Effect of medieval farming activities on elemental composition of soils – case study of deserted village Regenholz (Czech Republic)

Vliv středověkého zemědělství na prvkové složení půd – případová studie ze zaniklé vsi Regenholz (Česká republika)

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Abstract
Regenholz is a deserted medieval village existing approximately between the 13th and 15th centuries. It originated in the colonisation period when the villages were usually founded in upland regions of Central Europe in the High Middle Ages. The study presents the results of a research based on geochemical and spatial analyses of one of the village's field areas. The aim of the study was to reveal the spatial characteristics of the elemental composition of the previously ploughed soils which are now covered by forest. The analysed field area comprised bundles of 13 strip plots, which were approximately from 30 to 40 meters (up to 60 meters in two cases) wide and 300 meters long. The village and its fields were adjacent to the village Lovětín, which was analysed and published earlier. This made it possible to compare the geochemistry of the deserted fields of both villages with the same natural conditions and historical development. The soil samples were measured for elemental composition by portable XRF. The composition was dominated by elements generally interpreted as past human activity indicators: P, Zn, Mn, and Sr. Past human presence was represented mainly by Cu and partially by Mn content (P and Sr showed similar trends). The obtained results were compared with the data from the adjacent village Lovětín: the results were similar just by comparing the PCA data. The past human activity indicators reached less spatial diversity than those of natural factors.

Abstrakt
Regenholz je zaniklá středověká ves, která existovala přibližně ve 13. až 15. století. Její vznik spojujeme s vrcholně středověkým sídelním postupem do vyšších poloh. Studie představuje výsledky výzkumu založeného na geochemických a prostorových analýzách části plužiny vsi. Cílem výzkumu bylo odhalit prostorové charakteristiky prvkového složení v minulosti obdělávaných půd, které jsou nyní pokryty lesem. Analyzována byla plocha tratě složené ze 13 pásových parcel, které byly přibližně 30 až 40 metrů (ve dvou případech až 60 metrů) široké a 300 metrů dlouhé. Ves Regenholz sousedila se vsí Lovětín, jež byla analyzována již dříve a výsledky byly publikovány samostatně. To umožnilo porovnat geochemii bývalých středověkých polí obou vsí, které fungovaly ve víceméně totožných přírodních podmínkách a prošly obdobným historickým vývojem. U vzorků půdy bylo změřeno prvkové složení pomocí přenosného XRF. Ve složení převažovaly prvky obecně interpretované jako indikátory lidské činnosti v minulosti: P, Zn, Mn a Sr. Minulé lidské aktivity byly především reprezentovány obsahem Cu a částečně Mn (P a Sr vykazovaly podobné trendy). Získané výsledky byly porovnány s daty ze sousední vsi Lovětín se závěrem, že si jsou podobné jen při porovnání dat získaných z PCA. Doklady minulé lidské aktivity dosahovaly menší prostorové diverzity než doklady přírodních faktorů.

Keywords: Historic land use – past human impact – arable fields – multi-element analysis – spatial diversity – geoarchaeology – field patterns – Bohemian-Moravian upland – Later Middle Ages – 1200–1500

Klíčová slova: historický land-use – vliv člověka v minulosti – pole – víceprvková analýza – prostorová diverzita – geoarcheologie – plužina – Českomoravská vrchovina – mladší středověk – 1200–1500

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1. Introduction

The human impact on the environment has its origins in the distant past; awareness of this phenomenon led to the establishment of the term "Anthropocene" (*Crutzen – Stoermer 2000*). The importance of the study of the past landscape and environment is generally accepted for its cultural importance and for its contribution to the interdisciplinary research (e.g., *Antrop 2005*; *Yu et al. 2012*; *Ellis et al. 2016*). One of its aims is the study of the soil environment influenced by economic and agricultural activities (e.g., *Bork et al. 1998*; *Kristiansen 2001*; *Walkington 2010*) or by settlement activities (*Gojda – Hejcman 2012*; *Hejcman et al. 2013b*; *Salisbury 2013*). This impact is reflected by the soil spatial distribution (*Kristiansen 2001*), by the spatial distribution of elemental composition (*Entwistle et al. 1998, 2000*; *Wilson et al. 2005, 2006, 2008, 2009*) as well as by the current flora (*Dambrine et al. 2007*; *Dupouey et al. 2002*) or microbiota (*Diedhiou et al. 2009*).

The Central European region is characterised inter alia by numerous deserted medieval settlements: the majority of today's forested areas are actually secondary forests on former agricultural areas – in various regions there was a significant desertion of villages in Late Middle Ages (up to 10–50% of villages depending on the region; for Central Europe *Abel 1976*; *Poschlod 2017,* 87–88; for the Czech Republic cf. *Klápště 2012*, 274–304; *2016*, 15–39). Studying medieval settlements has a special position in the study of the past human impact on the landscape by introducing more qualitative aspects than the study of protohistoric and prehistoric times. The medieval era brought new technologies, new types of landscape structure and agricultural management as well as a broader colonization (*Klápště 2012*; *2016*). Many of these new settlements were abandoned already in the Middle Ages, their up-built areas and fields returned to the forests, but the impact on the soils has remained imprinted in them (*Hejcman et al. 2013a*). Despite intensive research of the deserted medieval settlements and their surface relicts especially (summarized in *Čapek – Holata 2017*; e.g., *Smetánka – Klápště 1981*; *Smetánka 1988*; *Černý 1992*; *Vařeka et al. 2006*; *Klír 2016*; *Mazáčková – Doležalová – Těsnohlídek 2016*), only little attention has been paid to the impact on the soil environment by archaeology or by natural sciences with a minimal focus on the previous field's environment (with a few exceptions e.g. *Klír 2008*; *Sklenička et al. 2009*; *Součková et al. 2013*). Central European deserted medieval settlements offer interesting possibilities of research of human impact in time and space. In addition, social factors strongly influenced geochemically significant activities like fertilization (*Jones 2009*). The archaeological point of view can contribute to the knowledge of the long-term processes in soils connected to human activities and agriculture which is usually obtained through long-term experiments (*Dick 1992*). The knowledge of past practices can also contribute to modern sustainable management practices (*Dick et al. 1994*; *Goodman-Elgar 2008*).

