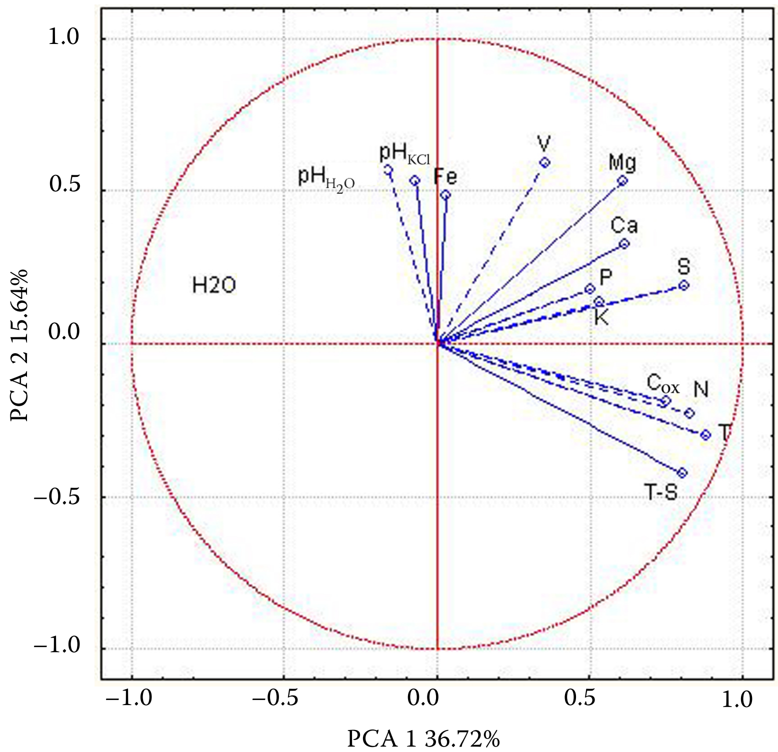

Fig. 4. Principal component analysis for the A-horizon samples at all sampling years.

