Acta Agronomica Hungarica, 55(4), pp. 453–474 (2007)
DOI: 10.1556/AAgr.55.2007.4.6

SOIL CHANGES AFTER FORTY YEARS OF SUCCESSION IN AN ABANDONED COPPICE IN THE CZECH REPUBLIC

R. HÉDL[1] and K. REJŠEK[2]

[1] DEPARTMENT OF ECOLOGY, INSTITUTE OF BOTANY, CZECH ACADEMY OF SCIENCES, BRNO, CZECH REPUBLIC; [2]DEPARTMENT OF GEOLOGY AND SOIL SCIENCE, MENDEL UNIVERSITY OF AGRICULTURE AND FORESTRY, BRNO, CZECH REPUBLIC

Received: 26 August, 2006; accepted: 24 September, 2007

Soil processes over forty years of woodland succession were studied in the abandoned coppices of the Děvín Nature Reserve, in the south-east of the Czech Republic. A total of 113 horizon samples from 34 profiles were taken in the 1960s and 2000s, following identical field and laboratory approaches, to characterize soil texture, contents of carbonates and organic matter, and soil reaction (pH/H_2O, pH/KCl). Changes in the soil properties were discussed in relation to the gradual development of the mature woodland that replaced the former intensively managed ancient coppice. Four soil types (Luvisols, Regosols, Leptosols and Chernozems) and their horizons were statistically treated to identify distributions/shifts in the measured values from the past to the present. The following results were obtained: (1) The horizontal transport and sedimentation of sandy calcareous particles into the Leptosols topsoil led to increased acidity. (2) In Luvisols, the same was detected for fine clayey particles. This can be explained by the topographical occurrence of the two types – on the upper parts of slopes and under limestone cliffs for the former, and in the flat foothills for the latter soil type. (3) No acidification appeared except for Luvisols, whose luvic horizons E and Bt are, in contrast to the others, poor in calcium carbonate and relatively acidic. A decrease in acidity was recorded in KCl solution, but not in H_2O. This is interpreted as the consequence of the buffering ability of the soil sorption complex. (4) Slightly improved humification was only detected in the surface horizons of Luvisols and Leptosols. (5) Contrary to expectations no illimerization, i.e. the migration of clay particles from topsoil to subsoil, was revealed.

As forty years is apparently too short a time for significant vertical clay migration, it was concluded that i) horizontal migration and the accumulation of substrate particles was of at least the same importance as *in situ* pedogenetic processes, and ii) soil property dynamics that could be linked with the changed woodland management were proved to act relatively slowly.

Key words: soil change, coppice, succession

Introduction

Coppices are an ancient management form of woodlands, widespread in Europe (Billamboz, 2003; Coch, 2003; Rackham, 2003; Szabó, 2005). Traditional coppice management involves a regular short-rotation cutting cycle and other practices such as litter raking and occasional wood pasture (Fuller and Peterken, 1996; Matthews, 2001). In Central European countries, coppicing was gradually abandoned at the latest by the mid-20th century. By this time, most coppices were singled out and allowed to grow as a high forest (Matthews, 2001). Woodland succession took over the main role in the shaping of the ecosystem.

The present study deals with long-term soil changes in the woodlands of Děvín, probably the best-preserved over-aged coppice in the Czech Republic. The establishment of a nature reserve in 1949 largely prevented the traditional management activities, especially coppice management, and counteracted the influence of litter raking (Hofmeister et al., 2002). Shady forest conditions began to develop. As the nature reserve was combined with a game preserve (Danihelka, 2003; Heroldová, 2003) the high concentration of ungulates led to mechanical damage to the vegetation and to eutrophication (Chytrý and Danihelka, 1993; Reimoser and Gossow, 1996), so in 1996, mouflon and red deer were removed from the area.

The research approach was based on a comparison of past and recent datasets for spatially corresponding sites – soil pits and horizons. Fresh data were compared with those recorded by J. Horák as part of a Czech forest typology survey in the 1950s and 1960s (Horák, 1967; 1969). Such temporal studies are commonly used for investigations of long-term forest dynamics, such as those of Falkengren-Grerup (1986), who studied 34 plots from 1949 to 1970, Billett et al. (1990), who studied changes from 1949 to 1987, Falkengren-Grerup (1990), who presented data on more than a hundred plots studied from 1929 to 1988, and Falkengren-Grerup and Tyler (1991), who studied 95 plots from 1979 to 1990. However, these authors generally focused on the influence of acidification and eutrophication.

The present study aimed to evaluate the changes in five soil properties between 1963–1964 and 2002–2004 in the woodlands of Děvín. Two basic parallel hypotheses were postulated: neutral H_0 "No statistically significant differences will be detected in measured parameters and soil categories (types and horizons)", and alternative H_A "Statistically significant differences will be detected in measured parameters and soil categories (types and horizons)". Four soil units were distinguished: Luvisols, Regosols, Leptosols and Chernozems (ISSS-ISRIC-FAO, 1998), including 14 more or less homogeneous types of pedogenetic horizons (see Material and Methods for descriptions). These obviously differ in physical and chemical composition, and have developed under different site conditions. It was therefore necessary to make the hypotheses more specific.

Considering the constitution and pedogenetic processes forming the particular soil types, and assuming changes related to abandonment of light, relatively drier coppice wood and gradual succession to the shady, moister microclimate of a closed forest, ten hypotheses were formulated:

H_1: In Luvisols, significant texture changes in luvic horizons: loss of clay in eluvial, and increase of clay in illuvial horizons.

H_2: No significant textural changes in other soil types.

H_3: No significant changes in other texture fractions.

H_4: Significant decrease in content of carbonates in upper soil horizons of Luvisols and Regosols.

H_5: No significant change in content of carbonates in other soil types and horizons, namely the subsoil.

H_6: Significant increase in organic matter content in the uppermost soil horizons of all soil types.

H_7: No change in the organic matter content in mineral soil horizons.

H_8: Significant decrease in the soil reaction in Luvisols and Regosols, particularly in the upper horizons.

H_9: More intensive decrease in the soil reaction in KCl than in H_2O for Luvisols and Regosols.

H_{10}: No significant change in the soil reaction in Leptosols and Chernozems.

The hypotheses cover the major potential changes/steady state that can be identified using the values of the five measured parameters: texture, content of carbonates, content of organic matter, pH in water and pH in KCl suspension. However, soils are very heterogeneous, complex entities, which implies that the detected changes do not necessarily tell us the complete story. The obvious limitation is the set of parameters selected 50 years ago, when it could not have been expected that the measurements would be repeated in the future in the search for soil changes.

Materials and methods

Study area

Děvín is the central peak of a small but conspicuous hilly area in the South-Eastern corner of the Czech Republic. With an elevation of 550 m a.s.l. it dominates the landscape, being surrounded by the lowlands and alluvial floodplains of NW Pannonia. Because of its natural and cultural values it became a National Nature Reserve (380 ha) and is one of the cores of the Dolní Morava Biosphere Reserve (Danihelka, 2003). Děvín is a Jurassic limestone cliff with foothills covered with Quaternary loess. The chemically pure limestone originated in the Upper Dogger or Callovian period, 170 million years ago, while the loess sediments are often decalcified. The carbonate content in the soils differs markedly from one place to the other; soils connected to limestone and to loess (sometimes decalcified) can be found close to each other. Roughly three quarters of Děvín's area is covered by forest; the rest is mainly thermophilous grassland, then shrubby and arable land, etc. The forests include a gradient from xerothermic oak-forests (*Quercion pubescenti-petraeae*), through thermophilous to mesophilous oak–hornbeam forests (*Carpinion*), to ravine forests dominated by broad-leaved lime (*Tilio-Acerion*). The forest had been managed for many centuries as coppices, with a cutting period of at most 30 years (usually 10–20 years); in the regular pattern, 100–150-year-old standards of sessile oak were left. The major part of the Děvín woodland preserved its coppice structure until the present (Fig. 1).

Fig. 1. Aged coppice wood in Děvín, 2002

Sampling design

Horák (1967, 1969) opened and sampled forty-one soil pits, determining the soil types using the classification system of Pelíšek (1964). It proved possible to locate the positions of the pits using Horák's map (scale 1:10,000) showing the position of the sites, and his original field notebooks with descriptions of the investigated spots. New surveys were made on 34 soil pits; the profiles were described and 113 soil samples were taken from the same horizons as Horák. The sampling methodology followed that reported by Catt (1990); the soil profiles and horizons are listed in the Appendix.

Soil units

The subrecent pedogenesis in the study area was substantially conditioned by humification (in Holocene), eolic accumulation (Quaternary origin of loess) and slope sedimentation (subrecent gravitative movement of soil masses); for more information on sedimentary substrates in the Czech Republic see Růžičková et al. (2003). Karstified limestones are the major bedrock. Anthropogenic erosion played an important role during the past five to eight thousand years (Hédl, 2005). The soils can be characterized on the basis of field descriptions and laboratory measurements (see Appendix). The soils usually contained 40–50% of particles with a size of <0.01 mm and, except for a few horizons, they were calcareous, humus-rich in the topsoil and neutral to moderately basic.