This study, as a part of a broader research, was focused on research and analysis of the soil environment on the site of the deserted medieval village Regenholz, located in the Bohemian-Moravian Upland. The study was performed by means of exploratory multivariate analyses of elemental composition regarding its spatial aspects. The aims of this study were: i) to reveal the geochemical patterns in the medieval fields; ii) to compare the results with the village Lovětín studied before and located ca 3 km from Regenholz; and iii) to assess potential diversity among the field strips.

2. Materials and methods

2.1 Study site

The village Regenholz was located approximately 5 kilometres east of the town Třešť in the Bohemian-Moravian Upland (cadastral area of Sokolíčko; the approximate centre of the researched area: 49°18‘55“N, 15°36‘21“E) – *Fig. 1*. There were approximately 14 farmsteads in the village. The village was mentioned in the written sources for the first time in 1359. Nevertheless, it can be assumed, based on the context of medieval colonisation, that the village already existed in the 13th century. The first record describing the village as abandoned was dated back to 1466 (*Navrátil 1986*). The site and the village have been researched up to now only by historiographical methods and by topographical survey for surface agricultural remains (*Navrátil 1986*). The remains were represented by the borders of the bundles of strips, the individual strip plots, and flat ridge belts (parts of one strip plot), all of them are a product of ploughing. There were usually from 6 to 12 ridge belts in one strip plot; the ridge belts were from 3 to 4 metres wide. Strip plots are slightly visible today (but not as well as in the 1980s), the ridge belts are not well visible or are not visible at all. The agricultural management of the farmland was common for peasants: all strip plots in every bundle (such as those researched in this study) were managed in the same way every year (the so-called communal three-field fallow system, using the rotation of winter and spring crops, and by being left fallow). The former built-up area and mainly the fields were naturally reforested after the abandonment of the vil-

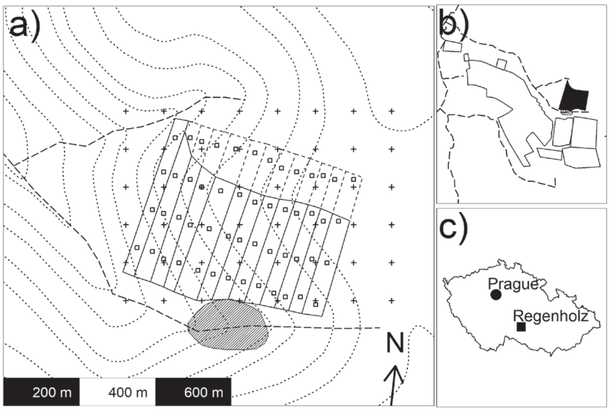

Fig. 1. The design of research (a), plan of all the village's fields (b) and the localization of a deserted village in the Czech Republic (c). Features on Figure 1a: built-up area is marked by hatched polygon, dashed longer lines depict water streams, dashed shorter lines depict altitude contours. Thin full lines depict the fields in 13 parcels. Dashed lines depict prolongation of parcels. Crosses indicate sampling points of the regular 100 m grid; squares depict the areas of group sampling (six randomly placed samples in every square). Features on Figure 1b: hatched polygon depicts built-up area, lines depict village fields, black polygon depicts researched field, dashed lines depict water streams. The position of fields is based on georeferenced documentation image by *Navrátil 1986*. Features on Figure 1c: full line depicts borders of the Czech Republic. The black circle marks the position of its capital Prague and the black square marks the position of researched village Regenholz. – *Obr. 1.* Design výzkumu (a), plán plužiny (b) a lokalizace zaniklé středověké vsi v rámci České republiky (c). Členění obrázku 1a: intravilán je vyznačen šrafovaným polygonem, delší přerušované čáry znázorňují vodní toky, kratší přerušované čáry znázorňují vrstevnice. Tenké plné čáry znázorňují pole rozdělená do 13 parcel. Přerušované čáry znázorňují předpokládané prodloužení parcel. Křížky označují body odběru vzorků v pravidelné 100 m síti; čtverce znázorňují oblasti odběru směsných vzorků (šest náhodně umístěných vzorků v každém čtverci). Členění obrázku 1b: intravilán je vyznačen šrafovaným polygonem, čáry znázorňují části plužiny vsi, černý polygon znázorňuje zkoumanou část plužiny, přerušované čáry znázorňují vodní toky. Poloha polí vychází z georeferencovaného dokumentačního snímku *Navrátila* (*1986*). Členění obrázku 1c: plnou čarou jsou znázorněny hranice České republiky. Černým kroužkem je vyznačena poloha hlavního města Prahy a černým čtvercem poloha zkoumané vsi Regenholz.

lage; meadow-like grass land cover was present in the built-up area at the end of the 18th century.

The village fields were placed mainly in the west and in the south from the built-up area (*Fig. 1*), the researched field area was placed in the north. The area was chosen for the research due to its preserved state (the remains of plot borders were visible in the terrain) and for its close connection to the village. There were 13 strip plots in this field's area which was of an approximately rectangular shape except the northern border. The parcels were between 30 and 40 metres wide with the exceptions of parcels 5 (60 metres) and 13 (50 metres) – the parcels were numbered from the west to the east. There was no indication (by field observation, by LiDAR data or by *Navrátil 1986*) that any of these wider parcels could be merely two undistinguished parcels of a normal width. This diversity of the widths could be related to the socioeconomic inequalities of the peasant community (*Navrátil 1986*).