Ordination coordinates of sample features are plotted

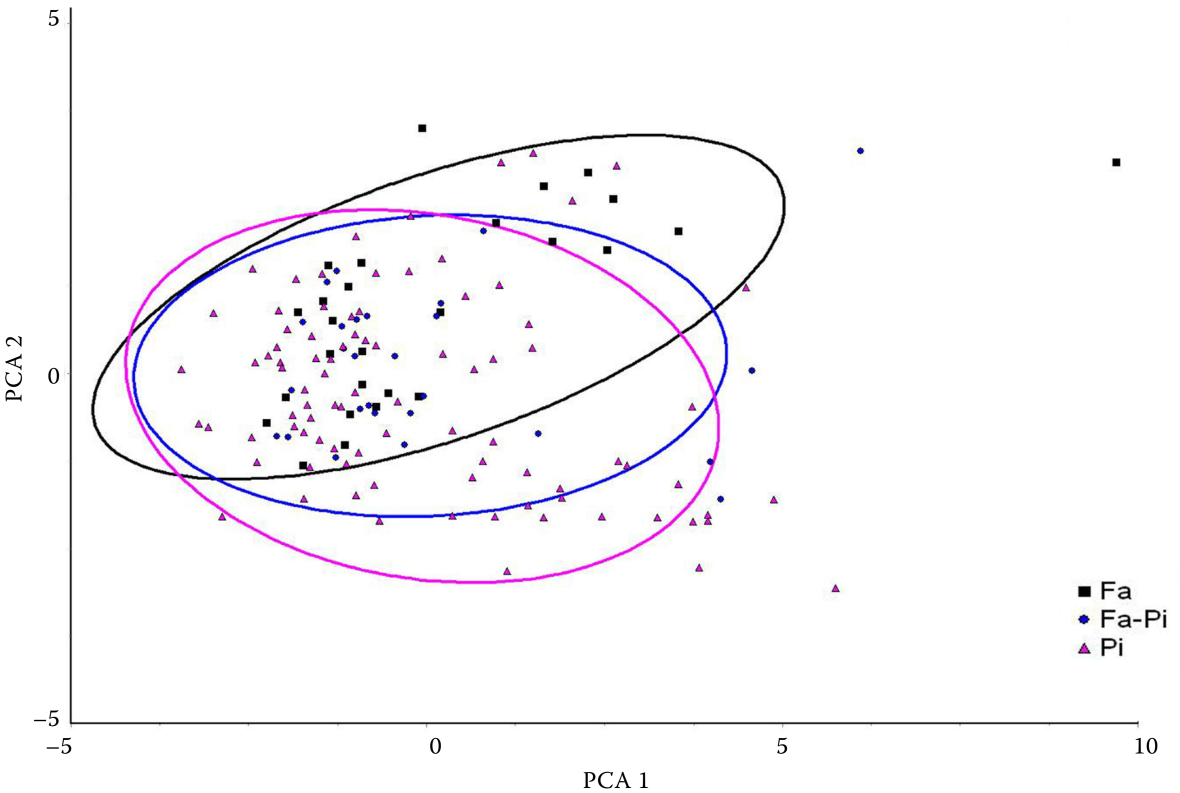

Fig. 5. Position of soil samples of the upper A horizon in the PCA ordination space. Points are grouped according to the stand type (Corresponding 95%-confidence ellipses are plotted)

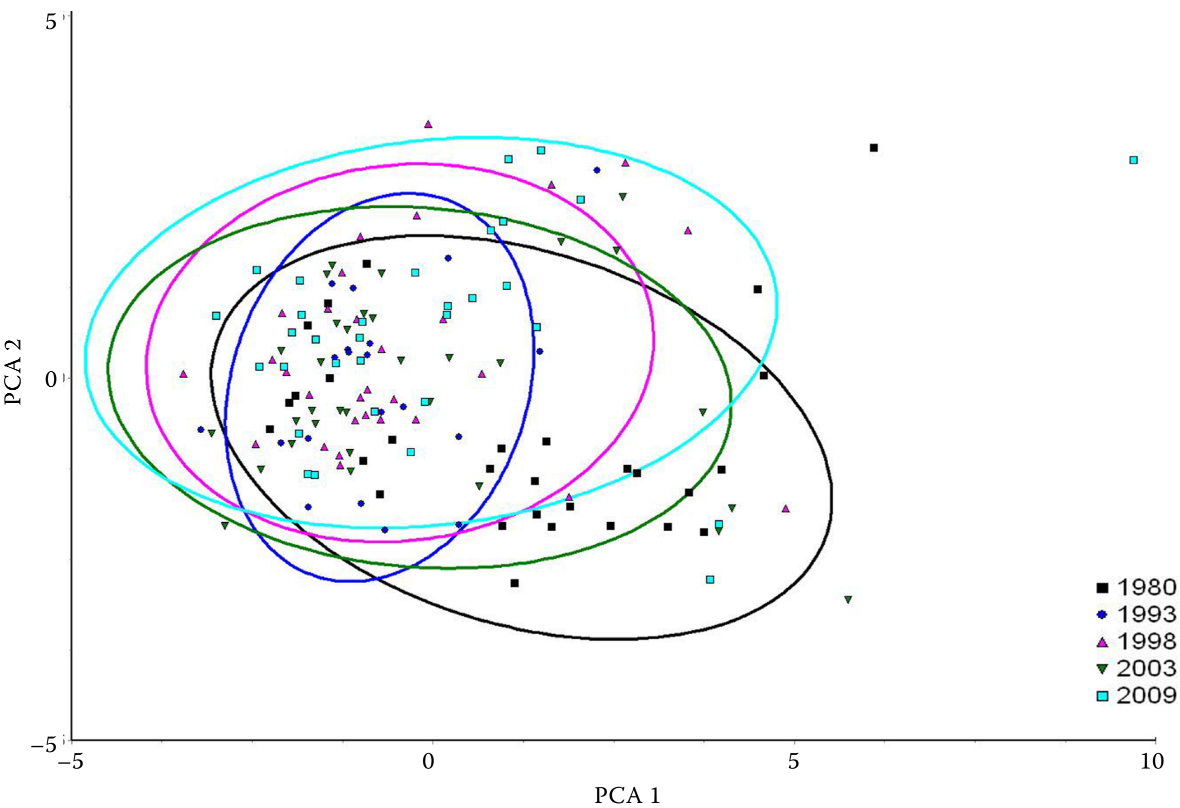

Fig. 6. Position of soil samples of the upper A horizon in the PCA ordination space. Points are grouped according to the year of sampling (Corresponding 95%-confidence ellipses are plotted)

Table 3. Contingency table for the soil classification group (Fig. 7) and the stand type. Counts with positive deference higher than 1 are marked by + sign.