The soils were basically classified in the field; older (Pelíšek, 1964) and more recent (ISSS-ISRIC-FAO, 1998) soil classification systems could be matched in all cases, though they delimited the recognized units in a narrower or broader sense.

i) Luvisols, 10 profiles. Characterized by clay accumulation and aggregation in Bt-horizons, and eluvial E-horizons, which were analytically detectable by texture differences. Little or no content of carbonates was found, except for the substrate C-horizons, and there was a low content of organic matter, except for the surface A-horizon. Acidity was around neutral or moderate. Haplic Luvisols were common all over the studied area, occurring on the moderately inclined middle and lower parts of the slopes.

ii) Regosols, 7 profiles. Soils originating from sub-recent slope accumulation having A-horizons partly accumulated in historical times, probably by erosion after deforestation, and C-horizons with a low humus content and much lighter colour, partly accumulated by solifluction. The content of carbonates was low to intermediate and soil acidity around neutral to basic. Calcic Regosols occurred on lower parts of the slopes with moderate inclination.

iii) Leptosols, 12 profiles. The soil bodies were developed by intensive humification on weathered limestone having humus- and carbonate-rich A-horizons with a thickness of at least 20 cm. Rendzic, Mollic or Eutric Leptosols were found on the upper parts of slopes with greater inclination.

iv) Chernozems, 5 profiles. The A-horizons were more than 30 cm thick, very dark in colour and contained carbonates. The C-horizon originated from loess materials rich in carbonates, sometimes with an admixture of stones. Haplic Chernozems were quite rare soil types – their persistence until recent times is probably due to continuous agricultural practices (vineyards) at these sites. Slight illimerization under woodland conditions led to their classification as Luvic Chernozems, occurring sparsely in the foothills.

Statistics

Statistical analyses were performed using STATISTICA, 6.0 version (StatSoft Inc., 2001). As the datasets did not show normal distribution, non-parametric testing was applied using the Wilcoxon test (Havránek, 1993; Sokal and Rohlf, 1981). Only datasets consisting of at least 5 cases were included; hence, for Chernozems only the textural classes and carbonate contents were considered. The data distribution was visualized by box-and-whisker plots depicting medians, interquartile range, non-outlier range (coefficient 1) and outliers (coefficient 1.5). The comparison was always within pairs of boxplots for old and new values.

For statistical comparison the following fourteen categories were set up (ISSS-ISRIC-FAO, 1998) consisting of fairly homogeneous horizons belonging to particular soil types. The statistical testing of the differences between old (1960s) and new (2000s) values was focused on the following categories:

i) Luvisols
- A: surface Ah organo–mineral horizons
- E: eluvial E, AE and partly transitional AB horizons
- Bt: argilic Bt, Bt1 and Bt2 horizons
- C: substrate Ck, C and partly transitional BC horizons

ii) Regosols
- A1: surface Ah1 organo–mineral horizons
- A2: Ah2 and Ah3 organo–mineral horizons, accumulated by geli– and solifluction
- C: (accumulated) calcareous substrate Ck, Ck1 and Ck2 horizons

iii) Leptosols
- A1: surface Ah1 organo–mineral horizons
- A2: subsurface Ah2 organo–mineral horizons
- C: substrate Ck (calcareous) and C horizons
- C+: as previous, plus transitional Bw and AC horizons

iv) Chernozems
- A1: surface Ah and Ah1 organo–mineral horizons
- A2: subsurface, transitional AC, Ah2 and AB horizons
- C: substrate calcareous Ck horizons

Laboratory analyses

In order to obtain data comparable with those provided by Horák (1967; 1969), the original analytical methods were repeated. The following treatments were performed on air-dried, sieved (mesh 2 mm) samples:

i) Weight percentage assessment of texture classes by the elutriation method of Kopecký (1928). Four texture classes were determined (note that the delimitation of fractions may differ from modern systems): i) clay (fraction I – particles with diameter less than 0.01 mm), loam (fraction II – 0.01–0.05 mm), fine sand (fraction III – 0.05–0.1 mm) and sand (fraction IV – 0.1–2.0 mm). The authors used the original laboratory equipment from the 1950s.

ii) Calcium carbonate content by the volumetrical determination of Laník and Halada (1956). The authors used the original laboratory equipment from the 1950s.

iii) Organic matter content determined in a mixture of $K_2Cr_2O_7$ and H_2SO_4 by the method of Walkley and Black (1934) modified by Novák (1950).

iv) Determinations of pH in water and KCl by the method of Válek (1954), where air-dried samples were treated in a l:2.5 solution of H_2O:1 M KCl and measured with a glass electrode.

Results

Data changes in textural classes are given in Table 1, and data on carbonate and organic matter contents and soil reactions in Table 2.

Table 1

Summarised results of Wilcoxon's matched pair test for differences in four texture classes, between old (1960s) and new (2000s) samples

Soil type	Horizon	N	I. Clay			II. Loam			III. Fine sand			IV. Sand		
			+/–	Z	p	+/–	Z	p	+/–	Z	p	+/–	Z	p
Luvisols	1.A	9	++	1.36	0.173		0.06	0.953	– –	1.24	0.214		0.77	0.441
	2.E	7		1.52	0.128	–	1.01	0.310	–	0.17	0.866		0.17	0.866
	3.Bt	10		0.89	0.374		0.53	0.594		0.18	0.589		1.13	0.260
	4.C	9	+	0.53	0.594	++	**2.19**	**0.028**	– –	**2.19**	**0.028**	–	**1.95**	**0.050**
Regosols	1.A1	6	–	0.73	0.463	– –	1.36	0.173	+	1.15	0.249	+	0.94	0.345
	2.A2	10	– –	**2.19**	**0.028**	+	1.56	0.114	+	0.97	0.333		0.97	0.333
	3.C	7	+	0.34	0.735	++	**2.03**	**0.043**	–	**2.03**	**0.043**	–	**2.20**	**0.023**
Leptosols	1.A1	12	–	0.46	0.650	– –	**2.40**	**0.017**	+	1.38	0.169	+	0.97	0.333
	2.A2	7	–	1.01	0.310	–	1.69	0.091		0.86	0.398	++	1.86	0.063
	3.C	13		0.87	0.386	+	**1.99**	**0.047**		0.87	0.386	–	**1.99**	**0.047**
	4.C+	16		0.87	0.386	+	**1.99**	**0.047**		0.87	0.386	–	**1.99**	**0.047**
Chernozems	1.A1	5	++	1.21	0.225	– –	1.75	0.080	+	0.40	0.686		0.67	0.500
	2.A2	6	+	1.57	0.116	–	0.52	0.600		0.10	0.917	– –	**2.20**	**0.028**
	3.C	5	++	0.94	0.345		0.40	0.686	–	0.94	0.345		1.48	0.138

N: number of cases, +/–: change observed from boxplots; ++: major increase; + increase; – decrease; – – major decrease; Z: test value; p: level of significance. For delimitation of soil horizons see text. Tests with p values significant at the 5% level are marked in bold.

Table 2

Summarised results of Wilcoxon's matched pair test for differences in soil parameters, between old (1960s) and new (2000s) samples

Soil type	Horizon	Carbonates				Org. matter content				pH H_2O				pH KCl			
		N	+/–	Z	p	*N*	+/–	Z	p	*N*	+/–	Z	p	*N*	+/–	Z	p
Luvisols	1.A	10		0.34	0.735	10	+	0.56	0.575	10		0.76	0.445	10	–	1.58	0.114
	2.E	7		0.00	1.000	7	+	0.85	0.398	7		0.51	0.612	7	– –	1.86	0.063
	3.Bt	10		0.67	0.500	11		0.76	0.445	11	+	1.51	0.131	11	–	1.42	0.155
	4.C	9	– –	**2.19**	**0.028**	10		0.30	0.767	10	+	0.56	0.575	10		0.66	0.508
Regosols	1.A1	6	–	**1.99**	**0.047**	6	–	1.48	0.138	7		0.34	0.735	7	–	0.85	0.398
	2.A2	10	–	**1.99**	**0.047**	10	+	0.46	0.646	10	+	**2.09**	**0.037**	10	+	1.38	0.169
	3.C	7	–	1.69	0.091	7		0.85	0.398	7	++	**2.37**	**0.017**	7		1.18	0.237
Leptosols	1.A1	12	+	**2.27**	**0.023**	11		0.97	0.333	11	++	**2.93**	**0.003**	11	+	1.69	0.091
	2.A2	7	+	0.34	0.735	6	+	1.15	0.249	6	++	**2.02**	**0.043**	6	+	1.78	0.075
	3.C	13		0.78	0.433	12		1.57	0.117	12	++	**3.06**	**0.002**	12	+	**2.35**	**0.019**
	4.C+	16		0.65	0.513	15		0.11	0.091	15	++	**3.40**	**0.000**	15	+	**2.47**	**0.013**
Chernozems	1.A1	5		0.40	0.686	3	/	/	/	3	/	/	/	3	/	/	/
	2.A2	6	+	0.52	0.600	4	/	/	/	4	/	/	/	4	/	/	/
	3.C	5		0.00	1.000	3	/	/	/	3	/	/	/	3	/	/	/

No test was performed for less than five cases (denoted as /). See Table 1 for explanation of symbols and abbreviations. Significant p values are marked as follows: **≤0.01**; **≤0.05**.

Texture

The subsoil horizons of all four soil types show an almost uniform loss of coarser fractions (fine sand and sand) and a corresponding gain in finer fractions (clay and loam). However, no such general pattern can be documented in the topsoil. In Luvisols (Fig. 2) and Chernozems (Fig. 5) the fine fractions (mostly I, clay) increased, while in Leptosols (Fig. 4) and Regosols (Fig. 3) the coarse fractions (mostly IV, sand) increased.

The following statistically significant changes were observed:

i) Clay: statistically significant ($p < 0.05$) decrease in the A2 horizon of Regosols; perceptible but statistically non-significant ($p > 0.05$) increase in the uppermost horizons of Luvisols and Chernozems and in the subsoil of Chernozems.

ii) Loam: statistically significant ($p < 0.05$) increase in the subsoil (C-horizons) of Luvisols, Regosols and Leptosols; decrease in the the uppermost horizon of Leptosols.

iii) Fine sand: statistically significant ($p < 0.05$) decrease in subsoil (C-horizons) of Luvisols and Regosols; perceptible but non-significant ($p > 0.05$) decrease in the uppermost horizon of Luvisols.

iv) Sand: statistically significant ($p < 0.05$) decrease in the C-horizon of Luvisols, Regosols and Leptosols, and in the A2-horizon of Chernozems.

