Physical, chemical, and biochemical characteristics of soils in watersheds of the Bohemian Forest lakes: I. Plešné Lake

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Abstract

Basic physical, chemical, and biochemical properties of mountain forest soils were determined in the Plešné Lake watershed in the 1997–2001 period. The watershed area was predominantly covered with an undeveloped ~0.2 m deep organic soil (38%), and ~0.45 m deep podzol (29%) or spodo-dystric cambisol (27%). Stones >2mm in diameter, fine soil, and moisture contributed on average 49%, 28%, and 23% to the total soil pool. Fine soil was sandy (~75%) with a low (~2%) content of clay and its watershed weighted mean (WWM) pool was 92 kg.m^{-2}. Concentration of organic C was the dominant parameter, affecting most of soil properties (N, S, exchangeable base cations and protons). Relationship between C and P was less straightforward due to inorganic P forms associated with the Fe and Al oxides in horizons rich in illuvial metals. The WWM pools of C, N, S, and P were 936, 39, 1.6, and 1.9 mol.m^{-2} (i.e., 112, 5.5, 0.52, and 0.58 t.ha^{-1}), respectively. Soil pH was generally low, with the lowest pH$_{CaCl2}$ values (2.5–3.1) in A horizons and highest (3.2–4.4) in the Bs and C horizons. The WWM cation exchange capacity was 129 meq.kg^{-1}, 15% of which was base saturation (Ca^{2+}, 9%; and Mg^{2+}, Na$^+$, and K$^+$ ~2% each), and was dominated by exchangeable Al^{3+} (57%) and protons (28%). The WWM C:N ratio was 24 for the whole soil profile and varied from 25 to 33 in the O horizons. Concentrations of C, N, and P in soil microbial biomass was on average 0.7%, 2.7%, and 11% of total C, N, and P contents, respectively, suggesting a high microbial activity of soil. Carbon and nitrogen mineralization was highest in the O horizons (30±9 and 0.24±0.10 mmol.kg^{-1}.d^{-1}, respectively), while the highest potential nitrification (0.08±0.03 mmol.kg^{-1}.d^{-1}) was associated with the A horizons. The average nitrification potential of the O, A, and Ae horizons (0.3, 0.9 and 2.6 mmol.m^{-2}.d^{-1}, respectively) was one order of magnitude higher than atmospheric deposition of NH$_4^+$ on the forest floor.

Key words: Carbon, nitrogen, phosphorus, sulfur, pH, cation exchange capacity, nitrification, mineralization

INTRODUCTION

The chemistry of lakes in mountain areas is primarily determined by atmospheric deposition, weathering of rocks (PSENNER & CATALAN 1994), properties of soil, type of vegetation (BARON et al. 1994, KOPÁČEK et al. 2000), and hydrology (WETZEL 1983). Before reaching the lake, the water composition is modified by terrestrial processes, being extremely sensitive to anthropogenic impacts like acid deposition or forestry practices (VITOUSEK et al. 1979, KELLY 1994, BINKLEY & HÖGBERG 1997). While the forestry activity has been restricted in watersheds of most of the Bohemian Forest lakes for more than a century (VESELÝ 1994), atmospheric acidi-

fication has dramatically increased during the period of Industrial Revolution (KOPÁČEK et al. 2001a). Such a long-term increase in concentrations of strong acid anions in soil solutions leads to the reduction in acid neutralizing capacity (ANC), soil depletion of base cations, and mobilization of Al, with adverse effects on both soil and surface water composition (e.g., REUSS & JOHNSON 1986, NORTON et al., 1999). While there are no consistent historical data to document soil acidification in the watersheds of the Bohemian Forest lakes, symptoms of strong acidification of the whole watershed-lake ecosystems are well shown by historical changes in the lake water chemistry (VESELÝ et al. 1998a,b, KOPÁČEK et al. in press).

Due to the pronounced decline in deposition of S (~80%) and N (~30%) compounds during the 1990s (KOPÁČEK et al. 2001a), the Bohemian Forest became a forest ecosystem with a high potential of recovery from acidification. However, the extent and timing of this recovery depends not only on the reduction in emission/deposition rate of acidifying pollutants but also on the way that soils and vegetation respond to their reductions (e.g., WRIGHT & HAUHS 1991). In concordance, the present changes in chemistry of the Bohemian Forest lakes (especially concentrations of sulfate and nitrate) are delayed compared to changes in atmospheric deposition (KOPÁČEK et al. in press). This implies that the future extent of water quality reversal from acidification will depend on the fate of S adsorbed in soils and on factors affecting terrestrial N cycling. The prediction of future impacts of various scenarios of acid emissions on soil and water quality can be simulated by process-based whole ecosystem chemical models (e.g., MAGIC – Modeling the Acidification of Groundwater in Catchments, COSBY et al. 1985), calibration of which is based on extensive chemical data from watersheds. Such detail data on the Bohemian Forest soils, including their type and pool, pH, cation exchange capacity, base saturation, C, N, and S contents, and sorption characteristics, are missing (with exceptions for data by PELÍŠEK 1978, KOPÁČEK et al. 1998, NOVAK 1999, PODRÁZSKÝ et al. 2000) in the available literature.

Another demand on the detail study on soil composition in strongly acidified mountain forest ecosystems has arisen in parallel with the declining soil fertility and its links to forest productivity (e.g. HRUŠKA & CIENCIALA 2001). Such a study is necessary to provide a desirable scientific base to solve the following questions concerning a possible soil restoration: To what extent and in what time horizon is the present adverse status of the acidified soil reversible?

As a part of the integrated study on the Bohemian Forest watershed-lake ecosystems (Biogeochemical cycles of nutrients in mountain watershed-lake ecosystems: Anthropogenic impacts and possibilities of recovery – project of the Grant Agency of the Czech Republic) we sampled and analyzed soils in the watersheds of three Bohemian Forest lakes. The major aim of this study is to present and evaluate basic physical, chemical, and biochemical properties of these soils with respect to differences in the bedrock composition and forest type. In this part (I) we provide data on spruce forest soils in the Plešné Lake watershed and compare them with similar data from nearby beech stand sites. The differences between soils underlined with granite (Plešné watershed) and mica schist (watersheds of Čertovo and Černé Lakes) are discussed in the following part II (KOPÁČEK et al. 2002 – this issue).

MATERIALS AND METHODS

Study site description

Plešné Lake (PL) is situated at 48°47' N, 13°52' E, at an altitude of 1090 m a.s.l., in the massive of Plechý (1378 m a.s.l.). The PL watershed covers an area of 66.6 ha (including the lake area of 7.5 ha; ŠVAMBERA 1939), and is north-east oriented and steep with the maximum local relief of 288 m. The bedrock is made up of granites (VESELÝ 1994). The forest covers ~90%

of the watershed, is on average 160 years old, dominated (99%) by Norway spruce (with minor contribution of mountain-ash and beech), and with the timber biomass ranging between 15 and 720 m³.ha⁻¹ (the watershed average of 230 m³.ha⁻¹) according to the forest management plans Stožec, 1995–2004, and Plešný, 1996–2005 (I. VICENA – pers. comm.). There are only few available data in the literature on the history of land-use in the PL watershed, summarized by VESELÝ (1994) and HEJZLAR et al. (1998). For example, prospecting for gold occurred there in the second half of the 16th century. There was a tourist cottage (from 1921 to the middle 1950s) and barracks (from the late 1950s to the late1980s) in the close vicinity of the outlet from PL lake. Other factors occasionally affecting the surroundings of PL watershed (logging, pasturing, or fires) were probably negligible within the PL watershed during the last ~250 years (I. VICENA – pers. comm.). Moreover, an access to the PL watershed and most kinds of land-use there have been restricted due to frontier protection (from World War II to 1989) and the designation as a protected area (since 1963).

Sampling and analyses

Soils were sampled in spruce forest between 1120 and 1355 m a.s.l. at 12 sites (PL1 to PL12) representative for a particular part of the PL watershed (Fig. 1). Two additional sites (PL13 and PL14) were sampled in close vicinity to the PL watershed at elevation of ~1100 m a.s.l. in the beech stands. Sampling was performed in September 1997, May to September 1999, and May 2001 (Table 1). Soil samples were taken from 0.25 m² pits (50×50 cm), excavated to the bedrock. All stones of the diameter >2–5 cm were removed and weighted separately. Soil from each horizon was taken separately, weighted, and mixed and a representative (1–2 kg)

Table 1. List of samples and horizons taken in the Plešné Lake watershed (spruce stands, samples PL1 to PL12) and in the close sites (beech stands, profiles PL13 and PL14) and their major physical soil characteristics. Not determined, n.

Profile	Date	Sampling				Soil characteristics[2]				
		Horizons	Coordinates[1]		Depth	Total	Stones		H₂O	Soil	LOI
			N	E	Alt.(m)	pool	Large	Small			
					m		kg.m²				%
PL1	May 99	O,A,E, Bh, Bs	48.7752	13.8680	1130	0.59	642	420	61	174	167	23
PL2	Jun 99	O,A,E, Bh, Bs	48.7711	13.8632	1315	0.50	611	280	47	134	150	19
PL3	Jul 99	O,A,E, Bh, Bs	48.7723	13.8575	1355	0.50	372	94	59	83	136	24
PL4	Aug 99	O,A,E, Bh, Bs	48.7760	13.8618	1140	0.46	496	180	50	106	152	21
PL5	Sep 99	O,A,E, Bh, Bs	48.7779	13.8581	1260	0.35	646	180	97	133	235	11
PL6	May 01	O,A,E, Bh, Bs	48.7732	13.8656	1165	0.54	784	389	135	111	148	19
PL7	Sep 97	A, E, Bh, Bs	48.7747	13.8600	1190	0.40	n	n	n	n	n	n
PL8	Sep 97	A, E, Bh, Bs	48.7754	13.8595	1250	0.50	n	n	n	n	n	n
PL9	May 01	O, A, Ae, C	48.7766	13.8547	1328	0.31	241	2	70	100	69	26
PL10	May 01	O, Ae, Bvs, C	48.7752	13.8620	1110	0.73	1099	463	184	192	259	12
PL11	May 01	O, Ae, C	48.7756	13.8577	1262	0.41	418	80	98	106	134	22
PL12	Sep 97	A, Ae, C	48.7745	13.8617	1120	0.45	n	n	n	n	n	n
PL13	May 01	O, A, AB₁, AB₂	48.7731	13.8699	1135	0.67	1238	531	273	169	264	10
PL14	May 01	O, A, AB₁, AB₂	48.7806	13.8627	1100	0.60	836	132	252	185	266	11