Soil group	Stand type			Year of sampling				
	Fa	Fa-Pi	Pi	1980	1993	1998	2003	2009
A	10+	7	16	4	8+	2	11+	8
B	7	7	19	6	7+	3	11+	6
C		2	14+			12+		4
D		2+	2			4+		
E	2	3	7		1	1	2	8+
F		1	1	2+				
G		3	20+	15+	3		3	2
H			2				2+	
I	6+				1	2	2	1
J	1		4			3+		2
K			2	1		1		

Classification of the A-horizon soil samples

Several classification groups (classes) of the A horizon soil samples were distinguished (Fig. 7). These classes show specific occurrence in some ecosystems and during observation period (Table 3). There is typical position of each class within the ordination space (Fig. 8).

Second ordination axis partly discriminates soils of the beech-dominated ecosystems with classification groups A, E, I and J (positive values of the ordination coefficients), against soils of the spruce-dominated ecosystems with groups B, G, H and K (negative values of the ordination coefficients). For the spruce ecosystems is typical high frequency of the class C (Table 3).

The first soil sampling (1980) in the spruce dominated ecosystems was marked by high frequency of samples in the classes F and G (Table 3), the class G is responsible for positioning of the spruce confidence ellipse (Fig. 5). These classification groups are rare in the next period – after the impact of liming.

The classification group E is of increasing frequency. This group was found in all ecosystem types. Dissimilarity between soils (according to A horizon) in spruce and beech dominated ecosystems probably decreases.

Organic matter accumulation can be characterized by the ratio: available Fe/C_{ox} (Table 4). Classes H and K are marked by high accumulation of organic matter. They represent peaty soils as a limit of the gradient within the group of spruce-dominated forests. Contrary, the A horizon soil samples from the beech-dominated ecosystems show low accumulation of organic matter.

Table 4. Average soil features according to classification groups (ordered by ratio Fe/C_{ox})

Soil group	C_{ox}	N	pH_{H_2O}	pH_{KCl}	S	T	V	P	K	Ca	Mg	Fe	Fe/C_{ox}
	(%)				H^{+*}		(%)	mg·kg^{-1}					
A	7.4	0.35	4.1	3.3	35.0	180.6	20.2	84	43	119	36	1,990	268.9
I	19.1	0.91	4.1	3.2	88.2	328.1	26.8	78	80	528	190	3,706	193.9
E	13.3	0.71	4.4	3.6	57.9	259.9	21.6	131	94	328	70	1,615	121.3
J	12.0	0.54	4.9	3.1	85.1	278.9	39.5	94	100	326	71	1,357	112.7
B	9.5	0.47	3.7	2.9	24.8	177.2	13.1	58	48	135	27	892	94.4
C	12.3	0.35	4.7	3.1	11.7	121.5	9.4	60	54	148	31	756	61.6
D	26.1	0.46	5.0	2.7	34.5	242.6	13.9	84	55	298	62	1,554	59.6
G	21.6	1.29	3.7	3.0	79.8	450.6	18.1	98	87	176	46	1,012	46.8
F	29.0	1.72	3.6	3.1	135.0	394.0	34.2	194	185	427	113	921	31.8
K	50.5	1.55	4.3	3.1	39.7	449.0	11.3	299	86	302	46	354	7.0
H	53.1	1.37	3.6	3.3	110.6	694.3	15.9	83	73	376	49	187	3.5