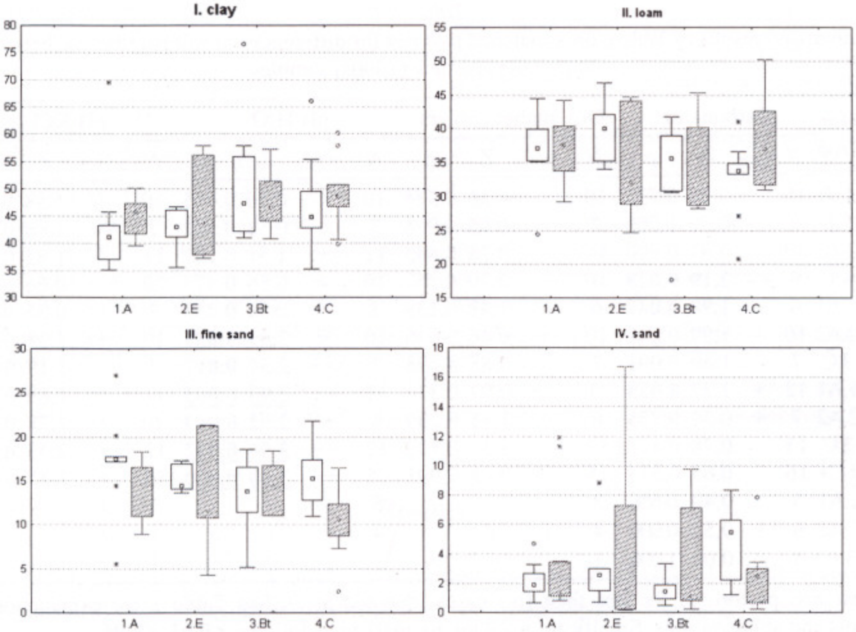

Fig. 2. Luvisols, changes in texture, four classes; X-axes show four horizon categories. Boxplots of medians (inside-squares), interquartile range (boxes), non-outlier range (whiskers), and outliers (circles, double-crosses) show old values (1960s) in left-hand white boxes and new values (2000s) in right-hand hatched boxes. The most striking changes are in horizon 4.C, with intermediate changes in the 2.E and 1.A horizons. No change can be observed in horizon 3.B

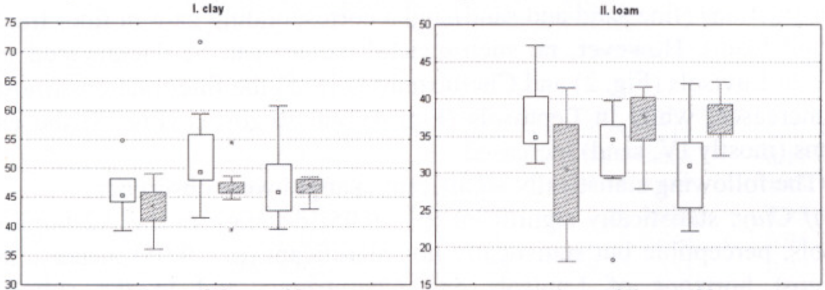

Fig. 3. Regosols, changes in texture, four classes; X-axes show three horizon categories. For graph design see Fig. 2. Amounts of most fractions changed; the overall process can be described as loss of finer fractions in the topsoil (1.A, less in 2.A) and their increase in the subsoil (3.C)

Content of carbonates

Low or even zero absolute values were recorded in most horizons, except for the substrate (C) horizons, but the changes were often statistically significant, including the statistically significant ($p < 0.05$) decrease in the C-horizon of Luvisols (Fig. 6) and the upper horizons of Regosols (Fig. 7), and the increase in the uppermost horizon of Leptosols (Fig. 8).

Organic matter content

No statistically significant changes. A slight increase could be observed in the topsoil horizons of Leptosols (Fig. 8) and Luvisols (Fig. 6), but there was no change in subsoil horizons containing a low amount of organic matter.

pH in H_2O

The overall change was an increase in almost all horizons, most notably in those of Leptosols (Fig. 8), which could be as much as 0.4 units. There was a statistically highly significant ($p < 0.01$) increase in Leptosols in most horizons, and a significant ($p < 0.05$) increase in Regosols, except for the uppermost horizon. In contrast, Luvisols (Fig. 6) changed the least, with practically no change in the topsoil horizons. A slight increase in acidity was observed in Chernozems.

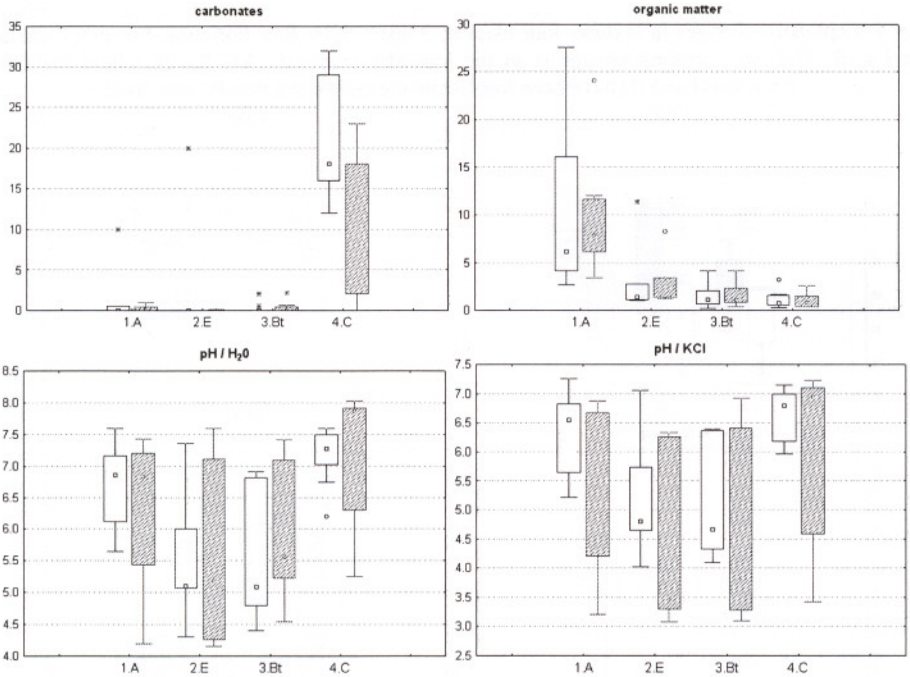

Fig. 6. Luvisols, changes in content of carbonates (%), content of organic matter (%), pH in H_2O and pH in 1 N KCl solution. X-axes show four horizons; for graph design see Fig. 2. The most interesting process is the decrease in pH/KCl in luvic horizons (2.E, 3.Bt) compared to almost no change for pH/H_2O

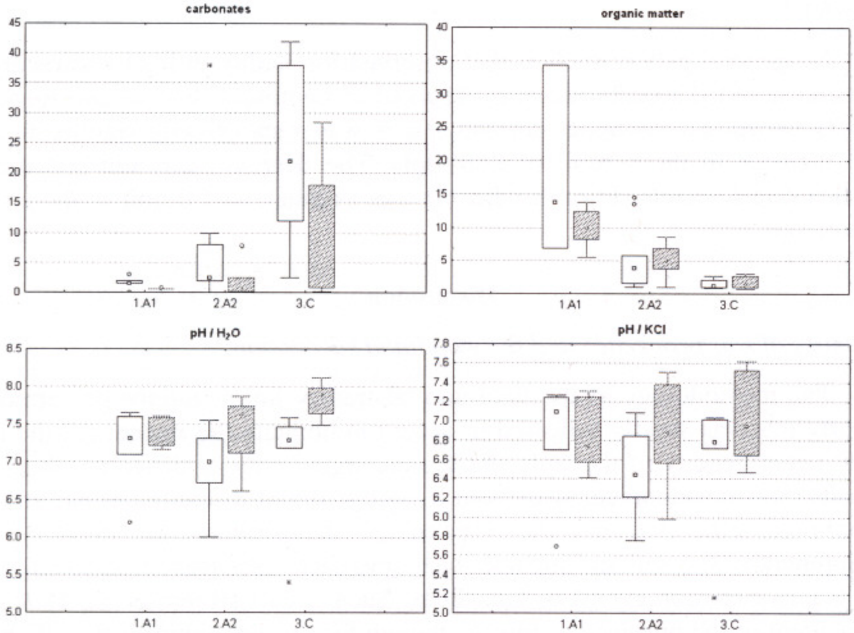

Fig. 7. Regosols, changes in content of carbonates (%), content of organic matter (%), pH in H_2O and pH in 1 N KCl solution. X-axes show three horizons; for graph design see Fig. 2. General loss of carbonates (mainly in topsoil) and increase in acidity (mainly in subsoil) are the most apparent changes