[1] Longitude and latitude are given in the WGS-84 coordinatesrelief; altitude (Alt.) is in m a.s.l.
[2] Soil characteristics refer to: Large stones (>50 mm), Small stones (2–50 mm), H₂O (loss on drying at 105°C), Soil (dry weight soil fraction <2mm), LOI (vertically homogenized loss on ignition at 550°C).
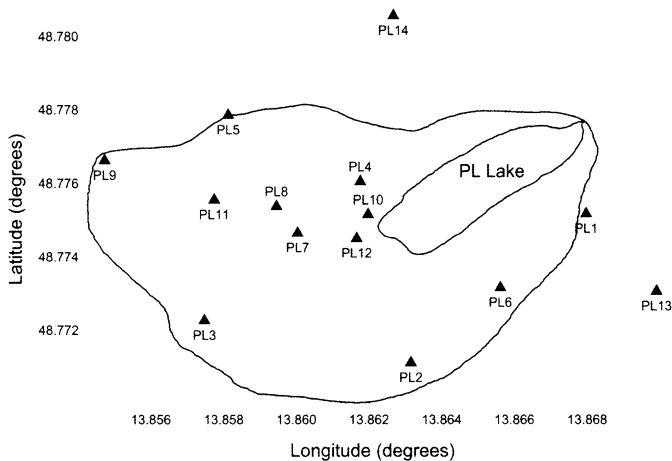
Fig. 1. Map of the Plešné Lake watershed with the location of sampling pits.

sample was taken and put in a plastic bag for chemical analyses. In the cases where the pit was not a regular quadrangular prism, the area for individual horizon was measured. The thickness of horizons was measured in every corner and in the middle of every side of the pit and the average value was calculated. Number of samples, which were taken from the pit, depended on the soil profile development. For the purpose of this study, we use the following classification of horizons. (i) In podzol, samples were taken from the organic litter layer consisting predominantly of decaying spruce needles, branches, and bark (O horizon), the uppermost mineral horizon with accumulated humified organic matter (A horizon); eluvial grey horizon with low content of organic matter (E horizon); dark upper layer of B horizon rich in illuvial organic matter (Bh horizon); and rusty-brown low part of B horizon rich in illuvial Fe oxides (Bs horizon). (ii) In spodo-dystric cambisol, samples were taken from O horizon, A horizon (if well distinguishable from the following Ae horizon), Ae horizon (organic rich mineral horizon), and all existing distinguishable mineral horizons (Bsv, C). (iii) In undeveloped soil on steep slopes and thin soils with no distinguishable diagnostic mineral horizons (lithosol and/or regosol), samples were taken from O horizon and, if present, from A horizon. (iv) In the beech stands (cambisol), samples were taken from the organic litter layer, consisting predominantly of decaying leaves (O horizon), the uppermost mineral horizon with accumulated humified organic matter (A horizon), and 2 other distinguishable mineral horizons (AB1 and AB2).

Chemical and physical analyses

Soil samples were stored at 4°C in the dark until used. In the laboratory, samples were weighted, passed through a 5-mm stainless-steel sieve to remove coarse particles (stones and roots), and weighted again. Then, the soil samples were dried between two sheets of filter paper for 14–21 days at laboratory temperature and weighted. The air-dried sample were sieved through a stainless-steel 2-mm sieve and weighted. The air-dried <2-mm soil fraction is further referred as AD. Subsamples of AD soils for elemental analyses were finely ground to pass through a 100-µm sieve and homogenized.

Soil texture was determined for eight mineral horizons of pits (PL7, PL8, and PL12) in samples dispersed by boiling with sodium hexametaphosphate in distilled water (HORÁČEK et al. 1994). The content of sand, silt, and clay was calculated as percentage by weight of particles >60 µm (determined by wet sieving), from 2 to 60 µm, and <2 µm in diameter, respectively. The clay fraction was determined by sedimentary analysis according to TUČEK (1983). More details are given by KAŇA (2001).

Chemical soil properties were determined as follows: Dry weight (DW) and loss on ignition (LOI) were obtained by drying at 105°C for 2 hours and combustion at 550°C for 2 hours in an oven, respectively, of a finely ground AD subsample. Total P was determined by HNO_3 and $HClO_4$ digestion of the finely ground AD soil according to KOPÁČEK et al. (2001b). Carbon (C) and nitrogen (N) were determined by CN analyzer (NC 2100, ThermoQuest, Italy), and total sulfur (S) by ignition of finely ground AD soil with MgO and Na_2CO_3 at 800°C followed by precipitation of liberated sulfate as $BaSO_4$ (Eschka method, ISO 334 International Standard). Total content of metals was analyzed by the flame atomic absorption spectrometry (Ca, Mg, Na, K, Fe, Mn, and Ti) and/or volumetric titration (Al) after mineralization of finely ground AD soil with H_2SO_4, HNO_3, and HF (200°C, 2 hours). Concentration of SiO_2 was calculated as the difference between DW and LOI and concentration of metal oxides (CaO, MgO, Na_2O, K_2O, Al_2O_3, Fe_2O_3, MnO, and TiO_2). This estimation was compared to the gravimetrically measured SiO_2 concentrations determined in 15 samples within the 3–12 mol.kg^{-1} concentration range (VESELÝ & KOPÁČEK – unpubl.). The relation between the measured SiO_2 concentrations (x) and calculated values (y) was tight ($y = 1.005x + 2.0$; n=15; r=0,998), suggesting reasonable results from this estimation.

The pH was measured in both distilled water (pH$_{H_2O}$) and 0.01M $CaCl_2$ solution (pH$_{CaCl_2}$), with a mass ratio of the AD soil to liquid phase of 1:5 after 2.5-hour extraction (horizontal shaker).

Exchangeable base cations (BC$_{Ex}$ = sum of Ca$^{2+}_{Ex}$, Mg$^{2+}_{Ex}$, Na$^+_{Ex}$, and K$^+_{Ex}$) and exchangeable acidity (Al$^{3+}_{Ex}$ and H$^+_{Ex}$) were determined by extracting 2.5 g of AD soil with 50 ml of a 1M NH$_4$Cl and a 1M KCl solution, respectively. In the extracts, base cations were measured by inductively coupled plasma spectrometry (PU 7450, Leemans Labs Inc., USA) and Al$^{3+}_{Ex}$ and H$^+_{Ex}$ were determined according to THOMAS (1982). Cation exchange capacity (CEC) was the sum of BC$_{Ex}$, Al$^{3+}_{Ex}$, and H$^+_{Ex}$, and all concentrations were expressed on an equivalent basis (meq.kg^{-1}; 1 equivalent is 1 mole of charge). Base saturation was given as a percentage of BC$_{Ex}$ in CEC. In addition, cation exchange capacity was also determined according to SANDHOFF (1954) by extracting 5 g of AD soil with 0.1M HCl and, after complete Cl$^-$ washing out, by conductometric titration of the sample with 0.1M Ba(OH)$_2$. This method provides an estimate of the total cation exchange capacity (CEC$_T$) due to high pH and complete dissociation of organic acids.

Oxalate-extractable Fe (Fe$_{Ox}$), Al (Al$_{Ox}$) phosphorus (P$_{Ox}$), and soluble reactive phosphorus (SRP$_{Ox}$) and citrate-dithionite extractable Fe (Fe$_{CD}$) and Al (Al$_{CD}$) were determined by extraction 0.5 g of AD soil with 50 ml of acid ammonium oxalate solution (0.2M $H_2C_2O_4$ +

$0.2 M$ ($NH_4)_2C_2O_4$ at pH 3) and citrate-dithionite solution ($0.09 M$ $Na_2S_2O_4$ + $0.57 M$ $Na_3C_6H_5O_7.2H_2O$), respectively, according to CAPPO et al. (1987). In the extracts, Fe_{Ox}, Al_{Ox}, Fe_{CD}, Al_{CD}, and P_{Ox} were determined according to KOPÁČEK et al. (2001b) and SRP_{Ox} colorimetrically (WOLF & BAKER 1990).

The above extraction procedures with NH_4Cl, KCl, oxalate, and citrate-dithionite solutions were performed in 3 steps at laboratory temperature as follows: (i) Soil sample was shaken (1 hour) with 20 ml of extracting solution in a capped 50-mL polyethylene centrifuge tube, then, centrifuged (10 min, 2 500 min⁻¹) and supernatant was decanted. (ii) The previous step was repeated with 15 ml of fresh extracting solution. (iii) The previous step was repeated with 15 ml of fresh extracting solution but the sample was shaken overnight (15 hour). Supernatants from the 3 steps were combined, stored in a polyethylene flask and filtered with membrane filters for base cations and with glass-fiber filters for other analyses.

Water extractable sulfate (SO_4–S) was determined according to ALEWELL (1998) by extracting of the wet samples (<5-mm) in 7–8 extraction steps (lasting 12 hour each) at laboratory temperature. Liberated sulfate was analyzed by ion chromatography (Dionex IC25, USA). Water extractable SO_4–S was measured only in samples taken in 2001, i.e., (i) in the A, E, Bh, and Bs horizons of the podzol profile PL6, (ii) in the A, Ae, and C horizons of spodo-dystric cambisol, prepared by mixing of 100 g subsamples from the identical horizons of the profiles PL9, PL10, and PL11, and (iii) in the A, AB1, and AB2 horizons of cambisol in the beech stands, prepared by mixing of 100 g subsamples from the identical horizons of the profiles PL13 and PL14.

Two representative samples of bedrock (granite) were taken in May 1997 (Czech Geological Survey in Prague). The samples were crashed and the size fractions between 0.125 and 0.2 mm was used for analyses of total contents of P, S, Ca, Mg, Na, K, Si, Al, Fe, Mn, and Ti after mineralization with H_2SO_4, HNO_3, and HF (200°C, 2 hours).

Biochemical analyses

Concentrations of C, N, and P in soil microbial biomass (C_{MB}, N_{MB}, P_{MB}) were measured by chloroform fumigation (JENKINSON & POWLSON 1976) of wet samples (<5-mm, 10 g), followed by extraction with 40 ml of $0.5 M$ K_2SO_4 (C_{MB} and N_{MB}) or with 200 ml of $0.5 M$ $NaHCO_3$ (P_{MB}), and filtration (Whatman, No 42). In the filtrate, concentrations of C, N, and P were determined by dichromate oxidation (VANCE et al. 1987), alkaline persulfate oxidation (CABRERA & BEARE 1993), and phosphomolybdate blue method (BROOKES et al. 1982), respectively.

Potential nitrification (N_{Nitr}) and N mineralization (N_{Min}) was determined according to ŠANTRŮČKOVÁ et al. (2002) by incubation of the wet soil samples (<5-mm, 20 g) under oxic conditions for 1 and 3 weeks. The NH_4^+ and NO_3 concentrations in $2 M$ KCl extract were analyzed by flow injection analyzer (Tecator FIAStar 5020) after 1 a 3 weeks of incubation. Daily net nitrification and N mineralization rates were calculated as the difference between final and initial NO_3 and NH_4^+ concentration, respectively, divided by the number of days.