* – eq. mol kg^{-1}

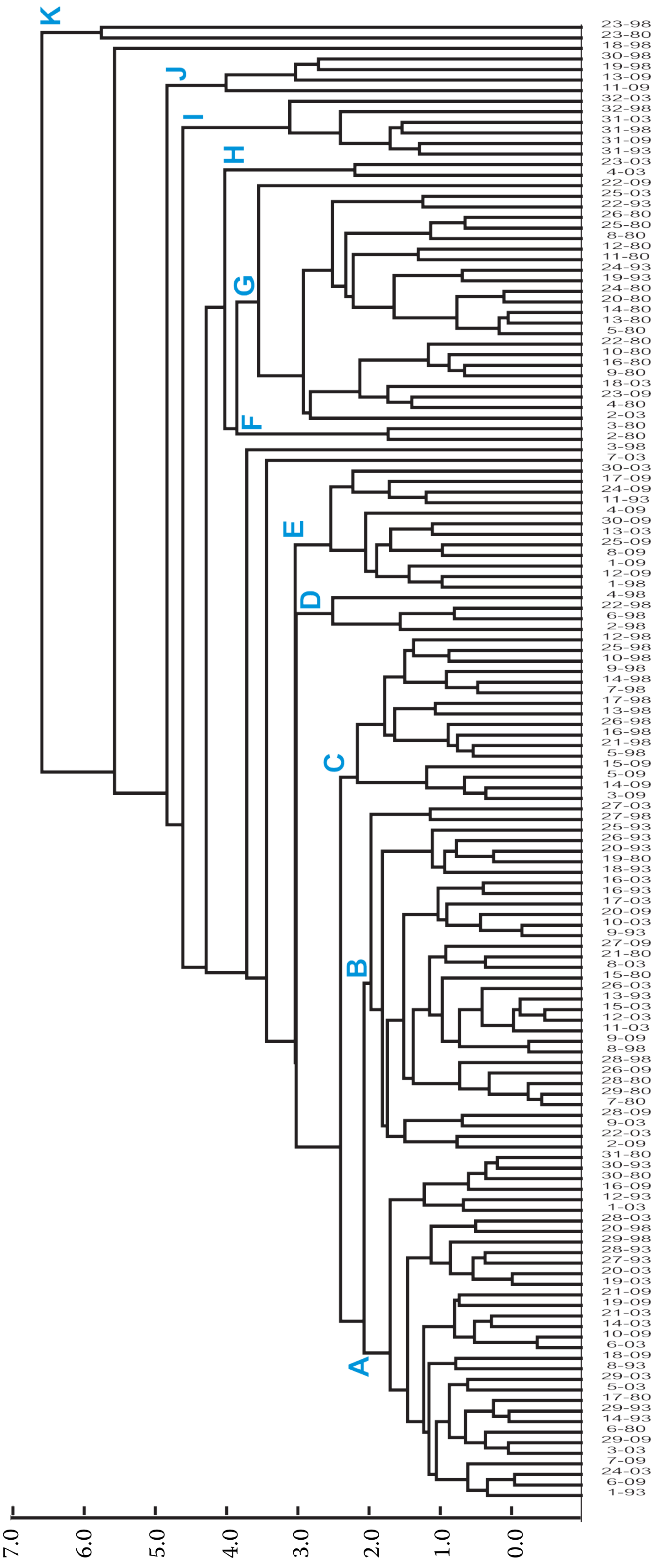

Fig. 7. Classification of soil samples of the upper A horizon – group average linkage with Euclidean distance calculated on the base of PCA coordinates of samples. The most distant samples 1–80, 24–98 and 32–09 were not classified. Basic classification groups are marked by capital letters

Table 5. Data variances for samples of the upper A horizon based on the PCA coordinates