2.2 Environment

The village was located in a small basin of the spring area of a stream. Its agricultural hinterland was located on mild slopes, the altitude ranged from 600 to 650 metres above sea level. The fields were placed on the slopes of the southwestern and western expositions. The average annual air temperature is between 4 and 6°C, and the average annual precipitation total is between 800 and 1000 mm (*Tolasz et al. 2007*). The geological bedrock is made mostly of Palaeozoic and Proterozoic migmatites and gneisses (geological maps 1:50 000 by the Czech Geological Survey, available online: *https://mapy.geology.cz/geocr50/*). The rocks are categorized by the amount of migmatisation into slightly migmatised rocks in the east and strongly migmatised rocks in the west. The division is placed in the north-western to south-eastern direction. There are also quaternary colluvial and alluvial sediments mainly in the northern part of the researched area. These were also placed in the surroundings of the streams where thick fluvial and colluvial sediments of weathered material can be found.

The soil cover of the researched area consists of Dystric Cambisols accompanied by Haplic Stagnosols in the northern area of the site (soil maps of the Czech Republic 1:25 0000 by Czech National Geoportal, available online: *https://geoportal.gov.cz/*). The general soil profile on the site is characterised by approximately from 1 to 3 centimetres of organic surface horizon comprising of spruce needles or locally moss. The organic and mineral A horizon is from 1 to 5 centimetres thick. The B horizon is characterised mainly by brown tones of colour. No distinct diversity of the soil profiles was observed during the field work. The soils in the proximity of streams are characterised by gleyic processes and high organic content. The vegetation cover consists of spruce forest (*Picea abies*). There were three anthropogenic activities (besides presumed medieval agricultural activities) which could possibly influence the geochemical patterns in the researched area: forestry roads, intensively managed young forest with dense canopy and fenced areas.

2.3 Research design and methods

There were two basic research designs covering the researched area. The first was based on a regular grid of 100 metres covering all the area of fields (infields) with its near vicinity (outfields). The second design was based on a net of squares (each square with a size of 10 metres) placed in the fields – four squares in every of the 13 parcels placed 50–60, 150–160, 250–260, and 350–360 metres from the beginning of the strip plots (*Fig. 1*). Six sampling points were randomly placed in every square. The fourth row of squares (at 360 metres) was placed outside the presumed northern border of the fields (based on the field observation of *Navrátil 1986*) to test if there was a threshold also in the geochemical record. This second design was planned to be used to obtain the geochemical characteristics of every single parcel and possibly to be used for a statistical testing of the differences between them. The samples were taken by hand drilling from a depth of 10–15 centimetres (B horizon) enabling analysis of the medieval geochemical imprint not influenced by younger geochemical inputs.

The samples were air dried and then dried in a laboratory drier at 40°C for 10 hours. The fraction under 2 mm was crushed in a porcelain bowl. The analysis of the elemental composition was performed on a portable Delta Professional ED-XRF (pXRF) analyser by Olympus InnovX with Soil Geochem measurement mode (for the applications of XRF spectrometry in archaeology, see *Canti – Huisman 2015*). The method enables to measure almost the total contents of the elements. All measurements were performed for a time of 1 minute with 30 s of 10 kV beam and 30 s of 40 kV beam. The pXRF model used provides data in the form of weight ppm. The quality of the device measurements was successfully tested by BAS Rudice Ltd. (*https://www.bas.cz/*) on 55 reference materials.

Each sample was measured three times; the basic input data for the all the subsequent analyses were computed as an arithmetic mean from these three measurements. In total, 360 samples were taken and measured. It was measured 38 elements (basic setting of measurement of the device used). Selected elements with their basic statistical characteristics can be found in *Table 1*. The results from pXRF device were compared using ICP-MS. Samples for ICP-MS were extracted in aqua regia (HNO_3:HCl = 1:3) at 180°C. The results of this comparison can be seen in *Table 2* and in the *Figures 2 and 3*.

In the following analysis only some variables and elements were analysed. This was due to several reasons: i) the limits of detection of the measurement device used; ii) the validity of the pXRF data diversity according to the standard deviation of the measurements (3 sigma intervals covering approximately 99.7% of probability); and iii) the unsatisfactory results of the comparison of the pXRF data with the ICP-MS data. The first reason led to dropping the elements according to the number of NAs in the dataset. If there were only a few NAs present in the variable, the values were calculated for them (as half of the lowest measured value). In the case of a higher proportion of NAs, the variable was excluded from the following analysis. The variable was also dropped due to the unsatisfactory results of 3-sigma intervals covering

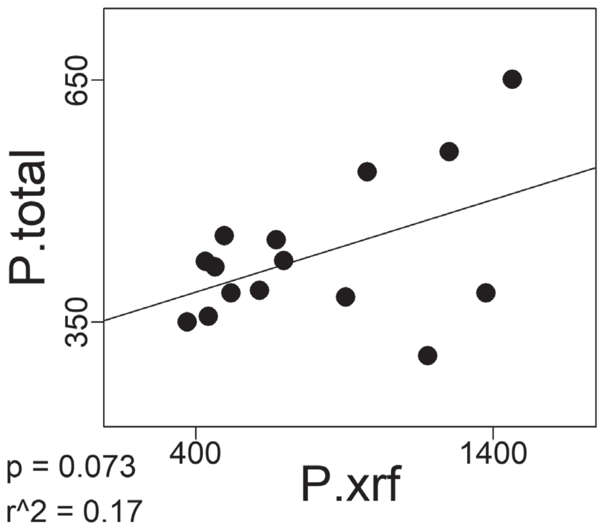

Fig. 2. Comparison of ICP-MS and XRF measurements of P. Elemental content is in mg/kg. – *Obr. 2.* Srovnání naměřených hodnot obsahů P z ICP-MS a XRF. Obsahy prvků jsou uvedeny v mg/kg.