Carbon mineralization rate (C_{Min}) was determined according to ŠANTRŮČKOVÁ et al. (1993). Ten grams of AD soil (<2 mm) were wetted and incubated at 25°C in the sealed glass bottle. Evolved CO_2 was trapped in $0.5 N$ NaOH and was determined by volumetric titration seven times during the 21-day incubation. Then, the cumulative soil respiration was calculated.

All chemical and biochemical results further reported in this paper were recalculated per the DW <2 mm soil samples. All abbreviations of soil constituents and analytical methods are summarized in Table 2.

Grid sampling of soils

The soil depth and type in the PL watershed was estimated from May to November 1999 by pushing a steel soil corer down to the bedrock (twice within ~10 m²) at each node in the 50 by 50 m grid. In the steep and less accessible western part of the lake wall, the sampling was not performed in the regular grid but was more random and less thick. In the total, the maximum depth of soil cover and depths of individual horizons were measured in 460 cores within the whole PL watershed.

Regionalization of soil properties

The vertical heterogeneity of soil properties within a soil profile was 'homogenized' to provide one set of soil parameters for each pit. This vertical weighting procedure, providing the pools of soil component (M: mol.m⁻²) and its average homogenized concentration (C; mol.kg⁻¹) were calculated for the whole pit from the following equations (1 and 2):

$$M = \sum C_i A_i \tag{1}$$

$$C = \left(\sum C_i A_i \right) / \sum A_i \tag{2}$$

Table 2. List of abbreviations and analytical methods used in this study.

Soil constituent	Analytical method
DW	Dry weight at 105°C
LOI	Loss on ignition at 550°C
C	Total (organic) carbon
N, P, S	Total nitrogen, phosphorus, and sulfur
Ca, Mg, Na, K, Al, Fe, Mn, Ti, and Si	Total content of metals after mineralization with H_2SO_4, HNO_3, and HF
pH_{H_2O}	pH in water; 1:5; 2.5-hour extraction
pH_{CaCl_2}	pH in 0.01M $CaCl_2$; 1:5; 2.5-hour extraction
BC_{EX}	1M NH_4Cl extractable base cations (sum of Ca^{2+}_{EX}, Mg^{2+}_{EX}, Na^+_{EX}, and K^+_{EX}).
Ca^{2+}_{EX}, Mg^{2+}_{EX}, Na^+_{EX}, and K^+_{EX}	1M NH_4Cl extractable Ca^{2+}, Mg^{2+}, Na^+, and K^+
Al^{3+}_{EX} and H^+_{EX}	1M KCl extractable Al^{3+} and H^+
CEC	Cation exchange capacity: the sum of BC_{EX}, Al^{3+}_{EX}, and H^+_{EX}
CEC_t	Total cation exchange capacity (SANDHOFF 1954)
Fe_{OX}, Al_{OX}	Oxalate-extractable Fe and Al
P_{OX}, SRP_{OX}	Oxalate-extractable phosphorus and soluble reactive phosphorus
Fe_{CD}, Al_{CD}	Citrate-dithionite extractable Fe and Al
SO_4-S	Water extractable sulfate (ALEWELL 1998)
C_{MB}, N_{MB}, P_{MB}	Concentrations of C, N, and P in soil microbial biomass (JENKINSON & POWLSON 1976)
C_{Min}	Carbon mineralization rate (ŠANTRŮČKOVÁ et al. 1993).
N_{Min}, N_{Nit}	Nitrogen mineralization rate and potential nitrification (ŠANTRŮČKOVÁ et al. 2002)
PL	Plešné Lake
WWM	Watershed weighted mean
meq.kg⁻¹	mmol(+).kg⁻¹; 1 equivalent is 1 mole of charge

where C_i is concentration of the component (mol.kg^{-1}) in the individual horizon (i) and A_i the amount (kg.m^{-2}) of the DW <2 mm soil fraction in this horizon.

Watershed weighted soil parameters were obtained by their weighting according to their spatial coverage in the watershed, assuming 3 dominant types of soil cover (podzol, spodo-dystric cambisol, and undeveloped organic rich soils with only O and A horizons covering the rocks):

$$A_{WWM} = (A_{POD} X_{POD} + A_{CAM} X_{CAM} + A_{ORG} X_{ORG}) / 100 \qquad (3)$$

$$C_{WWM} = (M_{POD} X_{POD} + M_{CAM} X_{CAM} + M_{ORG} X_{ORG}) / (100 A_{WWM}) \qquad (4)$$

In the equations (3) and (4), A_{WWM} (kg.m^{-2}) and C_{WWM} (mol.kg^{-1}) is watershed weighted mean (WWM) amount of the DW <2 mm soil and WWM concentration of the individual soil parameter, respectively. The M_{POD}, M_{CAM}, and M_{ORG} represent the average pool of soil component (mol.m^{-2}) and A_{POD}, A_{CAM}, and A_{ORG} the average amount of DW <2 mm soil (kg.m^{-2}). The abbreviations POD, CAM, and ORG refer to podzol, spodo-dystric cambisol, and undeveloped organic rich soil, respectively. The M_{POD}, M_{CAM}, A_{POD}, and A_{CAM} values were calculated as the geometrical mean for all M and A data on podzol and/or spodo-dystric cambisol in the watershed. The M_{ORG} and A_{ORG} were geometrical means for all O and A horizons (sampled in profiles of podzol and spodo-dystric cambisol) in the watershed and were recalculated from the average depths of these horizons in the pits proportionally to their average depths, measured by grid sampling. The X_{POD}, X_{CAM}, and X_{ORG} values represent a per cent spatial coverage of the respective soil types in the watershed and the coefficient of 100 is 100%. The X values are based on the grid sampling. The watershed weighting generates a single value for each parameter, which is both depth and spatially weighted across the watershed and represents a hypothetical situation when all soils are uniformly distributed over the whole watershed.

The average compositions of podzol (C_{POD}), spodo-dystric cambisol (C_{CAM}), and undeveloped organic rich soil (C_{ORG}) in the watershed were calculated as geometrical means of all particular C_i values. The variability in composition of individual soil horizons was evaluated by coefficients of variation of the mean. In this calculations and further in the text, the Bsv and C horizons of spodo-dystric cambisol were evaluated together as C horizons.

RESULTS AND DISCUSSION

Physical soil characteristics

Results on soil depth and type distribution within the PL watershed are given in Table 3 and Fig. 2. The grid sampling showed that soil cover was dominated (38%) by the undeveloped thin organic rich soil (O and A horizons), covering the rocks and being 0.20±0.13 m deep (average ± standard deviation). Podzol and spodo-dystric cambisol covered 29% and 27% of the watershed, respectively, and were both ~0.45±0.25 m deep. Wetlands and bare rocks covered ~1% and 5% of the watershed, respectively. However, the real soil distribution in the watershed was more heterogeneous than can be deduced from Fig. 2. There were often all types of soil and different depths even in the same node of grid. In that case, the deepest core was used for construction of Fig. 2. Consequently, the type and depth distributions given in Fig. 2 represent areas of their most probable (but not exclusive) occurrence. That is why, some podzol profiles were sampled even in the areas with the dominant occurrence of spodo-dystric cambisol (compare Figs. 1 and 2). Similarly, the total number of sites with undeveloped thin soil was higher than shown in Fig. 2 and this type of soil cover could be find in the whole watershed.

Of the 12 pits sampled in the PL watershed, 8 were in podzol and 4 in spodo-dystric cambisol (Table 1). Characteristic podzol with well distinguishable gray E, dark Bh, and rusty brown Bs horizons was developed in pits PL1 to PL8. Spodo-dystric cambisol with deep Ae horizons, exhibiting transition between A and E horizons with respect to the high content of organic matter and presence of light grains of resistant minerals, were found in pits PL9 to PL12. The mineral C horizons, underlying Ae horizons, showed signs of illuvial concentration of Fe in some pits and cores in the grid sampling. Two pits (PL13 and PL14) were dug in the beech stands and their soil can be determined as cambisol. Below the A horizon, there were well distinguishable 2 mineral horizons (AB1 and AB2) with continuously decreasing content of organic matter.

Total amount of material in the soil profiles varied between 241 and 1099 kg.m⁻³. Of this amount, 2–463 and 47–184 kg.m⁻³ were stones >50 mm and 2–50 mm in diameter, respectively, and 83–192 kg.m⁻³ was moisture. Pools of the <2-mm DW soil fraction varied between 69 and 259 kg.m⁻². Similar proportion of stones, moisture, and fine soil were found also in pits under the beech stands (Table 1). These figures show the dominance of stones (49%) in the dug material, while fine soil and moisture represented on average 28% and 23%, respectively. The average homogenized LOI concentrations varied between 10% and 26%, being lower in beech than in spruce sites (Table 1). This difference resulted from (i) higher pools of mineral soil (poor in organic matter) in the profiles below the beech stands (see later) and (ii) a generally higher degradability of beech than spruce litter. The pits in podzol and spodo-dystric cambisol had comparable proportion of fine soil, but podzol had a higher average proportion of stones (50% vs. 44%) and a lower proportion of moisture (21% vs. 28%) than spodo-dystric cambisol. The average amount of the <2-mm DW soil fraction was 162, 134, and 23 kg.m⁻² for podzol, spodo-dystric cambisol, and undeveloped organic soil, respectively, with the WWM of 92 kg.m⁻².

The particle size distribution was comparable in mineral horizons of podzol and cambisol, with the dominant contribution of sand (~75%), and the clay fraction of ~2% on average. The

Table 3. The percent distribution of major soil types (undeveloped organic rich soil, ORG; podzol, POD, spodo-dystric cambisol, CAM; wetland, WET; and rocks) in the Plešné Lake watershed (Part a) and the averages and quartiles of soil depth in individual horizons (Part b). The results are based on the grid sampling in the 50 by 50 m grid. Number of observations, No.

Part (a)	Unit	Soil type					
		All types	ORG	CAM	POD	WET	ROCK
No		480	185	130	137	4	24
Watershed cover	%	100	38	27	29	1	5

Part (b)	Unit	Total depth	Horizons					
			O	A	Ae	E	Bh	Bs	C
No		452	442	305	128	134	70	70	56
Average	cm	34	14	8	24	12	7	12	16
Standard Dev.	cm	22	12	7	17	8	7	7	12
Minimum	cm	1	1	1	5	2	1	2	5
25%	cm	15	5	5	10	7	4	5	10
Median	cm	30	10	6	20	10	5	11	15
75%	cm	49	18	10	30	15	9	15	20
Maximum	cm	100	80	55	80	40	45	35	60

Table 4. Soil texture (relative distribution) in mineral horizons from podzol (PL7 and PL8) and spodo-dystric cambisol (PL12) profiles in the Plešné Lake watershed.