Plot	*N*	$var_{1980–2009}$	*N*	$var_{1993–2009}$	Classification groups	Altitude	Stand type	Dieback	Dieback year	Ward		E1 dS	E1 dH
										E1	E0+E1		
1	5	15.08	4	2.73	*AEAE	730	Fa-Pi			A0	A	9.67	0.424
2	4	10.16	3	7.66	F*DGB	600	Fa-Pi			A0	A	8.50	0.395
3	4	13.53	3	5.96	F**AC	1,150	Pi	+	1983	D	D	6.83	0.166
4	4	12.72	3	14.58	G*DHE	1,180	Pi			C1	C1	5.00	0.190
5	4	6.74	3	2.97	G*CAC	1,130	Pi			B	B	2.67	0.280
6	4	3.49	3	2.66	A*DAA	1,060	Fa-Pi			A1	A	7.67	0.224
7	4	3.66	3	2.87	B*C*A	940	Fa-Pi			A0	A	7.83	0.210
8	5	4.64	4	3.64	GABBE	1,190	Fa-Pi			A0	A	7.50	0.519
9	5	8.34	4	3.10	GBCBB	1,170	Fa-Pi			A1	A	5.83	0.219
10	4	7.20	3	2.72	G*CBA	1,240	Pi			D	D	3.50	0.077
11	4	12.59	3	10.79	GE*BJ	1,220	Pi			B	B	1.43	0.267
12	5	7.11	4	3.20	GACBE	1,170	Pi			B	B	2.43	0.218
13	5	7.20	4	6.55	GBCEJ	1,120	Pi			B	B	6.14	0.349
14	5	5.15	4	3.06	GACAC	1,050	Pi	+	2006	B	B	7.43	0.294
15	3	1.95	2	0.76	B**BC	990	Pi	+	1997	C0	C0	3.57	0.335
16	5	10.45	4	2.48	GBCBA	1,170	Pi	+	1997	C1	C1	6.00	0.118
17	4	11.33	3	13.22	A*CBE	1,070	Pi	+	1989	C0	C0	7.67	0.380
18	4	16.04	4	16.04	*BJGA	1,200	Pi	+	1998	C1	C1	5.50	0.104
19	5	6.06	4	6.60	BGJAA	1,170	Pi	+	2000	D	D	5.33	0.143
20	5	3.82	4	3.20	GBAAB	1,260	Pi			D	D	2.67	0.087
21	4	2.67	3	1.27	B*CAA	1,230	Pi			A1	A	7.00	0.155
22	5	6.53	4	6.14	GGDBG	1,160	Pi			C0	C0	7.33	0.073
23	4	12.56	3	7.15	K*KHG	1,190	Pi			A1	A	1.17	0.182
24	5	18.37	4	21.03	GG*AE	1,250	Pi			D	D	7.33	0.178
25	5	6.41	4	5.63	GBCGE	1,140	Pi	+	1998	C1	C1	4.00	0.089
26	5	4.30	4	2.81	GBCBB	1,170	Pi	+	1983	C1	C1	4.17	0.224
27	4	2.77	4	2.77	*ABBB	1,030	Fa			C0	C0	2.00	0.128
28	5	2.17	4	1.91	BABAB	940	Fa			C0	C0	4.33	0.128
29	5	2.30	4	2.20	BAAAA	950	Fa			A0	A	4.67	0.327
30	5	5.68	4	5.66	AAJEE	790	Fa			A0	A	10.17	0.269
31	5	4.15	4	2.59	AIIII	740	Fa			A0	A	6.17	0.371
32	3	27.25	3	27.25	**II*	760	Fa			A0	A	10.33	0.421

var – variances; *N* – number of samples with comparison of the ecosystem and vegetation features; stand type according to main tree species (Fa – *Fagus sylvatica*, Pi – *Picea abies*), stand dieback occurrence, vegetation classification group (Ward's method) for data on herb layer (E1) and both herb and moss layer (E0+E1); herb layer vegetation changes were quantified by indices dS and dH (Vacek et al. 2007). Soil classification groups are assigned according to Fig. 7 in years 1980–1993–1998–2003–2009; *is used in the case when respective sample was excluded from the analyse (where probable error occurred or some feature was very distinct)

Groups A and I are typical for beech forests, groups H, K, F and G can be found in spruce forests.

Each locality can be described by succeeded sequence of classes of the A horizon samples (Table 5). A transition matrix for changes from one class to another can be constructed from these sequences. Four combinations of the classification classes in the spruce ecosystems represent the most frequent transitions: A → C, B → C, G → B and C → B. First three shifts represent decrease of ordination coordinate along 1st PCA axis. This change can be related to organic matter mineralization as a consequence of liming and/or soil draining.