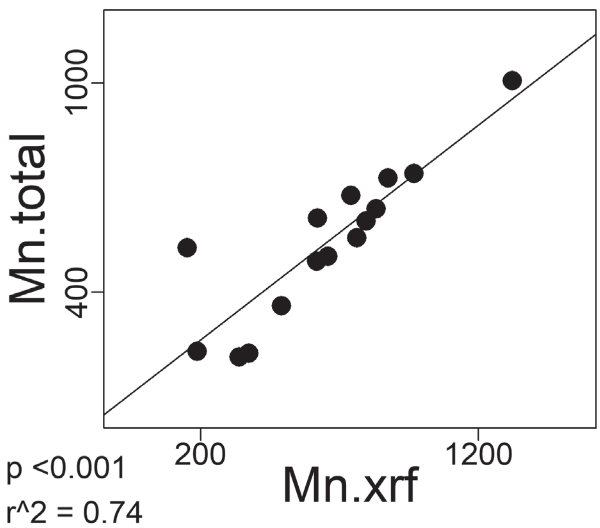

Fig. 3. Comparison of ICP-MS and XRF measurements of Mn. Elemental content is in mg/kg. – *Obr. 3.* Srovnání naměřených hodnot obsahů Mn z ICP-MS a XRF v mg/kg. Obsahy prvků jsou uvedeny v mg/kg.

the range of the data (indicated possible artefacts in the measurements). The 3-sigma intervals characteristics can be seen in *Table 1*. The third reason for excluding a variable was due to unsatisfactory results of the comparison between the pXRF data and the ICP-MS measurement (*Tab. 2*; *Fig. 2–3*).

Due to these reasons, the majority of the elements were excluded from the analysis. For the following analyses and interpretations, these elements were used: Si, K, Ti, Mn, Cu, Zn, Rb, and Pb. Some elements were described in more detail: P and Sr due to their usual anthropogenic sensitivity and Cr due to the spatial pattern of its contents.

Principal Component Analysis (PCA) was performed on a dataset after an ilr-transformation. According to *Reimann et al.* (*2008*) and *Egozcue et al.* (*2003*), ilr-transformed data of the original contents were used for further analyses. The abbreviation "ilr" stands for isometric log-ratio transformation, which should be used treating compositional (closed) data such as geochemical data (*Aitchison 1982*). For estimations of diversity between parcels, Kruskal-Wallis test was used with a post-hoc pairwise Wilcoxon test.

The statistics and GIS analyses were performed in a R statistical environment, version 3.3.2 (2016-10-31) – "Sincere Pumpkin Patch" Copyright (C) 2016 The R Foundation for Statistical Computing (*R Core Team 2016*) with the gstat (*Pebesma 2004*), raster (*Hijmans 2016)* and robCompositions (*Templ et al. 2011*) packages.

Table 1. Basic statistical description of selected elements. Length stands for the total number of samples, count for successfully measured samples and NAs for unsuccessfully measured samples leading to blank cells in the table of measurements. Sigma stands for median of 3-sigma values of the elements. Intervals depict how many 3-sigma intervals cover the range of element content. Elemental content is in mg/kg. – *Tabulka 1.* Popisná statistka vybraných chemických prvků. "Length" je celkový počet odebraných vzorků, "count" je počet úspěšně změřených vzorků a "NAs" je počet neúspěšně změřených vzorků. "Sigma" je medián hodnot 3-sigma daného prvku. "Intervals" je počet 3-sigma intervalů pokrývajících rozsah obsahu daného prvku. Obsahy prvků jsou uvedeny v mg/kg.

	P	K	Mn	Cu	Zn	Sr	Pb
Length	360	360	360	360	360	360	360
Count	352	360	360	360	360	360	360
NAs	8	0	0	0	0	0	0
Max	1 465	31 085	1 324	71	168	163	354
Mean	629	23 988	733	45	106	100	34
Sdev	225	2 080	181	7	19	17	18
Median	595	24 147	732	45	106	98	32
MAD	226	1751	177	6	19	20	6
Min	268	15 516	152	22	56	58	16
Sigma	93	194	31	6	5	2	3
Intervals	8	42	20	6	13	28	58

Table 2. Parameters of linear models between XRF and ICP-MS results. Abbreviations: p stands for p- value; r^2 stands for adjusted R-squared; b0, b1 and e are parameters of equation
y = b0 + b1x + e, where e ~ N (0, e^2); F stands for F statistic; DF stands for degrees of freedom.
Tabulka 2. Parametry lineárních modelů mezi výsledky měření XRF a ICP-MS. Zkratky: p je p-hodnota; r^2 je adjusted R-squared; b0, b1 a e jsou parametry rovnice y = b0 + b1x + e, kde e ~ N (0, e^2); F je výsledek F-testu; DF jsou stupně volnosti.