Profile	Horizon	Sand (>60 μm), %	Silt (2–60 μm), %	Clay (<2 μm), %
PL7	E	76.3	22.5	1.2
PL7	Bh	64.9	32.9	2.2
PL7	Bs	75.5	23.1	1.4
PL8	E	75.4	23.3	1.2
PL8	Bh	79.3	18.6	2.1
PL8	Bs	83.0	16.4	0.7
PL12	Ae	76.3	23.0	0.7
PL12	C	67.1	30.5	2.4

highest content of clay (2.2%) was in Bh horizons (Table 4). This particle size distribution differs from data by PODRÁZSKÝ et al. (2000), who have reported clay content between 4% and 10% in B and C horizons in the profiles sampled along to the elevation gradient of the Plechý massif. However, our data are similar to the results from nearby site at Trojmezná, with the clay content of mineral horizons varying between 3.2% and 3.8% (F. NOVÁK – pers. comm.).

The total soil depths, determined by coring in the individual nodes of the grid, varied from 0.01 to 1.0 m and are shown in Fig. 2. The WWM soil depth in the PL watershed was comparable both in pits (0.33 m) and grid sampling (0.34±0.22 m). In contrast, average depths of O, Ae, and E horizons measured by grid sampling were higher, while the B horizons were found thinner than in the pits (Tables 3 and 5). The WWM depth of individual horizons measured in the grid sampling was: O, 0.13 m; A, 0.06 m; Ae, 0.07 m; E, 0.04 m; Bh, 0.01 m; Bs, 0.02 m; and C, 0.02 m. These values differ from the average horizon depths in Table 3 and represent a hypothetical uniform distribution of all soil types over the whole watershed (i.e., depth of horizons not found in the individual cores was set to zero for the purpose of the calculation).

Chemical soil characteristics

A detailed list of chemical properties of the soil from profiles sampled in the 14 pits in the PL watershed and its surrounding is given in Appendix 1. The average composition of the individual horizons and WWM soil parameters are summarized in Table 5.

Concentration of organic C was the dominant parameter, affecting most of soil properties. The C concentrations positively correlated with N, S, exchangeable base cations and H^+_{Ex} ($P<0.001$ for all relationships) and negatively with pH (Fig. 3). Highest C and N concentrations were found in O horizons (38–43 and 1.3–1.6 mol.kg^{-1}, respectively) and lowest in E and C horizons (1.3–4.1 mol.kg^{-1} of C and 0.07–0.26 mol.kg^{-1} of N). The Bh horizons were substantially enriched by the illuvial C and N (2.5–10 and 0.10–0.54 mol.kg^{-1}, respectively) compared to the upper E horizons and underlying Bs horizons (Table 5). In spodo-dystric cambisol and cambisol, the C and N concentrations generally decreased with depth (Appendix 1). The WWM pool of C and N was 936 and 39 mol.m^{-2}, i.e., 112 and 5.5 t.ha^{-1}, respectively.

The C:N ratios decreased from the O horizons (25–33) to the A, Ae, or AB horizons (18–29) along with the decreasing concentrations of organic carbon (Fig. 3h) but were highest in Bs horizons probably due to the adsorbed humic acids (with low N content) on Al and Fe oxides (see later). The relatively low average C:N ratio (24) in the upper (O and A) horizons suggests a high risk of the elevated NO_3^- leaching from the PL soils, similarly to other Euro-
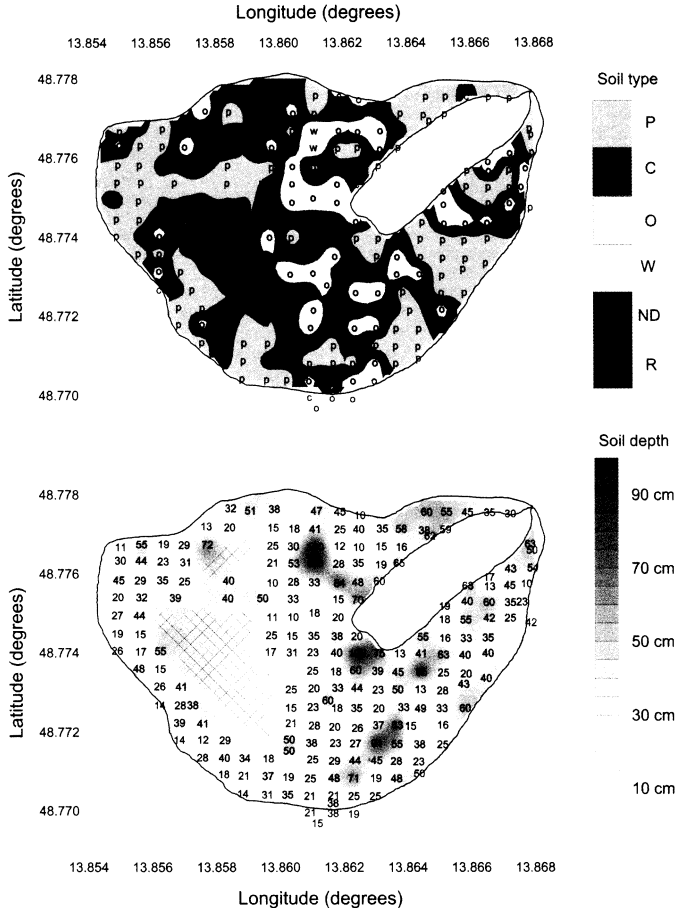
Fig. 2. Soil map of the Plešné Lake watershed with the areas of dominant occurrence of soil types (upper panel) and soil depths (lower panel). Abbreviations in upper panel refer to podzol (p), spodo-dystric cambisol (c), undeveloped organic rich soil (o), wetland (w), not-determined area (ND), and rocks (r) and are situated in the 50 by 50 m grid. The crossed area is steep lake wall. Numbers in lower panel represent maximum soil depth in each node of grid.

pean forest sites with C:N<25 (DISE et al. 1998, GUNDERSEN et al. 1998). In fact, the PL watershed assimilated only ~16% of the ~15 kg.ha^{-1} of inorganic nitrogen deposited on the forest floor by atmospheric deposition in 2000. Moreover, the NO$_3^-$ concentrations were elevated in all streams in the PL watershed even in the growing season, suggesting a pronounced stage of nitrogen saturation of this forest ecosystem (KOPÁČEK et al. 2001c).

Highest S concentrations were found in the O horizons (51–75 mmol.kg^{-1}) and lowest (one order of magnitude lower) in E and C horizons. The dominant S pool was associated with mineral horizons (60% on average) in podzol and with Ae horizons (70%) in spodo-dystric cambisol. Despite the higher S concentrations in the organic O and A horizons they represented lesser S pool than mineral horizons due to the lower amount of soil. The WWM pool of S was 1.6 mol.m^{-2} (i.e., 524 kg.ha^{-1}). The tight correlation between C and S (Fig. 3b) implicated the dominance of organically bound S in the total S pool in the PL soils, which is a common feature of forest soils even in areas exposed to the elevated atmospheric deposition of sulfate (e.g., JOHNSON & LINDBERG 1992).

Concentrations of water extractable SO$_4$–S were two orders of magnitude lower than total S, being respectively (i) 0.48, 0.07, 0.15, and 0.28 mmol.kg^{-1} in the A, E, Bh, and Bs horizons of the profile PL6; (ii) 0.32, 0.18, and 0.10 mmol.kg^{-1} in the A, Ae, and C horizons of spodo-dystric cambisol; and (iii) 0.36, 0.26, and 0.24 mmol.kg^{-1} in the A, AB1, and AB2 horizons of cambisol in the beech stands. The per cent contribution of SO$_4$–S to the total S pool increased with depth. It was lowest (<0.8%) in the A horizons (despite the highest SO$_4$–S concentrations), but increased up to 3.7% in the Bs, C, and AB2 horizons. This pattern was probably associated with sulfate immobilization in soil by adsorption onto hydrous oxides and sesquioxides in the horizons with the illuvial Fe and Al (see below).

Concentrations of total P generally decreased with depth in spodo-dystric cambisol with the averages of 29 and 14 mmol.kg^{-1} in the O and C horizons, respectively. In podzol, P concentrations decreased from O (26–35 mmol.kg^{-1}) to E (4–9 mmol.kg^{-1}) horizons, and then, increased rapidly in Bh and Bs horizons to 12–66 mmol.kg^{-1} (Apendix 1). The average P concentrations in the individual horizons are given in Table 5. Similar P data and their variations along the podzol profile were observed also at nearby Trojmezná site (NOVÁK et al. 2000). The WWM pool of P was 1.9 mol.m^{-2} (i.e., 584 kg.ha^{-1}), with the dominant storage in Bs and Ae horizons in podzol and spodo-dystric cambisol, respectively.