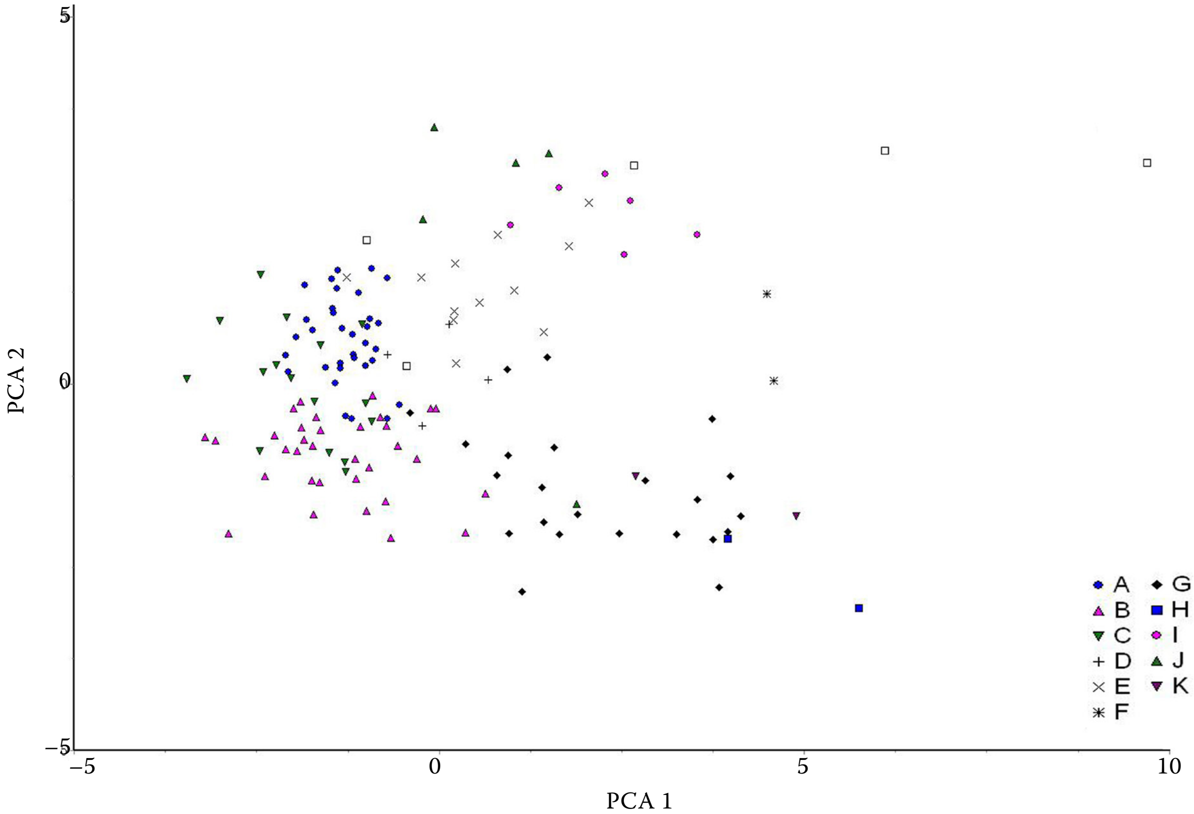

Fig. 8. The PCA ordination space of two first axes with representation of the classification groups (Fig. 7)

Comparing soil and vegetation dynamics

While vegetation dynamics probably decrease along the altitudinal gradient (correlation coefficient is slightly statistically significant by both indices dS and dH, $r = -0.55$ and -0.56 respectively, $N = 31$), soil variance do not show any altitudinal trend ($r = -0.05$ by $var_{1993-2009}$; Table 5). Direct re-