	Al	P	K	Cr	Mn	Fe	Ni	Cu	Zn	As	Sr	Pb
p	0.926	0.073	<0.001	0.177	<0.001	0.265	0.023	<0.001	<0.001	0.009	0.614	<0.001
r^2	-0.08	0.17	0.56	0.07	0.74	0.03	0.29	0.79	0.73	0.37	-0.06	0.99
b0	33064.17	341.72	601.1	37.14	139.22	23770.06	11.87	4.54	22.3	3.02	5.28	3.03
b1	-0.02	0.11	0.21	0.1	0.62	0.25	0.27	0.39	0.53	0.21	0.01	0.58
E	5782.27	82.02	831.42	6.92	110.91	4273.19	2.95	2.91	7.92	1.6	2.68	3.78
F	0.01	3.82	18.84	2.04	41.57	1.36	6.67	53.94	39.26	9.33	0.27	2310.39
DF	13	13	13	13	13	13	13	13	13	13	13	13

3. Results

3.1 XRF and ICP-MS comparison

A comparison of the selected elemental contents measured by XRF with the values measured by ICP-MS after extraction in aqua regia was performed. The comparison was performed on a set of 15 samples selected from the whole range of the pXRF analysed element's contents. Most of the elements compared did not reach a significant correlation. There was a problematic correlation, e.g., in cases of P and Sr, which are usually considered as an important human indicator; promising results were reached in cases of, e.g., K, Mn, Cu, Zn, and Pb (see *Tab. 2*; *Fig. 3*).

3.2 Dataset characteristics and contents

The contents reached the usual values that can be found at the sites in the Czech Republic, and they were mostly of normal distribution or similar to it. The exceptions were those elements following more likely log-normal distribution (P) and those indicating bi-modal distribution (Mn, Zn, Sr). The contents of the selected elements in ppm were displayed using inverse distance weighting (IDW), which showed that these chemical elements in the area of the former fields are spatially distributed only in certain parts of the study area (*Tab. 1*; *Fig. 4–9*).

3.3 PCA

PCA extracted 8 principal components (therefore PC, *Tab. 3*; *Fig. 10–13*). The first four components explained over 91% of the data variability. These components were dominated by a strong relationship to one element in every case, consecutively to: Mn, Pb, Zn, and Cu. PC1 was linked to Mn (the strongest loading recorded: 0.84), and then weakier to Cu (-0.34) and Zn (0.24). PC2 was connected mainly to Pb (0.7), to Zn (0.47), and to Cu (-0.35). PC3 was linked to Zn (0.71) and Cu (0.43), and negatively to Pb (-0.42). PC4 was linked to Cu (0.69), to Pb (0.42) and negatively also to Zn (-0.30). All other components were linked to elements usually linked to natural factors more than the anthropogenic factors (Rb, Si, Ti).

3.4 Spatial patterns of elements contents and scores of PCs

There were several spatial patterns of elements contents. The major pattern was the distinction between western and eastern sides of the researched area (Ni and Sr). Some of the elements were strongly manifested more in parts of the researched area – gradient between the north-western and south-eastern corner of the fields (Si, K, Zr, Pb, and Th) or between the south-western and north-eastern corners (P, Mn, Zn); Rb recorded a combination of these patterns. For some of these elements, see *Figures 4, 6, 8, and 9*.

There was a spatial relation to the fields in case of these elements: Ti, Cr, Ni, Cu, and Sr (*Fig. 5–7*). Although the distribution did not record any strict link to the village itself, there was an indication of respecting the fields' borders. The most interesting was the content of Cr, which seemed to respect the northern border of the fields – the forest road. None of these elements was clearly or unambiguously spatially linked to the village. It is also important to say that P, Zn and Mn which recorded very distinct patterns did not respect the historical borders of the fields or village. Their spatial distribution was manifested mainly outside of the forest road – i.e., outside the positively documented fields' area.

Spatial distribution of PCs roughly corresponded to the distribution of the elements linked to them. Therefore PC1-PC3 (correlated mainly with Mn, Pb and Zn) were manifested mainly in eastern part of the fields' area. PC4 connected to Cu, Pb and Mn was spatially linked to the village (*Fig. 10–13*).

Table 3. Eigenvalues and explained variability of PCA. Loadings of PCs and elements are presented. Those loadings greater or lesser than 0.5 or -0.5 respectively are marked ***bold and underlined***. – *Tabulka 3.* Vlastní čísla a vysvětlená variabilita PCA. Jsou prezentovány hodnoty zátěže pro všechny komponenty a prvky. Hodnoty zátěže, jejichž hodnota je větší nebo menší než 0,5 či -0,5, jsou zvýrazněny ***tučně a podtrženy***.

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Si					0.31	**–0.70**	0.37	
K				–0.26	–0.24	0.21		**–0.80**
Ti						**0.66**	0.42	0.41
Mn	**0.84**	–0.35		0.19				
Cu	–0.34		0.43	**0.69**				
Zn	0.24	0.47	**0.71**	–0.30				
Rb					**–0.78**		–0.22	0.41
Pb		**0.70**	–0.42	0.42			0.13	
LE			–0.24		0.43		**–0.77**	
eigenvalue	0.05	0.03	0.02	0.01	0.01	0	0	0
% variability	41.37	28.32	12.3	9.02	5.22	1.57	1.25	0.97
cumulative %	41.37	69.68	81.98	91.00	96.22	97.78	99.03	100

There was not a strong relationship of the contents' or PCs' spatial distributions to the site environmental characteristics or modern forestry management. The general western – eastern distinction of some elements was the only potential indication of possible relation to geology. This gradient (W-E) is also a gradient for the degree of the migmatisation of the rocks. The relation of the contents and PCs to geology was tested using Kruskal-Wallis test: it was strong in the western part of the studied area and weak in the eastern part of the studied area. According to this test there was a statistically significant difference recorded in the contents of elements: P, S, Ca, Cr, Mn, Fe, Cu, Zn, As, Sr, Pb, and Th. The difference was also found for PCs 1–4.