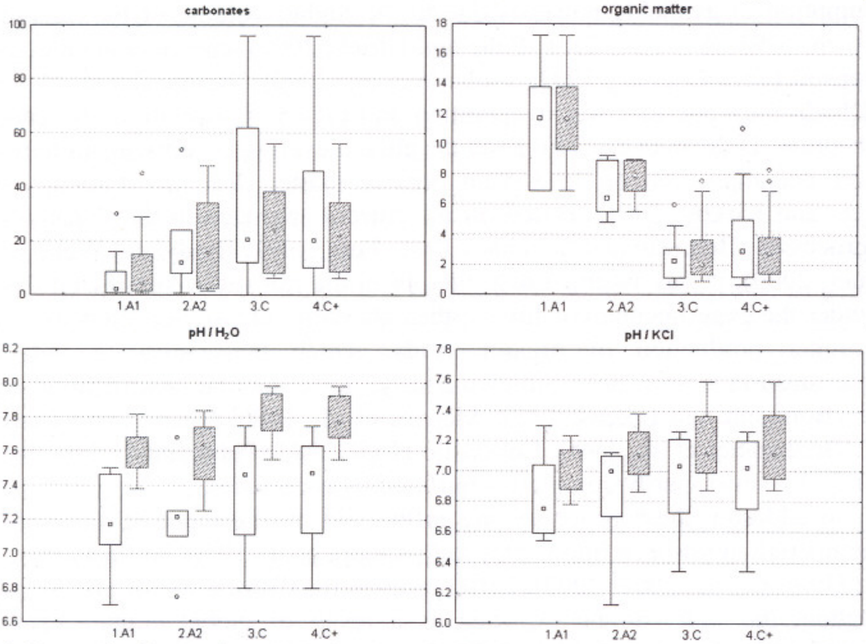

Fig. 8. Leptosols, changes in content of carbonates (%), content of organic matter (%), pH in H_2O and pH in 1 N KCl solution. X-axes show four horizons; for graph design see Fig. 2. The most profound change is the increase in acidity in all horizons

pH in KCl

No general pattern such as that observed for acidity in H_2O was recorded. An increase of 0.1 to 0.2 units was observed in Leptosols (Fig. 8) and Regosols (Fig. 7), except for the upper horizon. There was a statistically significant ($p < 0.05$) increase in the subsoil of Leptosols. The decrease was not statistically significant in Luvisols (Fig. 6), where it was as much as 1.0 unit in the eluvial (E) horizons.

Discussion

Dynamics of soil properties and the woodland succession

The methodology of the field and laboratory investigations performed in the early 60s was strictly followed in order to eliminate the impacts of the high spatial heterogeneity of the soils and the incompatibility of different laboratory methods. Soil development is of both a continual and discontinual nature. The discontinual processes can be viewed as disturbances in the continual development of the soil and include local episodical catastrophes such as short-term massive erosion events or landslides. Such events (Boero et al., 1992) are independent of the presence of forests, though forests can diminish the effects of erosive acts.

When interpreting the results, consideration was given to the higher consumption of available nutrients due to the higher volume of biomass (Van Breemen, 1993; Ae et al., 2001; Puhe and Ulrich, 2001), chemical alterations in the topsoil (Cresser et al., 1993; Violante et al., 2002), the impacts of changed local hydrology due to lower evaporation and higher transpiration and canopy interception (Dolman et al., 2001) and the altered cycling of nutrients in terms of quicker decomposition of dead plant organic matter (Van der Putten, 1997; Mengel and Kirkby, 2001). Based on the current approach to the dynamics of soil processes (Bonneau and Souchier, 1982; Foth, 1991; Brady and Weil, 1999; Sumner, 2000), it was assumed that the topsoil did not suffer significant drying out under the experimental conditions, thus allowing intense decomposition and the higher production of organic acids, which then infiltrate into the surface/subsurface horizons. Simultaneously, local natural acidification may occur (Bormann and Likens, 1979; Meiwes et al., 1986; Binkley and Richter, 1987; Bredemeier et al., 1990; Lükewille et al., 1993; Puhe and Ulrich, 2001), which is, however, partly/completely buffered by carbonates.

In addition, these processes are influenced by the input of atmospheric pollutants rich in nitrogen into the topsoil (Kauppi et al., 1990; Hofmeister et al., 2002; Hruška et al., 2002; 2003). Differences in the distribution of precipitation throughout the year can be expected as a result of global climate changes (Kalvová, 2000; Puhe and Ulrich, 2001; Rejšek, 2004), possibly leading to local landslides.

Interpretation of observed changes

Each of the ten hypotheses was tested against the results of the measurements. Most hypotheses had to be rejected. Most soil units remained unchanged, or at least the change was not statistically significant. For the formulation of the hypotheses, see Introduction.

i) H_1: rejected. Vertical transport of clay in the luvic horizons of Luvisols was not detected.

The data confirmed that textural changes are among the slowest soil processes. Within the process of illimerization, the vertical migration of the finest particles from the topsoil to the subsoil should result in an increase in clay in the neighbouring subsoil horizon. Retallack (2001) described how luvic and argilic horizons evolve over hundreds and thousands of years. Holliday (1988) stated that an argillic horizon may evolve within 450 years. The results proved that luvic processes cannot be documented with the data presented.

ii) H_2: rejected. Texture changes were observed in all soil types. When evaluating the interrelationships between natural plant succession and the dynamics of soil properties, it must not be forgotten that physical, chemical and biological soil properties are also acquired in response to external biotic factors (Karlen et al., 2003). The data presented showed that the succession of plant communities towards the closed forest has led to the considerably increased erosion of soil profiles and the markedly increased denudation of the Jurassic limestone cliffs; however, the forty-year period was not long enough to produce changes distinguishable at the pedon level.

iii) H_3: rejected. Texture changes were often detected in other than the clay fraction. The situation seems to be different in the topsoil horizons, which are the subject of processes of (sub)recent erosion and/or sedimentation (Schaetzl and Anderson, 2005). It is necessary to view the textural changes between the four classes (clay to sand) as the elements of a single system, where an increase or decrease in one element (e.g. textural class) results in an opposite change in other elements, within and between the adjacent horizons. In general, textural changes can have a threefold explanation: i) accumulation (or sedimentation), i.e. an increase in any fraction by horizontal migration, which concerns only the surface horizons in recent pedogenesis; ii) dissolution and weathering, i.e. relative loss of any fraction, but mostly of the coarser particles, leading to an increase in finer particles; iii) relative change, i.e. relative decrease or increase linked with one of the above-mentioned processes.

It is probable that the textural changes observed in topsoil horizons are due to the accumulation of coarser fractions, i.e. of sandy particles, in Leptosols and Regosols and of fine clayey fractions in Luvisols and Chernozems. This conclusion can be supported by the topographic position of the respective soil types, where the former (especially Leptosols) develop on the upper, often steep parts of the slopes, under the rocky cliffs, while the latter can be found on the lower, moderately inclined parts of the slopes and in the foothills. The sedimentation gradient probably resulted in the observed distribution of fine (<2 mm) soil particles. The share of other fractions within the soil types has relatively declined; however, the loss of coarse fractions could also be due to weathering and dissolving, leading to finer particles.

The situation is rather different in the subsoil horizons, where the dissolution and weathering of coarser (sandy) particles has probably led to the general increase in fine fractions (clay and loam). However, slight quasi-illimerization was observed in the Leptosols, which is in contradiction to the high carbonate content in the whole profile.

iv) H_4: supported for Regosols and rejected for Luvisols. A significant decrease in carbonate content was observed in the upper horizons of Regosols, while no change was determined in the topsoil of Luvisols. The data proved that changes in carbonate content may occur within a few decades (Juo and Franzluebbers, 2003). Carbonates are soluble in water, if it is neutral to moderately acidic (Ashman and Puri, 2005). In Regosols, the water regime appeared to have a slightly leaching effect, in contrast to the slightly dessicative regime in the 60s. In contrast no leaching of carbonates down the profile (resulting in a decrease) and no accumulation of calcium carbonate particles by horizontal transport down the slope were measured in Luvisols.

v) H_5: ambiguous. In Regosols and Luvisols, all horizons, including the substrate C-horizons, showed a decrease in carbonate content, probably due to leaching down the profile. In addition, a slight enrichment in carbonates due to capillarity uplift, which can be expected only at sunny sites without a closed canopy, was measured in the topsoil of Chernozems. Moreover, the increase in carbonate content in the topsoil of Leptosols could most probably be interpreted as the accumulation of fine grains of calcium carbonate.

vi) H_6: rejected. No significant increase in organic matter was observed in the uppermost horizons. The humification rate is probably influenced by the altered soil biotic communities linked to plant exudates and the litter of developing plant communities (Kreitz and Anderson, 1997; Vetter et al., 2004). The joint effect of the development of plant associations providing the soil with different quantities and qualities of dead plant organic matter should also be stressed (Violante et al., 2002). However, the data obtained did not prove either the increasing role of humified soil biota or a higher rate of humic substance formation due to the higher rate of litter accumulation expected on the soil surface.

The changes in organic matter content were difficult to interpret. A slight increase was detected in the organic matter content in the surface topsoil horizons of Luvisols and Leptosols but this change was not significant. Nevertheless, the improved humification could be attributed without doubt to the changed conditions of the ecosystem as the closed woodland developed during the succession.