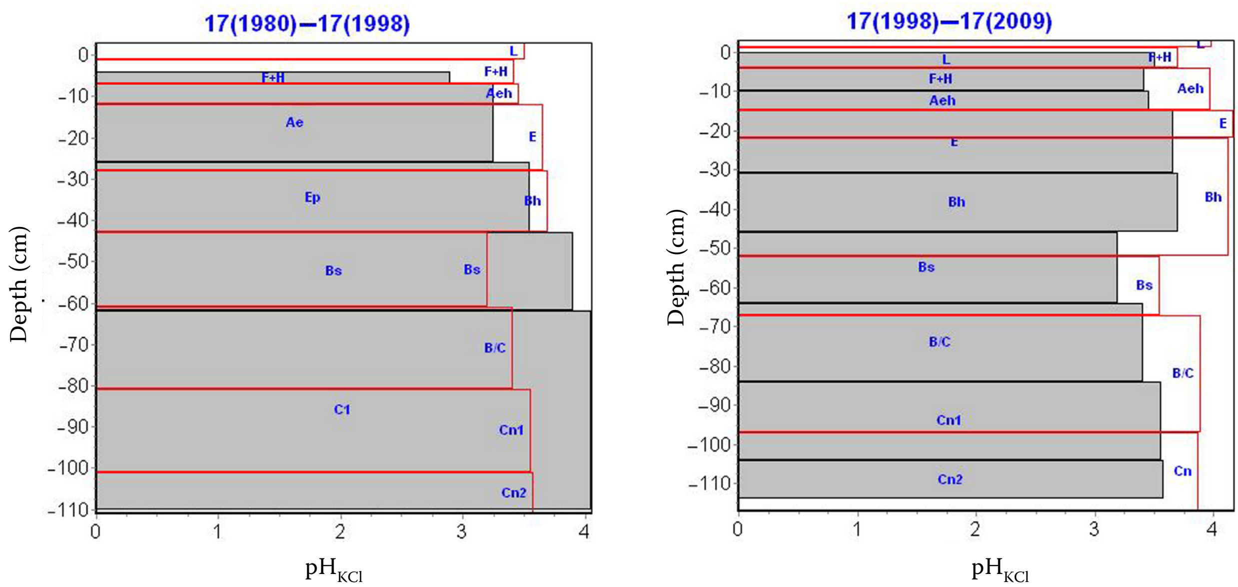

Fig. 9. Example of the development of single soil feature (ph_{KCl}) at plot 17 within whole soil profile, data processed in the SoilExplorer software. Liming was applied in first period (1980–1998), thus surface horizons were strongly influenced. Decrease of pH continued in lower horizons. Influence of liming is apparent in the whole soil profile during the second period (1998–2009)

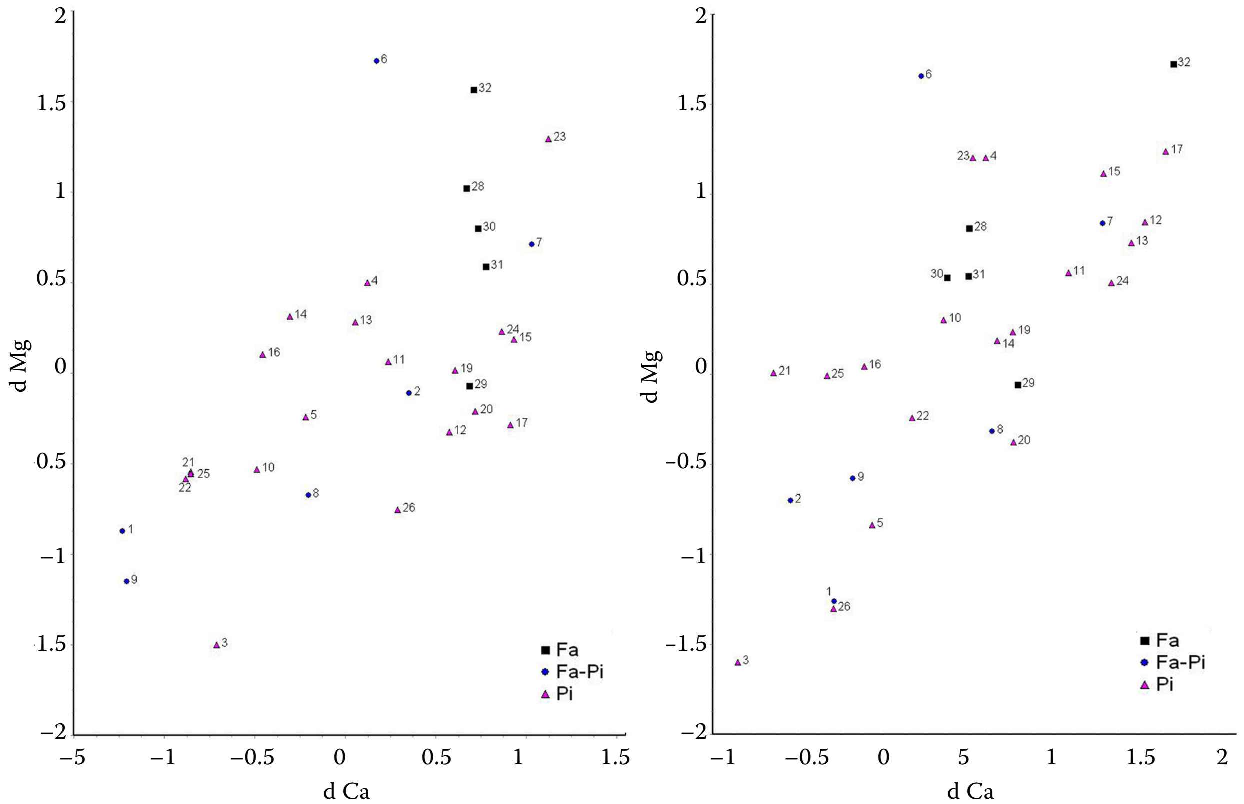

Fig. 10. The 1980–2003 (left) and 1980–2009 (right) differences in contents of calcium and magnesium in the soil samples of the A horizon

lation between vegetation dynamics and soil variance in the A horizon is insignificant: $r = 0.29$ by $dS \times var_{1993–2009}$ and $r = 0.12$ by $dH \times var_{1993–2009}$.