The relationship between C and P (Fig. 3c) was weaker than that between C and N (or S) due to the high contribution of inorganic P forms (SRP$_{OX}$) to the total P pool (SRP$_{OX}$:P ratio) especially in the B horizons, rich in illuvial Fe and Al. The Fe and Al oxides usually determine the phosphate sorption capacity of soils (e.g., YUAN & LAVKULICH 1994) and can be quantified as concentrations of oxalate and citrate-dithionite extractable Al and Fe. The Al$_{OX}$ and Al$_{CD}$ concentrations were well comparable (Al$_{CD}$ = 1.01×Al$_{OX}$; r = 0.98) for all the samples taken (Appendix 1) but the Fe$_{CD}$ concentrations were consistently 22% higher than Fe$_{OX}$ (Fe$_{CD}$ = 1.22×Fe$_{OX}$; r = 0.98) due to the redox conditions during citrate-dithionite extraction. This extraction liberated on average 66% of total Fe in the samples regardless the horizon (Fe$_{CD}$ = 0.66×Fe; r = 0.91). In contrast, Al$_{OX}$ and Al$_{CD}$ represented <2% of total Al in the E and C horizons, 3–16% in the A, Ae, AB, and Bh horizons, and 5–43% in the Bs horizon. This higher content of Al and Fe oxides in Bs horizons (Appendix 1, Table 5) implies their higher sorption capacity and ability to bind inorganic phosphates (and/or sulfate). In concordance, the SRP$_{OX}$:P ratio varied in a wide range between 0.07 and 0.88 (Fig. 3d), being lowest in E, O and A horizons and highest in Bs horizons with the highest Al$_{OX}$ and Fe$_{CD}$ concentrations (Table 5). Similarly, the SRP$_{OX}$ to P$_{OX}$ ratio increased with concentrations of Al and Fe oxides in the horizons and were highest (0.9 on average) in Bs horizons. Consequently, the P concentrations followed at least two variables. In the organic low horizons (E, Bh, Bs, and C), sig-
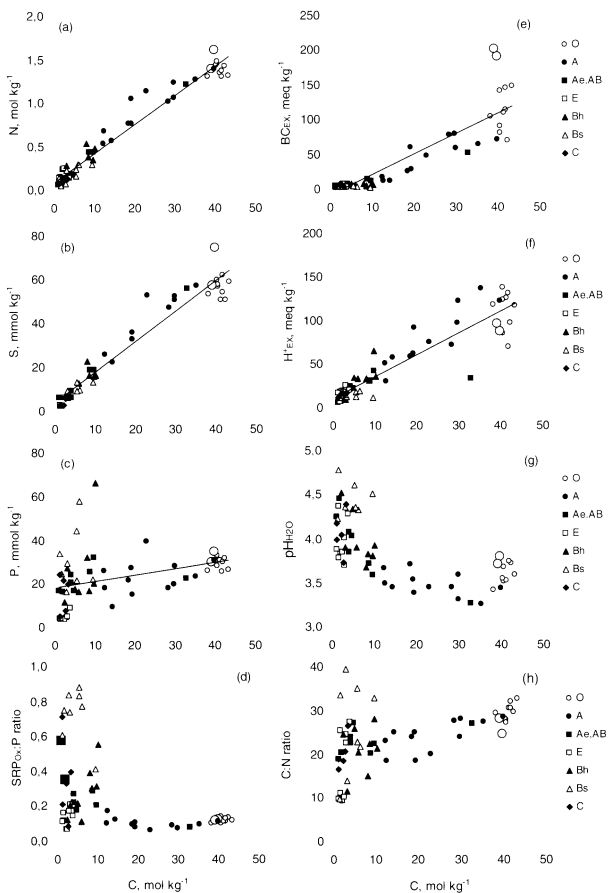
Fig. 3. The relationship between carbon concentration and selected soil characteristics in the soil horizons of Plešné Lake watershed. The large open circles and large full squares in panel (d) represent O and AB2 horizons, respectively, of soil taken in beech forest (PL13 and PL14). Solid lines represent linear regressions between the variables: (a): $y = 0.034x + 0.08$, $r = 0.98$; (b), $y = 1.4x + 3.8$, $r = 0.97$; (c): $y = 0.3x + 18$, $r = 0.36$; (e): $y = 2.9x - 8.3$, $r = 0.89$; (f): $y = 2.5x + 11$, $r = 0.92$.
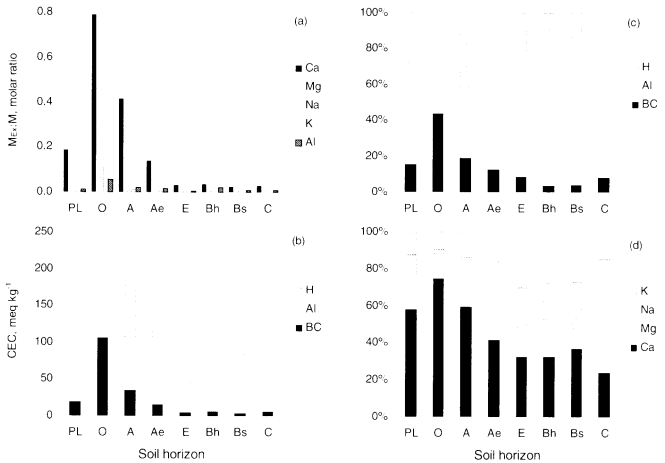
Fig. 4. Exchangeable cations in the soil horizons of Plešné Lake watershed: (a) The molar ratio of exchangeable metals to their total content in soil (M_{Ex}:M); (b) contribution of exchangeable H^+, Al^{3+}, and base cations to the cation exchange capacity; (c) relative contribution of exchangeable H^+, Al^{3+}, and base cations to the cation exchange capacity; and (d) relative contribution of exchangeable K^+, Na^+, Mg^{2+}, and Ca^{2+} to the pool of exchangeable base cations. The columns PL represent watershed weighted mean values.

nificant relationships were found between P and both C ($P<0.01$) and $Al_{Ox} + Fe_{CD}$ ($P<0.001$) concentrations, while in organic rich horizons (O, A, Ae, and AB), the P concentrations correlated predominantly with C ($P<0.01$).

Total soil content of base cations, as well as other components like Si, Al, Fe, Ti, and S in mineral horizons was roughly comparable to the bedrock composition, with the exception of Ca and Na, which were 5-fold and 2-fold, respectively, lower in the soil (Table 5). Moreover, the Ca concentrations followed different pattern than other base cations also along the depth gradient of soil profiles. While concentrations of Mg, Na, and K generally increased from organic to mineral horizons, the Ca concentrations were highest in O and A horizons (37–91 and 15–56 mmol.kg^{-1}, respectively) and lowest (25 mmol.kg^{-1} on average) in the E and C horizons (Appendix 1). This difference resulted predominantly from high concentrations of Ca^{2+}_{Ex} in organic horizons. The molar ratio of exchangeable metals to their total content in soil (M_{Ex}:M) was by far highest for Ca in the organic rich horizons, reaching maximum of 0.8 in the O horizons (Fig. 4a). The M_{Ex}:M ratio of all base cations and aluminum rapidly decreased with decreasing C concentrations to values <0.02 in the mineral horizons. However, even the WWM composition of PL soils exhibited high (~20%) contribution of Ca^{2+}_{Ex} to the total Ca pool (Fig. 4a, left column).

Cation exchange capacity expectedly decreased with decreasing C content (Fig. 4b) due to the tight relationships between C and concentrations of exchangeable base cations (Fig. 3e)

Table 5. Average chemical properties of soils profiles in the Plešné Lake watershed. Abbreviations refer to: WWM. watershed weighted mean; GM. geometrical mean; AVG. arithmetical mean; SD. standard deviation; No. number of observations; and n. not determined. Columns represent: WWM concentrations for Plešné watershed (PL), and average composition of podzol (C_{pzo}), spodo-dystric cambisol (C_{cd}), undeveloped organic rich soil (C_{org}), cambisol below the beech stands ($C_{B(cd)}$), individual soil horizons (C_O, C_A, C_B, C_C, C_{BC}, C_{AC} and C_C), and bedrock (C_{BR}).

	Unit	PL WWM	C_{pzo} GM	C_{cd} GM	C_{org} GM	$C_{B(cd)}$ AVG	C_O AVG±SD	C_A AVG±SD	C_B AVG±SD	C_C AVG±SD	C_m AVG±SD	C_r AVG±SD	C_{BR}
No		12	8	4	12	12	9	10	4	8	8	5	2
Depth	cm	33	46	45	19	19	6±2	7±3	14±7	10±4	5±2	13±8	n
Soil	kg m^{-2}	92	162	134	23	75	5.5±4.7	13±9	53±19	54±19	27±18	61±23	n
LOI	%	25	19	19	75	21	92±3	24±9	31±29	6±2	18±7	14±8	n
C	mol kg^{-1}	10.1	7.3	8.1	32.7	11.3	41±2	24±9	5.9±2.3	12.5±0.2	9.8±1.0	11.7±0.7	12.3
N	mmol kg^{-1}	424	335	351	1180	161	1410±93	961±287	731±338	513±121	511±44	601±94	1054
P	mmol kg^{-1}	20	21	19	24	25	30±3	25±6	42±13	31±21	26±18	16±9	37
S	mmol kg^{-1}	18	14	15	48	10	58±7	42±13	37±14	25±11	15±5	4±2	4.7
Ca	mmol kg^{-1}	31	31	28	40	34	60±18	36±18	36±18	29±9	35±17	26±8	112
Mg	mmol kg^{-1}	53	56	56	21	83	18±3	27±8	41±11	33±5	47±24	71±40	70
Na	mmol kg^{-1}	738	715	902	207	914	57±27	30±15	420±195	91±73	728±101	999±168	1010
Si	mol kg^{-1}	9.3	10.1	9.9	3.2	11.3	0.9±0.4	5.9±2.3	7.6±3.8	12.5±0.5	9.8±0.3	11.7±0.7	12.3
Al	mol kg^{-1}	2.2	2.4	2.4	0.7	2.4	0.2±0.1	1.2±0.5	1.8±1.0	2.3±0.1	2.4±0.1	3.0±0.3	2.8
Fe	mmol kg^{-1}	161	212	110	105	271	49±14	86±29	114±34	57±12	267±116	303±83	147
Mn	mmol kg^{-1}	1.6	1.8	1.4	1.4	2.9	2.3±1.0	2.2±2.0	2.3±1.9	2.0±1.8	1.4±0.7	2.1±1.2	3.0
Ti	mmol kg^{-1}	3.2	31	37	15	45	6.6±2.3	26±6	30±7	34±6	37±8	45±6	19
Ca^{2+}_{ia}	meq kg^{-1}	11.4	6.8	6.3	55.0	5.1	95±36	31±21	8.3±4.1	1.7±0.7	2.1±1.0	1.5±0.4	n
Mg^{2+}_{ia}	meq kg^{-1}	2.9	1.9	2.1	11.5	1.4	16.4±5.1	8.3±4.1	4.4±5.3	0.8±0.1	1.3±0.5	0.5±0.2	n
Na^{+}_{ia}	meq kg^{-1}	2.8	1.5	2.8	3.0	2.9	3.7±1.6	2.5±1.2	2.5±1.2	1.5±1.6	1.3±0.7	2.8±1.8	n
K^{+}_{ia}	meq kg^{-1}	2.5	2.0	2.0	7.0	1.8	11.4±4.1	5.4±2.0	3.4±3.3	1.5±0.3	1.7±0.5	0.9±0.3	n
Al^{3+}_{ia}	meq kg^{-1}	73	80	71	53	76	33±13	77±15	82±24	37±15	141±53	61±20	n
H^{+}_{ia}	meq kg^{-1}	35	29	27	103	19	108±22	82±33	33±8	18±5	33±16	15±3	n
SRP	mmol kg^{-1}	6.9	10.4	3.6	2.7	6.4	3.7±0.6	2.3±0.7	4.8±2.7	0.7±0.4	9.3±11.8	6.9±6.8	n
P_{ia}	mmol kg^{-1}	12	14	11	6	15	7±1	6±4	12±7	2±1	16±15	12±8	n
Al_{ia}	mmol kg^{-1}	158	245	71	52	130	43±10	68±23	81±8	28±20	207±126	91±63	n
Fe_{ia}	mmol kg^{-1}	83	126	40	29	138	32±7	36±23	64±16	11±16	216±121	86±87	n
pH_{H_2O}		3.1	3.2	3.2	2.7	3.6	2.9±0.2	2.7±0.2	3.0±0.3	3.1±0.2	3.3±0.2	3.6±0.2	n
pH_{CaCl_2}		3.8	3.9	3.7	3.5	4.0	3.6±0.1	3.5±0.1	3.7±0.3	4.0±0.2	4.0±0.3	4.1±0.2	n

or protons (Fig. 3f). However, while the CEC of the O and A horizons was dominated by protons and base cations, Al^{3+}_{Ex} represented the principal proportion of CEC in mineral horizons (up to on average ~80% in both B horizons, Fig. 4c). Total cation exchange capacity was determined in 26 samples representing all horizons (except O) and soil types (Apendix 1). The CEC_T concentrations were up to 5-fold higher than CEC, but there was linear relationship between them (CEC = 53 + 0.19×CEC_T; r = 0.91). While the CEC was a more realistic estimation of the real soil exchangeable capacity at ambient conditions, the CEC_T represented the uppermost limit, not accessible at natural conditions (due to high pH during determination). Nevertheless, the high CEC_T to CEC ratios highlighted the dominant role of organic matter in the soil sorption characteristics of the samples studied.