The results indicate the total organic carbon content added to the humus; hence this value can be treated as the intensity of humification, which concerns only the topsoil (A) horizons. In the subsoil, no humus particles should occur unless transported there by incidental pedoturbation, or as the fine roots of trees, which could not be removed from the samples. The changes in comparable horizons were approximately 5–10% in the A-horizons.

vii) H_7: supported. No change in organic matter could be detected in the subsoil. If a change in the organic matter content of the subsoil is measured, pedogenetical translocation can be expected to play a major role. The data obtained proved that no prominent changes in infiltration processes, water redistribution or evaporation from the soil surface (Mengel and Kirkby, 2001; Moffat, 2003), which may be reflected as a higher content of humification products in the subsoil, occurred on the study plots. Incidental pedoturbation or the presence of fine tree roots, which could not be removed from the samples, are the other sources for the transport of organic matter into the subsoil. It is important to evaluate the differences in the absolute values: the changes in comparable horizons amounted to approximately 0.5–1.0% in the C-horizons, i.e. as expected, no change occurred in the subsoil horizons.

viii) H_8: rejected. No significant decrease in the soil reaction could be detected in Luvisols or Regosols. In the calcium carbonate-rich soils of Děvín, acidification is only to be expected in non-carbonate or carbonate-poor horizons – as in Luvisols and Regosols. The data showed that the soil reaction in Luvisols and Regosols in the study area exhibited long-term stability, even though the authors are fully aware that soil acidity is a dynamic, highly variable parameter (White, 1997). In neither soil unit were any significant changes in pH values observed due to: i) the release of organic acids by humification processes, which is a typical process of woodland succession (Sumner, 2000), leading to a decrease in soil acidity, mostly in the topsoil; ii) carbonate leaching, which is closely linked with the acidity value, leading to a decrease in soil acidity; iii) the anthropogenic input of acidifiers, mediated mainly by precipitation, leading to a decrease in acidity; or iv) the accumulation of calcium carbonate particles by horizontal migration and sedimentation, leading to an increase in soil acidity. In addition, the role of airborne acidification by sulphur and nitrogen oxides of anthropogenic origin in Central Europe (Almer et al., 1974; Sutcliffe et al., 1982) was not proved either.

In Luvisols, both luvic horizons (E and Bt) were, in general, carbonate-free, while the pH reached the moderately acidic to acidic range (with values as low as 3 for pH in KCl). Because they were the most acidic of all horizons treated in general, they should be very sensitive to the input of H^+ ions. Nevertheless, the organic acids produced by improved humification and/or the atmospheric deposition of acidifiers were buffered by the sorption complex. Therefore, no significant decrease in acidity could be observed. The same probably holds true for the upper horizon of Regosols.

ix) H_9: supported. For both Luvisols and Regosols, the pH in KCl dropped more than the pH in water. A relatively strong decrease in the soil reaction in Luvisols and Regosols was measured in KCl. Soil acidity was measured in two ways: in a distilled water suspension, and in 1 M KCl. Measuring the acidity in water shows the concentration of H^+ ions actually present in the soil solution, while KCl treatment also releases H^+ ions bound electrochemically on the surface of the soil colloid particles (Courtney and Trudgill, 1993). The import of acidifying ions from outside can be documented by the decreasing value of pH in KCl, although this acid input does not necessarily affect the pH in water. The decrease in pH in an electrolyte (1 M KCl) was no doubt influenced by the local effects of global climate changes (Rejšek, 2004): in this part of Central Europe, the role of a long-term high air pollution rate (Purdon et al., 2004) must be considered. The data presented may also be influenced by continuous variations in soil buffering capacities followed by short-term enhancements in soil acidity (Boyle and Powers, 2001). The authors see the enhancement of exchangeable acidity as a result of both the humification processes and/or precipitation deposits. Based on the data evaluated, it was impossible to distinguish between acidification due to natural succession and acidic pollution.

x) H_{10}: rejected. A highly significant increase in the soil reaction was measured in Leptosols. This increase in pH throughout the whole profile in Leptosols was the most striking of all the changes in pH values determined in the study. This dramatic enhancement could be interpreted as the accumulation of calcium carbonate particles in the topsoil and the seeping of the carbonate-rich solution into the subsoil. In KCl, the increase in pH was not as high as in water, since a certain quantity of H^+ ions is present in the sorption complex. However, accumulation in the topsoil may be closely linked with other parameters (carbonate content, texture), while the seepage of the alkaline solution is not easy to prove. A slight increase in pH values in Chernozems can most probably be interpreted as the capillarity uplift of the calcium carbonate solution, but this increase was not statistically significant.

Conclusions

Based on the assumptions and on the soil changes detected, it was concluded that there were at least two Quaternary-geological and three pedogenetic processes:

(1) Gravitative accumulation of limestone particles arising from the continual mechanical denudation of the cliffs, though the transport of particles larger than 2 mm could not be detected by the present data.

(2) Weathering of coarser particles into finer particles in soils located on flat, under-hill sites. Such soils were the only soils displaying mild acidification. Weathering processes could be documented both in the parent materials and inside soil horizons.

(3) Changes in humidity, temperature and wind speed on the soil surface had a great influence on the dynamics of soil properties by dramatically reducing soil drying-up periods. This could only be detected indirectly.

(4) An improvement in the humification rate, resulting in mild acidification in non-calcareous horizons. This acidification cannot be distinguished from the effect of atmospheric depositions, mainly nitrogen compounds, which are certainly present.

(5) Although gravitative clay migration probably takes place, the 40-year period was too short to offer evidence for clayey particle translocations between adjacent horizons.

Acknowledgements

Our thanks go first to Dr. J. Horák for providing us with original data from the 1950s and 1960s; to Zuzka Maryšková for her substantial help with the laboratory analyses; and to Jiří Danihelka, without whose help this project would not have been possible. We are also obliged to M. Helan (soil sampling, laboratory analyses), Dr. V. Koblížková (laboratory analyses), V. Vranová, J. Houška and K. Boublík (soil sampling). This paper is one of the outputs of the project VaV 610/10/00: Effect of management interventions on biodiversity changes in particularly protected areas, funded by the Agency for Nature Conservation and Landscape Protection of the Czech Republic. Work on the paper was enabled by grant No. AV0Z60050516 from the Czech Academy of Science (first author).

Appendix

Soil profiles, sampled horizons, soil types and results of laboratory analyses for texture (content of four classes, %), content of carbonates (%), content of organic matter (%), and acidity in distilled water and 1 N KCl solution. Pairs of related values are given; Old denotes values taken from the literature, New denotes values measured in recently taken samples. Blank fields are due to missing values (not measured)

Plot No.	Depth (cm)	Soil type	Hori-zon	Texture classes								Carbonates		Organic matter		pH in H_2O		pH in KCl	
				I		II		III		IV									
				old	new	old	new	old	new	old	new	old	new	old	new	old	new	old	new
Luvisols																			
406	1–10	HL	Ah	41.1	50.2	38.7	34.5	17.6	14.1	2.7	1.3	0.5	1	6.90	8.28	6.70	7.21	6.40	6.87
	10–15		AE	46.1	57.9	36.8	28.9	14.1	11.6	3.0	1.6	0	0	1.15	3.45	5.07	4.72	4.81	3.47
	25–30		E	46.7	56.1	35.3	32.1	15.4	11.5	2.7	0.2	0	0	1.03	1.17	4.31	4.16	4.02	3.36
	40–50		Bt	55.8	57.3	30.9	28.2	11.5	11.0	1.8	3.4	0	2.2	0.41	0.48	4.41	7.10	4.10	6.92
	70–80		Ck	55.4	57.8	27.1	30.9	12.0	8.7	5.5	2.5	12	23	0.34	0.34	6.20	7.89	5.97	7.22
421	0–3	HL	Ah	45.7	41.3	35.1	39.8	14.4	18.0	4.7	0.8	10	0.05	16.1	11.73	7.50	7.43	7.25	6.35
	15–20		AE	43.5	50.9	34.0	44.7	13.7	4.3	8.8	0.2	20	0.02	11.37	2.76	7.36	7.59	7.05	6.33
	80–90		Ck	47.0	40.0	33.2	50.2	13.1	9.1	6.6	0.7	32	2.1	1.65	1.59	7.59	7.87	7.15	6.80
422	5–10	HL	Ah	40.2	45.7	40.0	44.2	17.2	9.0	2.7	1.1	0	0.1	5.50	6.21	7.02	7.20	6.82	6.40
	20–30		AB	42.0	38.0	42.1	38.5	14.1	21.3	1.7	2.2	0	0	1.38	3.45	6.00	7.11	5.73	6.26
	45–55		Bt	46.8	42.8	37.9	45.3	14.3	11.0	1.0	0.8	0	0.1	0.69	1.10	6.15	7.28	5.70	6.17
	90–100		Ck	49.6	40.7	34.9	42.6	12.8	16.5	2.7	0.2	20	6.8	0.57	0.69	7.50	7.91	7.00	6.99
423	30–40	HL	Bt											2.07	4.14	6.43	6.17	6.03	5.10
	50–60		Ck											1.26	1.52	6.74	6.30	6.12	4.59
424	2–5	HL	Ah	69.5	49.5	24.4	29.3	5.5	18.3	0.6	2.9	0.5	0.05	13.8	12.08	7.17	6.28	6.71	5.87
	30–40		Bt	76.6	51.4	17.7	32.8	5.1	14.8	0.5	1.0	2	0.03	4.13	3.68	6.82	5.56	6.36	3.74
	55–60		C	66.0	60.2	20.8	31.7	11.0	7.3	2.2	0.7	18	0	0.70	2.62	7.30	5.26	6.94	3.42