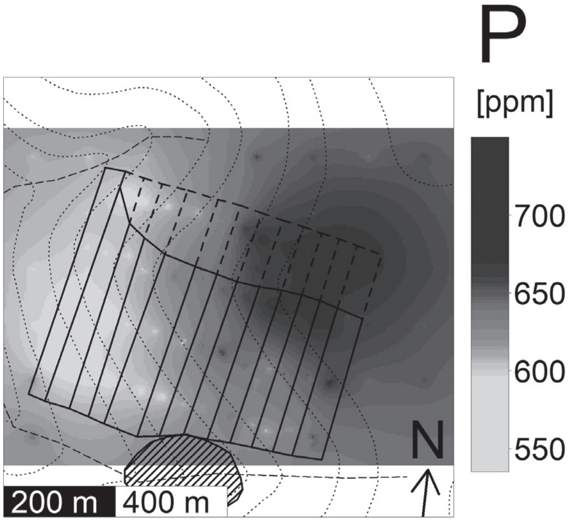

Fig. 4. Interpolation of contents of P. – *Obr. 4.* Interpolace obsahů P.

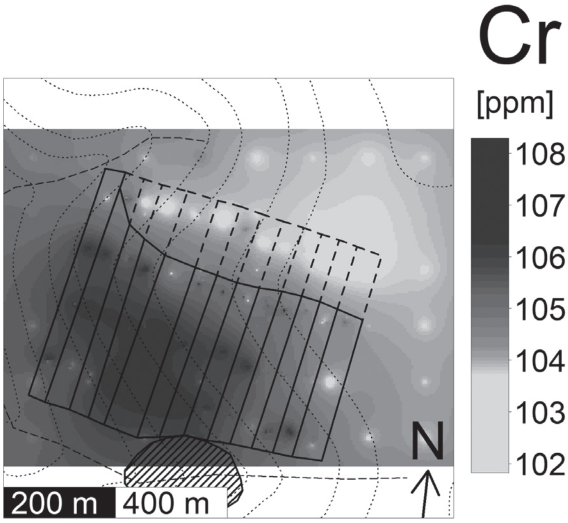

Fig. 5. Interpolation of contents of Cr. – *Obr. 5.* Interpolace obsahů Cr.

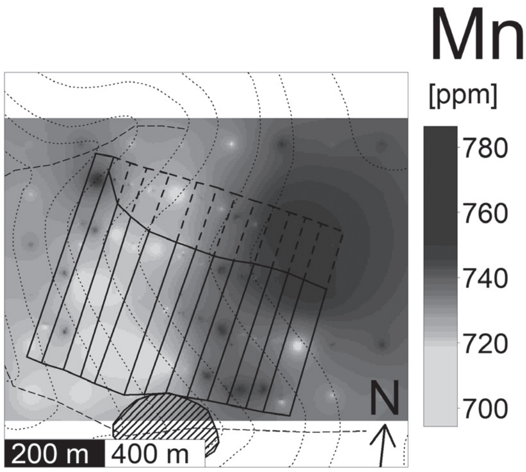

Fig. 6. Interpolation of contents of Mn. – *Obr. 6.* Interpolace obsahů Mn.

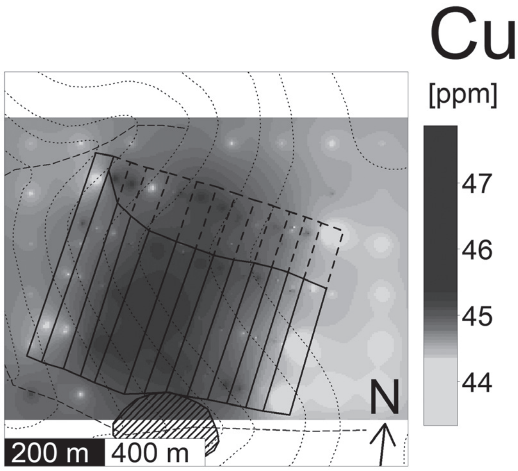

Fig. 7. Interpolation of contents of Cu. – *Obr. 7.* Interpolace obsahů Cu.

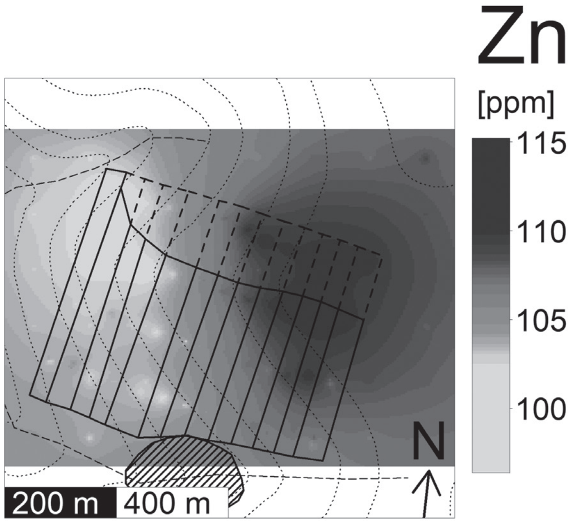

Fig. 8. Interpolation of contents of Zn. – *Obr. 8.* Interpolace obsahů Zn.

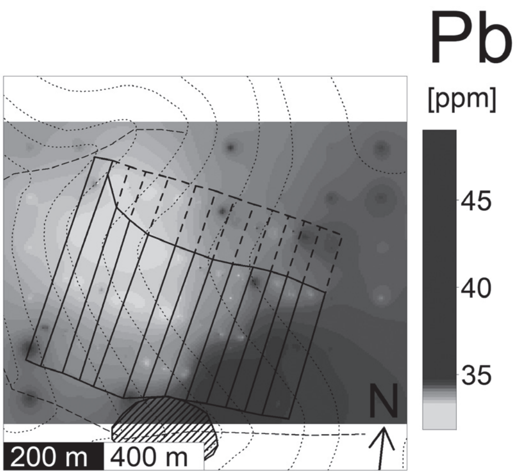

Fig. 9. Interpolation of contents of Pb. – *Obr. 9.* Interpolace obsahů Pb.