Base saturation is a key variable for the classification of soils with respect to base cation distribution and cycling (JOHNSON & LINDBERG 1992). In the PL watershed, the WWM base saturation was primarily based on Ca^{2+}_{Ex} (58% on average) and the contribution of other base cations was roughly equal (14%). In the individual soil horizons, the relative Ca^{2+}_{Ex} contribution to total BC_{Ex} pool decreased, while that of Na^+_{Ex} increased from organic to mineral horizons (Fig. 4d). Concentration of BC_{Ex} was significantly higher in the O horizons below beech than spruce stands (Fig. 3e). Also this difference was due predominantly to higher concentrations of Ca^{2+}_{Ex}, which were 143 and 163 meq.kg^{-1} in the beech forest floor, while 54–116 meq.kg^{-1} in the spruce forest floor.

To the watershed weighted mean value of CEC (129 meq.kg^{-1}), Al^{3+}_{Ex} and H^+_{Ex} contributed by 57% and 28%, respectively, and the WWM base saturation of the PL soils was 15%.

The pH_{CaCl2} values exhibited similar pattern along the depth profiles of all soils, being 2.7–3.2 in O horizons, lowest in A horizons (2.5–3.1) and increasing with depth to their maxima in Bs or C horizons (3.9 and 3.6 on average, respectively). The pH_{H2O} profiles were comparable to pH_{CaCl2} but were ~0.4–0.8 unit higher (Table 5). The pH_{CaCl2} values of podzol and spodo-dystric cambisol in spruce forest were ~0.5 unit lower than in cambisol under beech stands (Table 5). This difference was primarily due to lower concentration of C (and, consequently, H^+_{Ex}) in beech than in spruce forest soils (Table 5).

Biochemical soil characteristics

Biochemical analyses were performed only in soils sampled or re-sampled (O horizons) in 2001 (Apendix 1), hence, they covered only lesser set of samples and could not be regionalized in the same way as chemical data. Nevertheless, even this limited dataset provided useful information on proportional distribution of nutrients between microbial and total pools, as well as between external N fluxes and internal potential of its utilization.

Concentrations of C, N, and P in soil microbial biomass decreased with soil depth along with concentration of organic matter. Highest concentrations were found in A horizons (O horizons were not analyzed), with C_{MB} of 177±49 mmol.kg^{-1}, N_{MB} of 29±9 mmol.kg^{-1} and P_{MB} of 3.2±0.5 mmol.kg^{-1}. These concentrations represented on average 0.7%, 2.7%, and 11% of total C, N, and P contents, respectively. Ratios of C_{MB}:N_{MB} and C_{MB}:P_{MB} were low and varied from 5 to 7 and from 40 to 55, respectively, in individual horizons. These low C:P and C:N ratios in microbial biomass did not suggest P-controlled carbon mineralization in the PL soils. Moreover, the high content of P in the microbial pool with a short turnover time could be quickly released into the soil solution and then, exported from the watershed.

Interesting information was provided by comparison of the annual atmospheric deposition of inorganic nitrogen with the pools of N_{MB}. For example, N_{MB} pools in the A horizons (125–550 mmol.m^{-2}) were substantially higher than the annual atmospheric deposition of nitrogen (107 mmol.m^{-2} in 2000, KOPÁČEK et al. 2001c). This suggested that factors affecting soil microbial activity (e.g., chemical or climatic changes) could have more important impact on the

terrestrial N cycling (and NO_3^- export) than changes in N deposition and deserve further quantification.

Carbon and nitrogen mineralization was highest in the O horizons, ~2-fold and ~6-fold lower in A and Ae (or AB) horizons and negligible in deeper horizons (Appendix 1). Surprisingly, C_{Min} and N_{Min} were lower in the beech forest floor (12–19 and 0.16–0.20 mmol.kg^{-1}.d^{-1}, respectively) than below the spruce stands (30±9 and 0.24±0.10 mmol.kg^{-1}.d^{-1}, respectively). This disproportion between the measured data and usually lower decomposition rate of spruce needles compared to beech leaves was most probably due to the fact that sampling was carried out in spring, when the beech leaves were already in a progressed stage of decomposition.

Potential nitrification exhibited different pattern than N mineralization. The N_{Nitr} values were highest in the A horizons and were significant even in the organic low horizons (Appendix 1) with the following averages: 0.047±0.036 mmol.kg^{-1}.d^{-1} in the O horizons, 0.079± 0.026 mmol.kg^{-1}.d^{-1} in the A horizons, 0.058±0.032 mmol.kg^{-1}.d^{-1} in the Ae and AB horizons, and 0.011 and 0.046 mmol.m^{-2}.d^{-1} in the E and Bh horizons of profile PL6, respectively. The nitrifying potential of the PL soils was higher than atmospheric fluxes of NH_4-N. Atmospheric deposition of NH_4^+ was 0.12 mmol.m^{-2}.d^{-1} in 2000, i.e. within the range of potential nitrification in the O horizons (0.26±0.30 mmol.m^{-2}.d^{-1}) and about one order of magnitude lower than potential nitrification in the A and Ae horizons (0.86±0.63 and 2.6±0.6 mmol.m^{-2}.d^{-1}, respectively). This high difference suggested that most of atmospherically deposited NH_4-N could be oxidized to nitrate. However, the growth of most nitrifying chemoautotrophic organisms usually requires neutral conditions (pH>6), and only some acid-resistant strains may occur to pH 4.5 (KENNEDY 1992). In the acid soils, heterotrophic nitrification is referred to be of importance (GUNDERSEN & RASMUSSEN 1990). We hypothesize that the low N retention capacity of watersheds of Bohemian Forest lakes and high nitrate export (e.g., KOPÁČEK et al. 2001c) could also resulted from mineralization and heterotrophic nitrification of soil organic N pools. Consequently, a contribution of heterotrophs such as fungi to oxidation of organic N to nitrate (STROO et al. 1986) should be considered in the acid Bohemian Forest soils.

Variability in the measured soil characteristics

Chemical and biochemical composition of the O horizons was most uniform among the horizons sampled, with low coefficients of variation (between 5% and 78%; median of 26%). However, even in other horizons, concentrations of constituents varied in surprisingly narrow ranges with coefficients of variation only exceptionally exceeding 100% (see Table 5 for standard deviations). The highest variability in the chemistry was observed in Ae horizons with coefficients of variation ranging from 9% to 121% (median of 52%). In contrast, relatively high differences in the soil amount between the profiles resulted in higher variability in the pools of soil chemical constituents, which up to three-fold (especially in O and C horizons) exceeded concentration variability. This means that the sampled sites differed primarily in the pools of soil constituents and less in the soil composition, which was relatively uniform in the same horizons within the PL watershed.

CONCLUSIONS

The Plešné Lake watershed is covered with the undeveloped thin (0.2 m on average) organic rich soil (38%) and on average ~0.45 m deep podzol (29%) and spodo-dystric cambisol (27%). Wetlands and bare rocks represent only low proportion (1% and 5%, respectively) of the area.

Total amount of soil varies up to ~1100 kg.m^{-2}, with the average 49%, 28%, and 23% con-

tribution of stones >2mm in diameter, fine soil, and moisture, respectively. The average amount of fine soil is 162, 134, and 23 kg.m^{-2} for podzol, spodo-dystric cambisol, and undeveloped organic soil, respectively, with the watershed weighted mean (WWM) of 92 kg.m^{-2}. Clay content of fine soil is low (~2% on average).

Soils are acid with the lowest pH$_{CaCl2}$ in A horizons (2.5–3.1) and highest (3.2–4.4) in Bs and C horizons (the respective pH$_{H2O}$ values are ~0.4–0.8 unit higher). Exchangeable Al^{3+} (57%) and H$^+$ (28%) dominate the WWM cation exchange capacity (129 meq.kg^{-1}), while base saturation is low (15%). The WWM pools of C, N, S, and P are 936, 39, 1.6, and 1.9 mol.m^{-2}, respectively. The C:N ratios decreases from 25–33 in O horizons, to 18–29 in A or Ae horizons, to <20 in some mineral horizons along with the decreasing concentrations of organic carbon. The WWM C:N ratio is 24 for the whole soil profile.

Concentrations of C, N, and P in soil microbial biomass are on average 0.7%, 2.7%, and 11% of total C, N, and P contents, respectively, suggesting high microbial activity of soil, which is not limited by P availability. Carbon and nitrogen mineralization is highest in the O horizons (30±9 and 0.24±0.10 mmol.kg^{-1}.d^{-1}, respectively), 2 to 6-fold lower in A and Ae horizons, and negligible in deeper horizons. In contrast, the highest potential nitrification (0.08±0.03 mmol.kg^{-1}.d^{-1}) is associated with the A horizons.

The soil in the nearby beech stands sites is cambisol and differs from the soils in the spruce forest in ~50% higher concentrations of exchangeable Ca^{2+} and ~0.2 unit higher pH$_{CaCl2}$ and pH$_{H2O}$ values in the forest floor. Moreover homogenized concentrations of C, and H$^+_{TS}$ in the whole profile of cambisol are ~50% lower and the homogenized pH$_{CaCl2}$ values ~0.5 unit higher than in the spruce forest soils, due predominantly to higher pools of mineral soil (poor in organic matter) in the profiles below the beech stands.

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Appendix 1. Chemical and biochemical properties of soil samples taken in profiles within the Plešné Lake watershed and its vicinity in the 1997–2001 period. For abbreviations of soil horizons and soil constituents see chapter 'Sampling and analyses' and Table 2. Location of soil profiles is given in Table 1 and Fig. 1. All data are expressed per dry weight <2mm soil fraction. Not determined. n.