426	1–2	HL	O+Ah									0	0	27.6	24.15	7.60	5.16	7.04	4.11
	2–3		Ah	35.9	47.3	35.2	42.0	27.0	9.5	1.9	1.1	0	0	20.7	11.04	5.92	4.20	5.50	3.20
	5–15		E	43.0	43.9	40.0	44.1	14.5	10.8	2.5	1.3	0	0	2.76	8.28	5.10	4.26	4.70	3.09
	25–30		Bt1	53.1	57.2	31.2	42.5	13.3	0.0	2.4	0.2	0	0	1.15	2.30	4.64	4.54	4.30	3.10
	50–60		Bt2	57.8	46.0	30.6	40.1	10.2	12.7	1.4	1.2	0	0	0.17	0.83	4.90	5.23	4.57	3.32
427	5–10	HL	Ah	37.1	41.7	44.5	40.5	17.3	16.6	1.1	1.3	0	0.1	2.70	7.59	5.65	6.65	5.22	5.96
	20–30		AB	41.2	37.3	40.0	24.7	17.3	21.3	1.5	16.7	0	0.1	1.38	3.45	5.07	6.04	4.65	5.09
	55–65		Bt	45.7	44.2	34.3	28.4	18.6	17.7	1.4	9.8	0	0	0.69	0.97	5.02	5.54	4.67	3.84
	90–100		Ck	44.8	50.7	36.6	46.5	17.4	2.4	1.2	0.4	32	18	0.27	0.69	7.20	7.87	6.18	6.97
429	3–6	HL	Ah	35.1	39.6	43.3	33.8	20.1	15.3	1.4	11.3	0	0	5.50	4.14	6.12	5.44	5.64	4.21
	10–15		E	35.6	41.8	46.7	30.5	17.0	20.3	0.7	7.3	0	0.05	2.07	1.38	5.17	5.19	4.80	3.30
	30–40		Bt1	41.0	47.1	41.7	28.7	16.5	16.7	0.7	7.5	0	0	1.72	1.03	4.80	4.98	4.33	3.28
	50–60		Bt2	42.2	40.9	38.9	36.1	17.9	15.9	1.0	7.1	0	0	1.15	0.41	5.09	5.24	4.67	3.27
	80–90		BC	35.3	46.7	41.0	39.7	21.8	10.6	1.9	3.0	14	0	0.55	0.34	7.02	5.71	6.19	3.64
436	3–8	HL	Ah	43.4	44.3	37.0	37.6	17.8	14.6	1.8	3.5	0.5	0.65	2.70	3.45	6.47	7.00	6.02	6.72
	20–30		Bt	47.8	45.6	36.9	35.5	13.4	18.4	1.9	0.6	0.5	0.4	2.07	2.07	6.90	7.42	6.37	6.78
	50–70		C1	42.8	47.1	33.8	35.9	17.4	13.6	6.0	3.4	16	14	1.61	1.03	7.26	7.95	6.76	7.10
	80–90		C2	41.4	48.6	33.6	37.0	16.6	11.9	8.3	2.5	29	20.5	0.69	0.34	7.40	8.03	6.83	7.21
437	2–10	HL	Ah	42.1	47.0	37.1	30.1	17.5	11.0	3.3	11.9	0	0.4	4.10	6.90	7.10	7.04	6.80	6.67
	20–30		Bt	41.5	47.9	39.8	37.0	15.4	14.1	3.3	1.0	0	0.6	1.38	1.73	6.91	7.07	6.40	6.41
	60–70		Ck	44.3	48.5	34.1	31.3	15.2	12.3	6.3	7.8	18	15.5	3.21	1.21	7.52	7.81	7.10	6.92
Regosols																			
415	0–10	CR	Ah1	45.4	40.9	40.4	23.5	11.8	14.7	2.4	20.9	0	0.5	6.90	10.35	6.19	7.59	5.70	7.31
	20–30		Ah2	48.0	45.7	35.1	40.3	11.3	13.3	5.6	0.8	5	2	3.44	4.14	6.40	7.61	6.07	7.51
	60–70		Ah3	49.3	47.6	39.9	41.7	10.3	9.3	0.6	1.5	2	2.5	1.03	3.79	6.00	7.74	5.76	7.50
	85–100		Ck1	43.6	48.5	42.0	39.3	13.5	11.1	0.8	1.1	2.5	4	0.86	1.72	5.40	7.83	5.16	7.53
431	0–3	CR	Ah1	45.2	36.0	34.8	18.1	16.4	17.0	3.5	28.9	3	0.8	13.8	13.8	7.51	7.17	7.27	6.85
	20–30		Ah2	45.3	39.4	37.8	27.9	14.5	19.0	2.5	13.7	8	7.8	5.74	8.62	7.30	7.65	6.74	7.38
432	0–3	CR	Ah1	44.3	49.1	34.8	36.0	17.5	13.9	3.4	1.1	1.5	0.5	6.90	5.52	7.60	7.28	7.10	6.41
	10–25		Ah2	41.4	46.2	36.6	34.8	18.8	16.6	3.2	2.3	3	0.3	4.48	2.42	7.32	7.34	6.85	6.56
	50–60		Ck	50.8	46.6	25.4	38.6	19.7	13.3	4.2	1.5	38	0.2	1.18	1.52	7.19	7.49	6.72	6.65
441	0–5	CR	Ah1	54.9	43.4	31.3	41.5	12.0	13.9	1.8	1.2	2	0.5	13.8	8.28	7.65	7.22	7.24	6.74
	15–25		Ah2	55.8	54.5	29.6	39.1	12.2	5.0	2.4	1.4	10	0.1	13.45	7.59	7.47	6.61	7.00	5.98
	50–60		Ah3	71.7	46.0	18.4	39.4	9.1	13.4	0.8	1.1	38	7.9	0.96	1.03	7.56	7.87	7.09	6.93
442	5–10	CR	Ah1													7.20	7.22	6.70	6.57
	10–20		Ah2	49.3	46.3	36.5	34.4	12.5	18.9	1.7	0.4	0	0.5	2.76	5.86	6.83	7.11	6.24	6.63
	20–30		Ah3	51.3	45.8	34.0	36.3	12.6	16.2	2.1	1.7	0	0.1	1.61	3.80	6.74	7.12	6.29	6.23
	40–50		Ck1	49.5	48.1	34.1	38.6	11.0	13.1	5.4	0.2	12	0.8	1.51	2.76	7.42	7.64	6.78	6.47
	70–80		Ck2	45.8	48.1	34.1	37.2	15.0	10.4	5.1	4.3	42	18	0.98	1.38	7.59	7.95	7.04	6.95
443	0–5	CR	Ah1	39.2	45.8	47.3	36.6	12.1	16.7	1.4	0.8	1.5	0.6	34.4	12.42	7.32	7.42	7.22	6.70
	10–20		Ah2	59.5	48.7	29.2	40.7	10.3	9.8	1.0	0.8	2	0.6	14.47	6.90	7.17	7.74	6.60	6.84
	50–60		Ck	60.8	45.8	22.2	42.3	13.5	11.8	3.5	0.1	29	14.5	2.07	3.10	7.30	8.12	6.79	6.95
129a	0–10	CR	Ah1	48.2	43.7	34.0	24.9	14.9	16.7	3.0	14.7	1.5	0.5	34.4	9.66	7.10	7.61	6.96	7.25
	25–35		Ah2	48.3	44.6	31.4	34.4	16.9	18.1	3.5	2.9	2	0.2	5.17	5.86	6.72	7.65	6.21	7.34
	60–70		Ck1	42.7	47.2	31.0	35.3	20.4	15.6	5.9	2.0	19	17	2.66	0.97	7.25	7.89	6.86	7.51
	90–100		Ck2	39.5	42.9	30.5	32.4	23.9	18.9	6.1	5.7	22	28.5	1.11	0.76	7.47	7.98	7.02	7.62
Leptosols																			
404	2–10	ML	Ah1	51.4	45.3	25.6	23.9	14.1	24.3	8.9	6.4	16	29	6.90	8.97	7.15	7.82	6.75	7.23
	20–25		Ah2	52.8	46.1	21.6	25.9	13.7	22.1	11.9	5.9	24	34	4.82	5.52	7.24	7.72	7.00	7.38
	60–70		C	67.9	46.2	17.6	27.0	12.8	19.5	1.7	7.2	23	47	0.96	0.90	7.40	7.68	7.02	7.51
408	2–5	EL	Ah1	33.5	47.9	42.4	30.0	22.8	18.8	1.3	3.3	7.5	20	10.3					
	10–15		Ah2	37.0	44.3	40.1	27.4	20.0	15.6	2.9	12.7	12	25	6.90					
	40–50		Ck	45.0	47.9	38.0	34.8	15.4	15.2	1.6	2.2	20.5	24	2.76					
411	0–3	ML	Ah1	48.1	44.2	29.1	18.1	17.6	12.6	5.1	25.0	2.5	3.5	6.90	13.8	6.92	7.64	6.90	7.20
	20–30		Ah2	49.2	44.8	29.9	19.7	14.0	12.6	6.8	22.9	8	9	5.51	7.59	7.10	7.55	7.00	7.26
	60–70		Ck	46.4	53.4	27.8	31.2	11.4	11.1	14.5	4.2	12	38.5	2.89	3.45	7.39	7.82	7.04	7.59
412	0–5	ML	Ah1	48.7	44.6	35.6	37.6	13.3	17.7	2.5	0.1	1	0.5	16.1	17.25	6.70	7.56	6.68	7.04
	25–35		Ah2	48.2	50.5	37.3	24.7	11.6	13.0	2.9	11.8	10	2.4	8.96	9.00	7.25	7.25	7.10	6.98
	60–70		Ck	50.5	46.5	30.0	29.7	8.0	14.9	11.5	8.9	30	15	2.89	3.79	7.63	7.76	7.22	7.34