Soil variances do not differ among three groups of forest ecosystems according to dominant tree species (beech, mixed and spruce stands) – *F*-test for ANOVA by $var_{1993–2009}$: $F_{2.28} = 0.60$, $P = 0.55$. An insignificant dependence of soil variance in time on the vegetation classification (Ward's method, data on herb layer species structure) was observed: the ANOVA *F*-test was $F_{5.25} = 0.40$, $P = 0.85$. The lowest soil variance was observed in the ecosystems of spruce or spruce-beech-mixed stands without stand dieback (vegetation group A1). On the contrary, ecosystems of the groups C1 and D with spruce stand, which had been completely damaged in many cases, may have the highest soil variance. If one has taken into account stand dieback only, this factor has no effect on soil variance ($F_{1.29} = 0.004$, $P = 0.95$).

Possibilities of the result interpretations

Detailed statistical analyse of the results is difficult to unacceptable for several reasons: Soil sampling was carried out in similar manner but not identically. There is considerable spatial heterogeneity in soil stratigraphy, but only one sample was picked up from the plot for each soil horizon. Some methodological mistakes occurred – soil body could be influenced by established pit. Thus, it can result in some changes in water dynamics, aeration in the lower soil horizons etc. Nevertheless, the collected data are still unique and allow the comparison of soil development in the forest ecosystems in the Krkonoše Mts.

The most important changes are bounded with acidification and the air pollution impact during second half of the 20th century. Liming was applied in this region. Several investigated plots were influenced as shown on the example of the plot 17 (Fig. 9). This plot belongs to the group of spruce ecosystems with tree layer dieback (Vacek et al. 2007) and substantial soil changes (Table 5).

No precise categorization of the plots according to the liming influence is known. Effect estimation of liming can be based on change of calcium and magnesium contents in the upper soil horizons between compared years. Indices in the form $d = 2 \times (x_{year2} - x_{year1})/(x_{year2} + x_{year1})$ were calculated for both element content (d_{Ca}, d_{Mg}) and the year couplets 1980–2003 and 1980–2009 (Fig. 10). The strong liming effect is evident for plots where both indices are greater than zero for both year couplets. There are 13 plots with such properties: 4 beech-dominated plots (28, 30, 31 and 32), 2 beech-spruce-mixed plots (6 and 7) and 7 spruce-dominated plots (4, 11, 13, 15, 19 23 and 24).

Another approach how to describe soil changes related to acidification was applied in the Jizerské hory Mts. (Slodičák et al. 2005) and in the Krušné hory Mts. (Slodičák et al. 2008). Both methods are not fully compatible, nevertheless trends in the Krkonoše Mountains are similar to processes in both mentioned regions, mainly in the Jizerské hory Mts. (acidification culminating in 1980s, influence of liming). On the contrary, our results cover only last 30 years of the acidification-regeneration processes. Original situation before 1950 or sooner is unknown. Nevertheless, regeneration of some soil features is obvious. Some parameter changes are probably irreversible. The calcium and magnesium input changes nutrient balances, dynamics of soil organic matter (e.g. increase of mineralization, mainly in surface horizons, more intensive transport or organic compounds to the lower horizons, where C_{ox} has increased). These threats have been confirmed also from other regions (Vavříček 2001).

CONCLUSIONS

Large and long term research of the soil development in the area of interest, i.e. in the Krkonoše Mts., did not confirm very clear and simple development trends. The general type of the soil-genesis is represented by the podzolisation, overlapping the other soil-genetic factors, including the tree species composition. Nevertheless, this development is mostly expressed in the spruce stands.

Other features, important for the soil development, are changes of canopy cover, tree layer decay on some localities and also the large scale liming, despite the fact that the plots were not primary target areas of this measure.

The beech dominance and/or co-dominance are reflected especially by more efficient N-cycling, higher pH, S and V values and fluctuation and lower extractable Al content. More efficient cycling for beech is insignificantly documented for plant available phosphorus, calcium and magnesium contents, on the contrary higher dynamics for iron ions was registered in the spruce stands.

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