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Profile	Horizon	Depth (m)	Pool (kg m⁻²)	LOI (%)	pH	pH	C (mg kg⁻¹)	N (mg kg⁻¹)	S	P	Ca (mmol kg⁻¹)	Mg	K (mg kg⁻¹)	Na	Si (mg kg⁻¹)	Al	Fe (mmol kg⁻¹)	Mn (mmol kg⁻¹)	Ti
PL1	O	0.09	10	93.2	2.69	3.47	41.9	1.31	62.0	25.8	57.4	16.4	40	19	0.8	0.2	48	2.1	6
PL1	A	0.09	32	33.7	2.61	3.45	14.4	0.57	22.7	9.6	14.8	25.7	581	251	8.9	1.6	49	0.9	29
PL1	E	0.12	64	4.0	2.95	3.79	1.7		34.9	4.1	19.9	35.3	974	452	12.8	2.4	49	0.9	29
PL1	Bh	0.10	20	23.8	3.28	3.83	8.6	0.38	16.6	16.9	26.5	52.7	669	486	9.1	3.3	426	1.3	39
PL1	Bs	0.20	41	28.0	4.12	4.52	9.7	0.29	13.5	12.5	25.0	50.8	581	480	8.0	2.5	272	1.7	27
PL2	O	0.07	6	92.9	2.88	3.59	43.4	1.32	59.3	26.9	61.8	13.9	43	18	0.9	0.2	42	2.2	4
PL2	A	0.02	5	70.6	2.63	3.59	29.9	1.25	50.8	19.9	40.7	24.2	274	161	3.7	0.8	62	1.2	20
PL2	E	0.16	42	7.4	3.26	4.01	3.1	0.14	6.3	16.7	16.3	37.7	790	340	12.5	2.2	61	1.6	39
PL2	Bh	0.07	31	15.9	3.21	3.91	6.0	0.27	13.1	16.7	33.6	54.5	687	529	10.6	2.4	273	1.8	37
PL2	Bs	0.18	66	18.2	4.08	4.61	5.6	0.25	13.3	44.5	36.0	97.5	574	497	9.5	3.2	402	2.7	32
PL3	O	0.10	17	97.3	2.84	3.52	40.6	1.45	57.1	30.5	36.5	18.7	46	24	0.0	0.2	82	1.1	11
PL3	A	0.05	9	29.5	2.80	3.49	12.7	0.68	25.9	18.3	22.2	41.1	604	347	9.2	1.9	116	0.7	31
PL3	Bh	0.06	39	6.6	3.06	3.85	2.3	0.24	6.4	4.6	20.0	32.9	941	523	12.3	2.5	57	1.0	28
PL3	Bs	0.10	22	21.4	3.08	3.68	8.2	0.54	23.2	32.4	30.3	71.0	627	502	9.8	2.3	306	1.8	30
PL3	Bs	0.06	6	11.7	3.82	4.36	3.3	0.29	9.7	29.7	38.9	118.5	738	653	8.7	2.9	325	3.4	7
PL4	O	0.13	21	92.4	2.77	3.52	41.4	1.36	50.9	30.8	50.4	13.5	489	270	1.0	1.4	60	1.4	27
PL4	A	0.16	67	47.1	2.97	3.85	19.5	1.05	33.1	15.5	24.6	26.3	822	527	7.0	2.5	48	1.3	31
PL4	E	0.05	21	7.6	3.24	3.94	2.7	0.13	6.3	4.2	25.4	30.2	626	600	12.3	2.5	339	1.6	5
PL4	Bs	0.07	38	26.6	3.71	4.32	10.3	0.48	16.7	66.6	38.2	50.4	758	742	9.5	3.1	338	2.0	38
PL4	Bs	0.09	10	17.4	3.16	3.74	3.2	0.29	9.9	58.2	62.4	76.2	758	18	0.8	0.6	47	3.6	50
PL5	O	0.09	10	65.2	2.52	3.74	28.4	1.02	47.5	30.3	83.3	18.8	37	18	4.8	0.1	47	3.8	36
PL5	A	0.09	81	5.6	3.18	3.88	1.4	0.28	3.2	4.4	23.6	40.4	900	137	12.5	2.4	62	0.8	7
PL5	E	0.05	61	10.6	3.28	3.91	3.2	0.28	6.5	27.6	39.1	77.5	758	492	11.4	2.5	255	1.1	19
PL5	Bs	0.07	78	6.1	3.71	4.23	1.5	0.15	3.2	34.2	57.3	120.7	815	528	11.8	2.6	367	2.5	39
PL5	Bs	0.06	7											618	11.8			4.5	40
PL6	O	0.06	7	92.5	2.79	3.55	40.5	1.44	60.2	28.6	42.0	18.6	48	28	0.9	0.5	58	0.9	7
PL6	A	0.07	4	80.5	2.59	3.26	35.3	1.23	57.3	23.5	26.9	18.7	156	76	2.5	0.5	54	0.5	19
PL6	E	0.08	33	8.0	3.00	3.71	3.2	0.13	6.3	5.1	12.6	32.5	974	406	12.3	2.1	44	0.4	39
PL6	Bh	0.06	8	24.3	3.34	3.82	9.8	0.35	16.2	20.4	20.3	43.7	793	514	9.2	2.1	335	0.6	40
PL6	Bs	0.27	97	14.9	3.95	4.37	5.7	0.16	9.7	21.7	27.7	64.2	830	691	10.2	2.7	341	1.6	32

Appendix 1. Chemical and biochemical properties of soil samples taken in profiles within the Plešné Lake watershed and its vicinity in the 1997–2001 period. For abbreviations of soil horizons and soil constituents see chapter "Sampling and analyses" and Table 2. Location of soil profiles is given in Table 1 and Fig. 1. All data are expressed per dry weight <2mm soil fraction. Not determined. n.

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Profile	Horizon	Exchangeable cations (meq.kg⁻¹)						CEC	CEC_B	Oxalate and citrate-dithionite extracts (mmol.kg⁻¹)						Biochemical properties					
		Ca^{2+}	Mg^{2+}	Na^+	K^+	Al^{3+}	H^+			SRP_{ox}	P_{ox}	Al_{ox}	Fe_{ox}	Al_{DC}	Fe_{DC}	C_{mic}	N_{mic} (mmol.kg⁻¹)	P_{mic}	C_{min}	N_{min}	N_{nit} (mmol.kg⁻¹.d⁻¹)
PL.1	O	82.4	18.4	3.5	9.3	43	132	289	n	2.9	5.4	50	25	35	34	n	n	n	25	0.184	0.001
PL.1	A	3.9	3.0	2.9	3.1	64	58	135	430	1.2	2.5	74	10	32	16	n	n	n	n	n	n
PL.1	E	0.9	0.7	1.8	1.5	57	19	81	59	0.5	1.7	27	6	16	2	n	n	n	n	n	n
PL.1	Bh	0.9	1.1	1.4	1.6	190	32	227	778	5.2	10.3	364	312	407	389	n	n	n	n	n	n
PL.1	Bs	0.8	0.3	1.2	1.0	120	13	136	552	9.3	17.3	1418	211	1594	245	n	n	n	n	n	n
PL.2	O	116	17.1	4.1	10.9	33	117	298	n	3.3	3.5	35	18	43	33	n	n	n	30	0.239	0.074
PL.2	A	61.1	11.1	2.7	5.0	80	97	257	n	1.5	4.0	64	21	58	3	n	n	n	n	n	n
PL.2	E	3.1	0.9	1.6	1.6	20	17	44	n	0.8	1.6	24	7	12	2	n	n	n	n	n	n
PL.2	Bh	2.8	1.0	1.6	1.7	139	34	180	n	1.9	4.1	84	234	194	308	n	n	n	n	n	n
PL.2	Bs	2.2	0.5	1.4	1.5	88	19	113	548	37.3	38.8	1016	217	855	270	n	n	n	n	n	n
PL.3	O	58.4	11.6	1.6	7.3	56	138	274	n	3.1	7.2	58	38	43	51	n	n	n	25	0.279	0.053
PL.3	A	5.6	2.5	1.5	3.3	89	31	132	n	3.2	8.8	64	49	19	46	n	n	n	n	n	n
PL.3	E	1.6	0.7	1.9	1.9	34	19	55	70	0.3	1.6	21	4	3	1	n	n	n	n	n	n
PL.3	Bh	2.9	1.9	1.2	2.4	158	34	200	960	12.8	22.3	158	173	200	211	n	n	n	n	n	n
PL.3	Bs	2.1	0.4	0.5	1.1	92	13	109	562	22.0	23.9	363	103	403	179	n	n	n	n	n	n
PL.4	O	79.1	14.8	6.2	9.8	31	126	267	n	3.5	6.4	35	23	31	30	n	n	n	35	0.202	-0.009
PL.4	A	16.0	6.3	0.8	4.8	61	92	181	n	1.7	3.3	48	31	30	2	n	n	n	n	n	n
PL.4	E	1.2	0.8	0.8	1.6	29	19	52	n	0.3	1.2	10	6	2	14	n	n	n	n	n	n
PL.4	Bh	1.5	1.5	0.8	2.2	105	20	230	252	37.2	49.4	305	223	379	252	n	n	n	n	n	n
PL.4	Bs	1.5	0.5	0.6	1.2	105	20	129	188	45.1	49.4	401	164	434	188	n	n	n	n	n	n
PL.5	O	114	18.9	3.7	9.3	17	70	233	n	3.9	7.2	36	21	36	34	n	n	n	19	0.095	0.095
PL.5	A	59.1	12.5	1.8	5.6	84	72	236	n	1.7	3.5	20	18	55	26	n	n	n	n	n	n
PL.5	E	1.3	0.6	0.8	1.5	30	18	51	n	0.5	1.8	21	4	9	1	n	n	n	n	n	n
PL.5	Bh	1.3	1.0	1.7	1.7	83	10	97	136	5.8	19.3	113	89	124	136	n	n	n	n	n	n
PL.5	Bs	1.3	0.6	0.5	1.2	70	15	88	242	21.0	22.8	130	145	163	242	n	n	n	n	n	n
PL.6	O	62.5	17.3	2.2	8.1	45	124	259	n	4.0	7.1	53	26	48	37	n	n	n	30.3	0.159	0.085
PL.6	A	43.7	14.7	5.2	3.5	80	137	282	975	2.3	4.9	82	4	53	16	216	38	3.7	11.7	0.196	0.050
PL.6	E	1.6	0.9	5.2	1.2	26	38	72	1038	1.1	2.5	25	8	8	232	23	3.1	0.6	0.5	-0.007	0.011
PL.6	Bh	1.8	1.2	2.7	1.2	206	66	279	760	6.4	11.8	327	232	380	299	37	6.0	0.8	0.5	-0.002	0.146
PL.6	Bs	1.1	0.5	3.6	0.8	127	13	146	n	19.1	21.8	712	230	548	235	7	1.3	0.1	0.8	0.001	0.001

Appendix 1. Chemical and biochemical properties of soil samples taken in profiles within the Plešné Lake watershed and its vicinity in the 1997–2001 period. For abbreviations of soil horizons and soil constituents see chapter "Sampling and analyses" and Table 2. Location of soil profiles is given in Table 1 and Fig. 1. All data are expressed per dry weight <2mm soil fraction. Not determined. n.