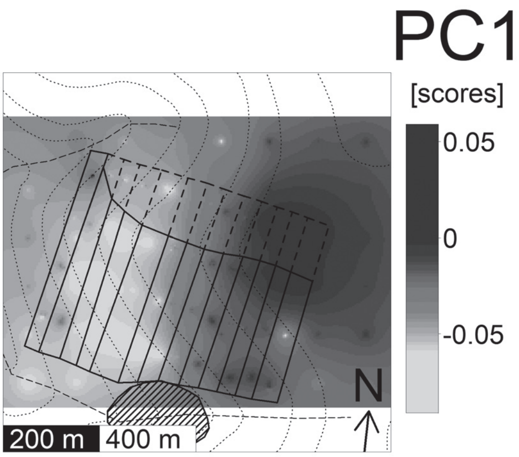

Fig. 10. Interpolation of scores of PC1. – *Obr. 10.* Interpolace skóre hodnot proměnné PC1.

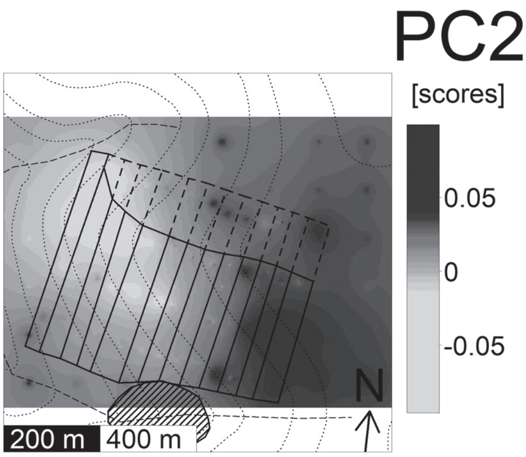

Fig. 11. Interpolation of scores of PC2. – *Obr. 11.* Interpolace skóre hodnot proměnné PC2.

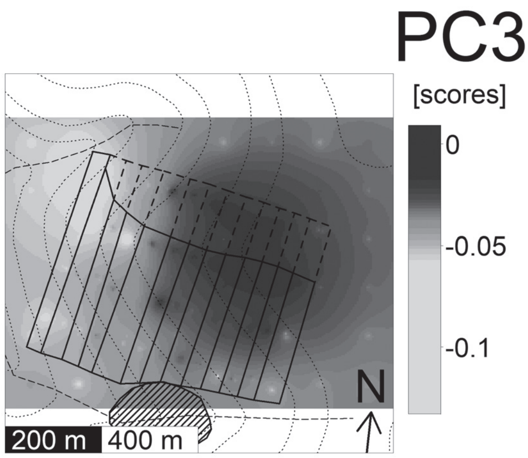

Fig. 12. Interpolation of scores of PC3. – *Obr. 12.* Interpolace skóre hodnot proměnné PC3.

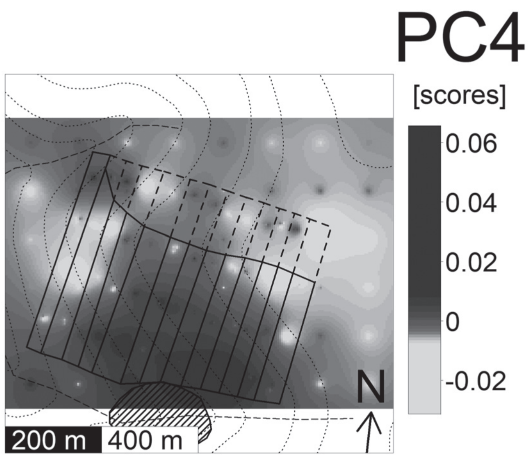

Fig. 13. Interpolation of scores of PC4. – *Obr. 13.* Interpolace hodnot skóre hodnot proměnné PC4.

4. Discussion

4.1 General interpretation

Analysing the geochemical traces in the area of deserted medieval fields is usually focused on traces of past agricultural activities – identification of manuring, its spatial distribution, intensity gradients and possible geochemical diversity among different possessions (*Horák – Klír 2017*; *Horák et al. 2018*). Such topics should contribute to a variety of areas of scientific interest from both the natural sciences and humanities, e.g., human impact on soils; spatial variability factors of soils and vegetation; human perception of landscape; and human past economic strategies (both communal and individual).

The anthropogenic factors influencing the spatial-geochemical characteristics can be identified by: i) the association of PC with known anthropogenic indicators; ii) the spatial connection to the anthropogenic features in the landscape. The PCA of the ilr-transformed data (using the R package robCompositions by *Templ et al. 2011*) helped with this as it produced a well separated pattern in elements loaded by PCs (Mn, Zn and Cu or Pb – e.g., *Davidson et al. 2007*; *Entwistle et al. 1998, 2000*; *Holliday – Gartner 2007*; *Misarti et al. 2011*; *Nielsen – Kristiansen 2014*; *Wilson et al. 2005, 2006, 2008, 2009*). The elements generally connected to the anthropogenic origin tended to be loaded by significant PCs: most of them were connected to PCs 1 to 4. These elements were usually connected to past human settlement activities or directly to manuring of agricultural areas.

4.2 Regenholz interpretation

Conclusively, Regenholz site could be characterized by manifestation of anthropogenic-linked elements Mn, Zn, Cu. The only part of the Regenholz data, which could be interpreted as possible human indicator was found in PC4 (*Fig. 13*). PCs 1–3 were indicators of other factors than medieval agriculture (possibly natural factors).