414	0–3	ML	Ah	44.0	34.5	38.2	18.8	13.3	17.3	4.5	29.4	2	5	17.2	10.35	7.17	7.70	7.03	7.06
	30–40		AC	44.5	43.2	38.9	25.4	12.0	13.4	4.5	18.0	8	10.5	4.99	3.45	7.18	7.77	6.86	7.37
435	5–10	EL	Ah	35.8	43.6	47.3	38.2	14.8	15.2	2.2	3.1	0	2	9.65	11.73	7.09	7.38	6.70	6.83
	25–30		Bw	51.1	52.5	35.6	36.9	11.2	9.7	2.0	0.9	0	7.8	3.10	6.90	6.80	7.55	6.34	6.93
	50–60		Ck	46.2	46.0	30.8	34.8	14.0	12.6	9.1	6.7	18	20.5	0.69	1.90	7.12	7.84	6.70	7.11
446	0–3	RL	Ah1	56.5	38.0	30.2	18.7	9.6	14.3	3.6	29.1	6	10	13.8	13.8	7.22	7.55	6.58	6.89
	15–20		Ah2	60.9	43.2	20.4	16.3	11.8	13.5	6.8	26.9	18	15.5	9.30	6.90	7.19	7.74	6.70	6.98
	20–40		AC	49.2	45.7	26.5	18.7	13.1	13.4	11.3	22.2	26	30	8.04	3.10	7.57	7.72	6.99	7.04
	60–70		Ck	44.3	53.4	16.1	23.9	17.2	12.6	22.3	10.1	62	39	1.03	1.10	7.52	7.96	7.02	7.10
447	0–3	RL	Ah1	42.7	39.9	27.5	24.7	19.0	23.6	10.8	11.9	30	45	13.09	11.73	7.50	7.68	7.04	7.14
	20–30		Ah2	41.9	43.7	24.4	26.0	19.9	18.9	13.8	11.4	54	48	6.66	8.28	7.68	7.84	7.12	7.23
	70–80		Ck	42.4	45.9	14.2	26.2	17.1	17.0	26.4	10.9	76	56	1.28	1.79	7.75	7.93	7.22	7.39
451	5–10	EL	Ah	47.6	45.4	37.6	33.1	11.7	16.9	3.1	4.6	2	9.5	11.71	12.42	7.46	7.67	7.13	6.96
	30–40		Bw	44.4	51.5	39.0	36.6	11.3	10.2	5.3	1.7	7	7	5.97	7.59	7.63	7.91	7.26	7.05
	70–80		Ck	47.1	47.0	34.3	40.2	13.7	11.8	4.9	1.0	20	8	2.56	2.76	7.60	7.95	7.20	7.11
452	0–5	RL	Ah	42.0	51.7	36.3	37.5	13.7	10.6	8.0	0.2	10	3.5	13.80	17.25	7.48	7.50	7.30	6.90
	15–25		AC	48.0	45.4	31.1	31.7	11.1	15.8	9.8	7.1	13	9	11.02	8.28	7.47	7.61	7.07	6.95
453	5–10	EL	Ah	48.1	46.6	37.3	23.5	12.5	12.1	2.1	17.8	0.5	0.75	6.89	6.90	7.05	7.50	6.54	6.78
	15–25		AB	53.0	47.1	31.0	34.5	12.4	15.8	3.5	2.6	2	6.2	4.59	2.07	7.00	7.76	6.49	6.87
	60–80		Ck	61.2	44.0	18.4	32.1	13.0	18.3	7.4	5.6	92	26	1.91	1.24	7.66	7.98	7.11	7.24
455	5–10	ML	Ah1	53.5	51.3	28.4	22.0	13.3	12.6	4.9	14.1	0.5	1.3	11.71	9.66	7.22	7.42	6.59	6.88
	15–25		Ah2	59.1	50.7	29.9	21.8	9.3	11.0	1.8	16.5	0.5	1.5	6.20	8.97	6.75	7.43	6.12	6.86
	50–60		Ck	45.3	58.8	13.7	21.7	8.7	12.3	32.3	7.2	96	26	1.17	1.37	7.10	7.65	6.75	6.90
Chernozems																			
405	1–10	HC	Ah	38.0	53.5	34.0	31.6	22.7	10.8	5.3	4.1	1.5	5	8.30	6.90	7.19	7.63	6.50	7.31
	25–30		AC	38.1	58.7	31.0	27.0	22.9	13.1	8.0	1.2	2	9.5	3.79	2.76	7.12	7.67	6.74	7.43
	60–75		Ck	48.4	55.0	30.5	29.8	17.9	15.0	3.2	0.2	8	31	1.24	0.83	7.60	8.40	7.19	7.67
407	2–5	HC	Ah1	33.5	44.3	42.4	14.9	22.8	30.9	1.3	9.9	7.5	20.5	12.4					
	10–15		Ah2	37.0	43.6	40.1	33.6	20.0	20.9	2.9	2.0	12	24.5	4.59					
	40–50		Ck	45.0	63.7	38.0	19.5	15.4	15.5	1.6	1.3	20.5	30	1.08					
409	2–5	HC	Ah1	45.9	50.4	36.1	29.7	16.3	18.1	1.7	1.9	1	11	12.4					
	10–15		Ah2	48.3	44.9	37.9	38.3	12.4	16.0	1.4	0.7	3.5	26	5.34					
	40–50		Ck	38.9	46.5	37.2	38.4	21.0	14.8	3.0	0.3	18	18	1.57					
420	2–5	LC	Ah1	46.3	39.5	35.7	36.9	14.9	22.2	3.1	1.4	6	5.4	6.90	8.28	7.35	7.49	7.02	7.20
	20–30		Ah2	46.8	42.1	35.7	38.5	12.3	18.1	5.2	1.3	10	6.4	6.20	6.90	7.40	7.68	7.09	7.12
	50–60		Bt	45.9	58.2	30.7	32.7	14.6	8.7	8.8	0.5	34	32	2.53	1.79	7.39	8.06	7.05	7.20
	80–90		Ck	66.7	53.3	22.0	30.0	9.1	12.4	2.3	4.3	54	54	0.14	1.38	7.57	8.04	7.12	7.32
434	0–3	LC	Ah1	38.0	43.3	40.6	33.9	15.2	14.3	6.2	8.5	23	0	18.4	6.98	7.54	6.03	6.97	5.33
	10–20		Ah2	33.4	40.6	34.9	33.3	21.7	23.3	10.0	2.8	22	0	8.96	2.76	7.50	4.88	7.02	3.43
	50–70		Ck	36.4	42.9	31.0	36.3	24.5	17.1	8.1	3.6	38	0	1.03	0.34	7.65	4.71	7.11	3.36

LC: Luvic chernozem; HC: Haplic chernozem; ML: Mollic leptosol; EL: Eutric leptosol; RL: Renzdic leptosol; CR: Calcaric regosol; HL: Haplic luvisol

References

Ae, N., Arihara, J., Okada, K., Srinivasan, A. (2001): *Plant Nutrient Acquisition. New Perspectives.* Springer, Tokyo, Berlin.

Almer, B., Dickson, W., Ekstrom, C., Hornstrom, E., Miller, U. (1974): Effects of acidification on Swedish lakes. *Ambio*, **3**, 30–36.

Ashman, M. R., Puri, G. (2005): *Essential Soil Science: a Clear and Concise Introduction to Soil Science.* Blackwell Sci. Publ., Oxford.

Billamboz, A. (2003): Tree rings and wetland occupation in southwest Germany between 2000 and 500 BC: dendroarchaeology beyond dating in tribute to F. H. Schweingruber. *Tree-Ring Research,* **59**, 37–49.

Billett, M. F., Parker-Jervis, F., Fitzpatrick, E. A., Cresser, M. S. (1990): Forest soil chemical changes between 1949/50 and 1987. *J. Soil Sci.* **41,** 133–145.

Binkley, D., Richter, D. (1987): Nutrient cycles and H+ budgets of forest ecosystems. *Advances in Ecological Research*, **16**, 2–49.

Boero, V., Premoli, A., Melis, P., Barberis, E., Arduino, E. (1992): Influence of climate on the iron oxide mineralogy of Terra Rossa. *Clays Clay Miner*., **40,** 8–13.

Bonneau, M., Souchier, B. (1982): *Pedology, Constituents and Properties of Soil.* Academic Press, New York, U.S.A.

Bormann, F. H., Likens, G. E. (1979): *Pattern and Process in a Forested Ecosystem*. Springer, New York.

Boyle, J. R., Powers, R. F. (2001): *Forest Soils and Ecosystem Sustainability*. Elsevier, Amsterdam.

Brady, N. C., Weil, R. R. (1999): *The Nature and Properties of Soils*. 12th ed. Prentice Hall, New Jersey.

Bredemeier, M., Matzner, E., Ulrich, B. (1990): Internal and external proton load to forest soils in northern Germany. *J. Environ. Qual*., **19,** 469–477.

Catt, J. A. (1990): Paleopedology manual. *Quatern. Int.*, **6,** 1–95.

Chytrý, M., Danihelka, J. (1993): Long-term changes in the field layer of oak and oak-hornbeam forests under the impact of deer and mouflon. *Folia Geobot. Phytotx*., **28,** 225–245.

Coch, T. (2003): Strukturelle Klassifikation der Niederwälder im Zentralen Kaiserstuhl als Grundlage von Pflege- und Entwicklungskonzepten. *Mitt. bad. Landesver. Naturkunde u. Naturschutz*, **18,** 97–117.

Courtney, F. M., Trudgill, S. T. (1993): *The Soil: An Introduction to Soil Study*. Hodder & Stoughton, London.

Cresser, M., Killham, K., Edwards, T. (1993): *Soil Chemistry and Its Implications*. Cambridge University Press, UK.

Danihelka, J. (2003): *Pálava na prahu třetího tisíciletí.* Správa chráněných krajinných oblastí České republiky, Správa chráněné krajinné oblasti Pálava, Mikulov. (Pálava at the beginning of 3rd millennium.) (Report on protected areas in the Czech Republic. Report on protected region of Pálava Mikulov.) CHKO Pálava, Mikulov.

Dolman, A. J., Hall, A. J., Kavvas, M. L., Oki, T., Pomeroy, J. W. (2001): *Soil-Vegetation-Atmosphere Transfer Schemes and Large-Scale Hydrological Models.* Inter. Ass. Hydrol. Sciences, Wallingford, U.K.