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			Basic soil properties						Total concentrations										
Profile	Horizon	Depth m	Pool kg.m⁻²	LOI %	pH$_{CaCl2}$	pH$_{H2O}$	C mol.kg⁻¹	N mol.kg⁻¹	P	S	Ca mmol.kg⁻¹	Mg	K	Na	Si mol.kg⁻¹	Al	Fe mmol.kg⁻¹	Mn	Ti
PL7	A	0.05	n	41.3	2.69	3.71	18.6	0.77	21.6	n	55.3	18.4	552	360	n	n	110	5.6	n
PL7	E	0.09	n	7.5	3.35	3.59	4.1	0.15	9.0	n	41.8	23.0	956	677	n	n	83	4.8	n
PL7	Bh	0.05	n	13.0	3.46	4.34	5.1	0.19	18.0	n	28.5	12.5	751	468	n	n	146	0.6	n
PL7	Bs	0.06	n	7.2	4.36	5.02	3.1	0.08	16.7	n	14.4	14.9	717	600	n	n	239	1.5	n
PL8	A	0.05	n	81.3	2.48	3.44	40.0	1.39	30.9	n	53.3	23.5	137	115	n	n	71	5.4	n
PL8	E	0.04	n	3.2	3.31	4.37	1.7	0.07	4.2	n	36.6	31.2	975	684	n	n	55	4.8	n
PL8	Bh	0.02	n	6.0	3.59	4.52	2.5	0.10	11.7	n	12.7	10.9	913	462	n	n	59	0.6	n
PL8	Bs	0.05	n	4.7	3.75	4.78	1.8	0.05	24.8	n	18.4	22.4	811	527	n	n	140	1.6	n
PL9	O	0.05	2	96.0	3.12	3.72	42.5	1.43	31.8	50.8	52.3	16.1	35	14	0.4	0.1	31	2.1	3
PL9	Ae	0.07	6	67.0	2.76	3.31	30.0	1.06	28.5	52.4	33.7	23.4	327	203	4.2	0.9	102	0.9	18
PL9	C	0.10	56	20.6	3.21	3.72	8.9	0.44	19.1	19.2	27.3	48.0	539	539	10.1	2.2	140	1.6	36
PL9	C	0.10	4	3.6	3.52	4.00	1.3	0.08	5.4	3.1	21.5	39.8	1062	469	12.7	2.4	58	1.1	41
PL10	Ae	0.03	2	90.1	3.09	3.68	40.6	1.49	32.3	58.0	68.2	18.9	67	39	1.2	0.2	40	3.2	5
PL10	C	0.15	73	21.7	3.12	3.59	9.8	0.44	32.3	19.2	38.3	50.7	878	699	9.5	2.5	142	1.9	32
PL10	Ae	0.54	182	6.6	3.65	4.04	2.4	0.13	21.8	3.2	36.1	77.8	1082	725	11.2	3.2	183	2.1	49
PL10	Bvs	0.01	2	4.9	3.88	4.17	1.4	0.07	24.6	3.2	34.3	98.0	1065	731	11.2	3.3	342	4.1	51
PL11	O	0.03	1	87.6	2.80	3.42	38.3	1.30	26.3	53.6	44.0	21.3	114	55	1.5	0.3	58	1.7	9
PL11	Ae	0.23	29	74.1	2.65	3.27	32.8	1.22	22.7	56.2	18.9	26.2	227	130	3.3	0.7	65	1.2	23
PL11	C	0.15	104	7.1	3.23	3.74	2.8	0.14	8.0	6.3	21.6	67.5	1086	631	11.8	2.7	64	1.4	39
PL12	A	0.07	1	27.5	2.74	3.67	4.9	0.54	26.0	n	56.3	25.7	733	513	n	n	130	5.4	41
PL12	Ae	0.06	n	9.3	3.21	4.04	4.9	0.18	17.2	n	59.4	37.5	948	672	n	n	117	5.1	n
PL12	Ae	0.17	n	10.2	3.60	4.39	3.5	0.13	20.0	n	18.6	20.5	700	461	n	n	294	1.9	n
PL13	O	0.06	3	91.3	3.11	3.80	39.9	1.62	35.0	74.8	77.7	18.9	67	32	1.0	0.2	46	2.5	7
PL13	Ae	0.06	15	52.1	2.92	3.45	23.0	1.15	39.8	53.2	28.5	36.9	257	114	6.1	1.3	114	1.2	31
PL13	AB	0.29	131	9.6	3.44	3.85	4.2	0.17	24.4	6.3	27.2	60.5	1008	524	11.5	2.4	204	2.3	47
PL13	AB2	0.26	116	3.6	3.83	4.25	1.2	0.07	17.1	6.3	30.7	80.3	1005	581	12.4	2.5	261	3.7	41
PL14	O	0.04	2	87.5	3.15	3.54	39.2	1.39	27.7	57.5	90.8	21.5	99	59	1.5	0.3	49	4.0	8
PL14	A	0.07	15	43.7	3.07	3.54	19.3	0.77	27.7	36.0	46.8	41.6	572	396	7.1	1.6	100	2.1	35
PL14	AB	0.25	126	10.7	3.64	4.08	4.3	0.19	20.9	9.5	36.3	88.2	875	583	11.2	2.5	303	2.6	48
PL14	AB2	0.25	123	5.9	4.08	4.45	2.1	0.10	16.6	6.3	39.8	118.2	895	650	11.7	2.6	370	3.4	48

Appendix 1. Chemical and biochemical properties of soil samples taken in profiles within the Plešné Lake watershed and its vicinity in the 1997–2001 period. For abbreviations of soil horizons and soil constituents see chapter "Sampling and analyses" and Table 2. Location of soil profiles is given in Table 1 and Fig. 1. All data are expressed per dry weight <2mm soil fraction. Not determined, n.

Part (4 of 4)

Profile	Horizon	Ca²⁺	Mg²⁺	Na⁺	K⁺	Al³⁺	H⁺	CEC	CEC$_n$	SRP$_o$	P$_o$	Al$_o$	Fe$_o$	Fe$_d$	Al$_d$	C$_{mic}$	N$_{min}$	P$_{min}$	C$_{mic}$	N$_{min}$	N$_{net}$	N$_{net}$
		Exchangeable cations (meq kg⁻¹)								Oxalate and citrate-dithionite extracts (mmol kg⁻¹)						Biochemical properties (mmol kg⁻¹)					(mmol kg⁻¹ d⁻¹)	
PL7	A	12.6	6.6	1.5	5.4	58	59	143	n	2.1	3.9	49	16	43	69	n	n	n	n	n	n	n
PL7	E	1.8	0.8	0.1	1.2	63	21	87	n	1.3	1.3	76	27	48	66	n	n	n	n	n	n	n
PL7	Bh	4.0	2.0	1.0	1.6	103	34	146	n	3.9	10.1	251	122	114	157	n	n	n	n	n	n	n
PL7	Bs	1.3	0.4	1.0	1.1	36	15	55	n	14.0	16.3	529	199	235	562	n	n	n	n	n	n	n
PL8	A	44.9	13.7	4.0	8.4	62	123	256	n	3.6	7.5	84	32	51	84	n	n	n	n	n	n	n
PL8	E	1.7	0.6	<0.5	1.1	32	8	43	n	0.7	1.0	10	7	7	12	n	n	n	n	n	n	n
PL8	Bh	1.5	0.5	0.7	1.0	64	18	85	n	1.5	3.6	50	11	19	51	n	n	n	n	n	n	n
PL8	Bs	2.8	0.6	1.2	1.2	53	12	70	n	18.6	22.7	117	32	76	172	n	n	n	n	n	n	n
PL9	O	54.5	3.6	0.4	10.9	8	97	179	n	4.4	7.3	32	14	22	26	185	19	3.6	43.2	13.1	0.459	0.010
PL9	A	40.1	9.2	4.0	5.9	82	122	263	587	2.2	5.1	76	56	62	68	n	n	n	13.1	n	0.024	0.084
PL9	Ae	4.2	2.0	7.0	2.2	68	31	115	406	7.4	16.4	88	46	54	72	n	n	n	1.1	n	-0.005	0.035
PL9	C	1.2	0.4	2.9	1.0	25	12	42	60	1.2	2.8	21	7	9	11	n	n	n	0.4	n	0.000	0.024
PL10	A	110	16.8	3.2	11.7	21	85	248	n	4.8	9.0	37	18	26	40	n	n	n	31.3	n	0.217	0.065
PL10	Ae	6.6	2.2	1.9	1.3	69	43	124	318	6.7	19.0	73	40	58	78	n	n	n	1.8	n	0.170	0.045
PL10	Bvs	1.4	0.5	5.5	0.8	65	17	91	211	7.2	18.0	84	34	62	92	n	n	n	0.6	n	0.002	0.004
PL10	C	2.0	0.6	1.0	0.5	66	119	82	197	17.6	22.1	127	121	139	101	n	n	n	0.4	n	0.003	0.001
PL11	O	66.9	18.9	4.3	14.2	34	34	257	1015	2.8	4.6	88	26	33	92	189	39	3.6	32.5	n	0.341	0.013
PL11	Ae	26.7	12.3	1.3	8.2	72	15	94	n	0.7	5.3	47	7	57	41	n	n	n	8.6	n	0.127	0.095
PL11	C	1.7	0.8	<0.5	1.3	74	51	151	151	2.6	4.8	60	40	88	74	n	n	n	0.4	n	0.004	0.000
PL12	A	9.7	3.6	1.6	4.1	74	23	104	n	3.1	7.9	75	75	88	89	n	n	n	n	n	n	n
PL12	Ae	2.4	1.0	<0.5	1.6	76	18	96	n	7.9	12.7	179	214	210	205	n	n	n	n	n	n	n
PL12	C	2.0	0.6	0.6	1.1	75	75	311	n	4.3	8.5	48	18	28	39	n	n	n	n	n	n	n
PL13	O	143	20.7	4.9	22.4	32	88	232	961	2.7	16.1	104	37	66	109	200	36	2.8	18.7	n	0.200	0.061
PL13	A	26.8	8.2	3.6	9.5	109	75	115	274	5.4	15.9	81	73	100	76	n	n	n	10.0	n	0.179	0.070
PL13	AB	1.1	1.0	3.0	1.6	83	85	97	127	9.9	15.6	113	98	137	107	n	n	n	0.3	n	0.001	0.021
PL14	O	163	22.2	5.4	12.0	88	96	336	n	3.7	7.8	55	19	27	36	106	23	2.6	11.7	n	0.163	0.064
PL14	A	42.1	8.5	6.0	5.4	86	63	209	416	2.3	10.2	91	29	41	154	n	n	n	6.3	n	0.070	0.112
PL14	AB	3.3	1.3	2.8	1.6	81	22	113	339	5.7	16.7	174	149	181	168	n	n	n	0.4	n	0.001	0.026
PL14	AB2	1.3	0.4	2.4	0.8	53	8	66	164	5.9	10.6	164	123	161	160	n	n	n	0.5	n	-0.002	0.011