Falkengren-Grerup, U. (1986): Soil acidification and vegetation changes in deciduous forest in southern Sweden. *Oecologia*, **70,** 339–347.

Falkengren-Grerup, U. (1990): Distribution of field layer species in Swedish deciduous forests in 1929–54 and 1979–88 as related to soil pH. *Vegetatio*, **86,** 143–150.

Falkengren-Grerup, U., Tyler, G. (1991): Changes of cation pools of the topsoil in south Swedish beech forests between 1979–1989. *Scand. J. For. Res*., **6,** 145–152.

Foth, H. (1991): *Fundamentals of Soil Science*. Wiley, Chichester, U.K.

Fuller, R. J., Peterken, G. F. (1996): Woodland and scrub. pp. 327–361. In: Sutherland, W. J., Hill, D. A. (eds.), *Managing Habitats for Conservation*. Cambridge University Press, Cambridge.

Havránek, T. (1993): *Statistika pro biologické a lékařské vědy*. (Statistics for biological and medicinal sciences.) Academia, Praha.

Hédl, R. (2005): *Srovnání stavu lesních ekosystémů NPR Děvín po 50 letech přirozené sukcese.* (Comparison of the condition of forest ecosystem. Nature protected region (NPR) Devin after 50 years of Natural Succession.) Ph.D. Thesis, Mendel University of Agriculture and Forestry, Brno.

Heroldová, M. (2003): Potravní strategie kopytníků na Pavlovských vrších. pp. 81–84. In: Danihelka, J. (ed.), *Pálava na prahu třetího tisíciletí*. Správa chráněných krajinných oblastí České republiky, Správa chráněné krajinné oblasti Pálava, Mikulov. (Pálava at the beginning of the 3rd millennium. Report on protected areas in the Czech Republic. Report on protected region of Pálava Mikulov.) CHKO Pálava, Mikulov.

Hofmeister, J., Mihaljevič, M., Hošek, J., Sádlo, J. (2002): Eutrophication of deciduous forests in the Bohemian Karst (Czech Republic): the role of nitrogen and phosphorus. *Forest Ecol. Manag.*, **169,** 213–230.

Holliday, V. T. (1988): Genesis of the late-Holocene soil chronosequence at the Lubbock Lake archeological site, Texas. *Ann. Assoc. Am. Geogr.*, **78,** 594–610.

Horák, J. (1967): *Lesní typy Pavlovských kopců.* (Forest types on the Pavlovsky Hills.) Doctoral Thesis, Vysoká škola zemědělská, Brno.

Horák, J. (1969): Waldtypen der Pavlovské kopce (Pollauer Berge). *Přírodovědné práce ústavů Československé akademie věd v Brně*, **3,** 1–40.

Hruška, J., Kohler, S., Laudon, H., Bishop, K. (2003): Is a universal model of organic acidity possible: Comparison of the acid/base properties of dissolved organic carbon in the boreal and temperate zones. *Environ. Sci. Technol.*, **37,** 1726–1730.

Hruška, J., Moldon, B., Krám, P. (2002): Recovery from acidification in central Europe – observed and predicted changes of soil and streamwater chemistry in the Lysina catchment, Czech Republic. *Environ. Pollut.*, **120,** 261–274.

ISSS-ISRIC-FAO (1998): World reference basis for soil resources. *World Soil Resources Reports 84*. FAO, Rome.

Juo, A. S. R., Franzluebbers, K. (2003): *Tropical Soils. Properties and Management for Sustainable Agriculture.* Oxford University Press, Oxford.

Kalvová, J. (2000): *The regular monitoring of climate changes, an estimation of changes in the variability and frequency of extreme climatological phenomena and the precision of climate development scenarios in the Czech Republic*. MSc thesis. Faculty of Mathematics and Physics, Charles University, Prague.

Karlen, D. L., Ditzler, C. A., Andrews, S. S. (2003): Soil duality: why and how? *Geoderma,* **114,** 143–144.

Kauppi, P., Posch, M., Kauppi, L., Kämäri, J. (1990): Modelling soil acidification in Europe. pp. 179–221. In: Alfami, J., Shaw, R., Hordijk, L. (eds.), *The Rains Model of Acidification. Science and Strategies in Europe*. Kluwer, Dordrecht.

Kopecký, J. (1928): *Soil Science. Part A: Soil Physics for Agricultural Soils* (In Czech). Ministry of Agriculture, Prague.

Kreitz, S., Anderson, T. H. (1997): Substrate utilization patterns of extractable and non-extractable fractions in neutral and acidic beech forest soils. pp. 149–160. In: Insam, H., Rangger, A. (eds.), *Microbial Communities. Functional versus Structural Approaches*. Springer Verlag, Berlin.

Laník, J., Halada, J. (1956): *Soil Laboratory Analyses* (in Czech). Státní zemědělské nakladatelství, Praha.

Lükewille, A., Bredemeier, B., Ulrich, B. (1993): Input-output relations of major ions in European forest ecosystems. *Agron. Ecosyst. Environ.*, **47,** 175–184.

Matthews, J. D. (2001): *Silvicultural Systems*. Oxford University Press, Oxford.

Meiwes, K. J., Khanna, P. K., Ulrich, B. (1986): Parameters for describing soil acidification and their relevance to the stability of forest ecosystems. *Forest Ecol. Manag.*, **15,** 161–179.

Mengel, K., Kirkby, E. A. (2001): *Principles of Plant Nutrition*. 5th ed. Kluwer Academic Publishers, Dordrecht.

Moffat, A. J. (2003): Indicators of soil quality for UK forestry. *Forestry*, **76,** 547–568.

Novák, V. (1950): *The Guide to Practical Soil Scientifical Analyses* (in Czech). Agricultural University, Brno.

Pelíšek, J. (1964): *Forest Soil Science*. SZN, Prague.

Puhe, J., Ulrich, B., Dohrenbush, A. (2001): Global climate change and human impacts on forest ecosystems - Postglacial development, present situation and future trends in Central Europe. *Ecological Studies*, Vol. 143. Springer, Berlin, Heidelberg.

Purdon, M., Cienciala, E., Metelka, V., Beranova, J., Hunova, I., Cerny, M. (2004): Regional variation in forest health under long-term air pollution mitigated by lithological conditions. *Forest Ecol. Manag.*, **195,** 355–371.

Rackham, O. (2003): *Ancient Woodland. Its History, Vegetation and Uses in England*. 2nd ed. Castlepoint Press, UK.

Reimoser, F., Gossow, H. (1996): Impact of ungulates on forest vegetation and its dependence on the silvicultural system. *Forest Ecol. Manag.*, **88,** 107–119.

Rejšek, K. (2004): The HadCH2 climate change model, elevated CO_2 model (SRES A2) and assessments on their likely impacts on forest soils in the Czech Republic. *Ekológia (Bratislava)*, **23,** Supplement 2/2004, 80–87.

Retallack, G. J. (2001): *Soils of the Past. An Introduction to Paleopedology*. 2nd ed. Blackwell, Oxford.

Růžičková, E., Růžička, M., Zeman, A., Kadlec, J. (2003): *Kvartérní klastické sedimenty České republiky*. (Quaternary clastic sediments in Czech Republic.) Česká geologická služba, Praha.

Schaetzl, R., Anderson, S. (2005): *Soils: Genesis and Geomorphology*. Cambridge University Press, Cambridge.

Sokal, R. R., Rohlf, F. J. (1981): *Biometry*. 2nd ed. Freeman and Co., San Francisco, U.S.A.

StatSoft, Inc. (2001): *STATISTICA (data analysis software system), version 6*. URL: www.statsoft.com.

Sumner, M. E. (2000): *Handbook of Soil Science*. CRC Press, Boca Raton, FL, U.S.A.

Sutcliffe, D. W., Carrick, T. R., Heron, J., Rigg, E., Talling, J. F., Woolf, C., Lund, J. W. G. (1982): Long-term and seasonal changes in the chemical composition of precipitation and surface waters of lakes and tarns in the English Lake District. *Freshwater Biol.*, **12,** 451–506.

Szabó, P. (2005): *Woodland and Forests in Medieval Hungary*. Archaeopress, Oxford.

Válek, B. (1954): Soil reaction (in Czech). pp. 520–532. In: Klika, J., Novák, V., Gregor, A. (eds.), *Praktikum fytocenologie, ekologie, klimatologie a půdoznalství*. Czechoslovak Academy of Science Publishing House, Prague.

Van Breemen, N. (1993): Soils as biotic constructs favouring net primary productivity. *Geoderma*, **57,** 183–211.

Van der Putten, W. H. (1997): Plant-soil feedback as a selective force. *Trends Ecol. Evol.*, **12,** 169–170.

Vetter, S., Fox, O., Eksmitt, K., Wolters, V. (2004): Limitations of fauna effects on soil carbon flow: density dependence, biotic regulation and mutual inhibition. *Soil Biol. Biochem.*, **36,** 387–397.

Violante, A., Huang, P.M., Bollag, J.-M., Gianfreda, L. (2002): *Soil Mineral-Organic Matter-Microorganism Interactions and Ecosystem Health. Vol. 28B: Ecological Significance of the Interactions Among Clay Minerals, Organic Matter and Soil Biota.* Elsevier, Amsterdam.

Walkley, A., Black, I. A. (1934): An examination of the Dedtfareff Method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* **37,** 29–38.

White, R. E. (1997): *Principles and Practice of Soil Science: The Soil as a Natural Resource*. Blackwell Sci. Publisers, Oxford, U.K.

Corresponding author: K. Rejšek
Fax: +420-5-45211422
E-mail: kr@mendelu.cz