There were elements of special interest (P, Sr, Cr), which were excluded from rigorous analyses. However, P and Sr are also linked to the past human activity. Their contents and their spatial patterns in Regenholz were quite significant with clearly manifested spatial patterns but with no clear connection to the village. PCA was performed with these elements to see how they would behave in complex with other elements – P was manifested in the same way as Mn; and Sr was similar mainly to Cu. It seems that these two elements should be seen as potential anthropogenic indicators in Regenholz.

It was shown that there was a significant difference between the areas of strong and slight migmatisation both in elements and PCs. There are two possible ways of interpretation: i) the majority of data follows the geological diversity and hence this is the most influential factor at the site; and ii) such an interpretation is weakened by the fact that contents diversity was recorded mainly in contents of those elements which are usually connected with past human activity (mostly P and Zn) – such activity manifested mainly in the area of north-eastern corner of the studied area, could produce a false geological signal. This problem cannot be solved with the existing data – it could be overpassed by a better design of sampling – mainly by sampling in more levels of soil profiles (like it was performed in the case of the village Spindelbach by *Horák – Klír 2017*). The general spatial distribution of the elemental contents was also an argument against the geological influence: high (or low) contents do not cover all the areas of their geological units.

4.3 Historical interpretation

Historically there are two main topics which will be discussed: i) spatial manifestation of past human indicators – spatial distribution of human agricultural activities and ii) the diversity of such activities among landholdings.

Strong spatial manifestation was observed in the north-eastern corner of studied area (potentially geological feature represented mainly by anthropogenic indicators like P and Zn). PC4 demonstrated a different management strategy, because it was manifested in the immediate vicinity of the built-up area (*Fig. 13*).

The second topic of possessions diversity touches the ways human activities and local agrarian institutions could influence the environment in the past and the present. In general, there are two agricultural systems and field patterns: communal 'open-fields' and non-communal 'enclosed-fields' (cf. *Hopcroft 1999*, 15–45; for terminology *Uhlig–Lienau 1978*). In 'enclosed fields' (such was studied in the case of Spindelbach – *Horák – Klír 2017*), every peasant household had a spatially compact land tenure usually concentrated in one wide and long strip plot with the farmstead situated at the head of the strip. Its management was therefore individualistic and independent on the management of other parcels. In the communal 'open-fields' with a pattern of fragmented holdings (studied in Lovětín or in Regenholz), there were bundles of narrow strips – and such bundles were managed as unified and all the households were obliged to follow this unified management. This communal 'open-fields' system was connected to the medieval agricultural technique of three-field fallow system of spring crop, winter crop and fallow (which was used for grazing). The studied area of Regenholz belonged to the communal 'open-fields' system: there were 13 strip plots, but the whole bundle was managed as one unit in the way described above. The differences among the plots were tested using Kruskal-Wallis test and by the post-hoc pairwise Wilcoxon test (hence the design of sampling used was different than that used in the neighbouring village of Lovětín; *Tab. 4*).

Historically, there were two questions to answer: i) possible indications of decisive local placement of intensive management through the fields (as found in Spindelbach or Lovětín); ii) if there could be an indication of possible individual management of the fields even in the communal 'open-fields' system.

4.4 Comparison with Lovětín

Regenholz has a neighbouring village Lovětín (the distance between both sites is about 3 km). That is why it is possible to compare the results from these villages. The natural environment, historical settings and agricultural systems were the same, although the sampling designs were different (Lovětín focused on all field areas / bundles of strips; Regenholz focused on landholdings diversity in one of the bundles'). A comparison of main similarities / dissimilarities is presented in *Table 5*.

There was a significant difference between villages from the point of view of the chemical contents: in Regenholz, almost none of the elements were clearly spatially linked to the anthropogenic features – village or the fields (with slight exceptions of Cu, Pb and Cr). The situation revealed in Lovětín was the opposite: there were many elements spatially linked to the village. Potentially, this could be explained by a shorter existence of Regenholz.

In the case of Lovětín, there were more PCs representing medieval agricultural activities, but there was just one in Regenholz. This was probably due to the fact that only a small part of the fields was analysed in Regenholz. The difference was also found in the position of the anthropogenic PCs. There were PC1, PC5 and PC6 in Lovětín and PC4 in Regenholz. The fields analysed in Regenholz were located in the nearest vicinity to the village – its parallel in Lovětín would be area A (described in *Horák et al. 2018*), where mainly PC1 was manifested (PC1 explained 33.5% of the variability). On the other hand. Regenholz's PC4 in similar conditions (fields in vicinity of the village) explained just 9% of the variability. Although there was a strong manifestation of Mn in geochemical signals at both sites (strong correlation of Mn with PC1), it is possible to interpret Mn as an anthropogenic element in Lovětín due to a strong connection to the village. That interpretation was not possible in Regenholz, where Mn was manifested mainly outside the fields. To sum up: a connection to the anthropogenic influence was recorded in the cases of Sr, Zn, Cu, Mn, K, Pb, and Ni.

4.5 Soil spatial diversity

One of the interesting findings is related to the topic of spatial diversity of soils and their characteristics. As the previous studies showed, there were some human inputs which can be well spatially diversified even between the wide strip plots (Spindelbach – *Horák – Klír 2017*). In searching for such individual management in Regenholz, the results showed that all of the PCs 1–4 recorded the differences among the narrow strip plots. The result for PC4 would indicate the diversity of the individual management. This could be an interesting historical finding with consequences for research of topics like spatial diversity of soils under natural or human induced development (e.g., problematics of soil genoform and phenoform – *Droogers – Bouma 1997*). On the other hand, the diversity was observed in cases of other PCs leaving the potential to interpret the situation as the result of soil condition diversity. It should be stated that an interesting finding was the indication of pairs of parcels with differences: according to this parameter, there was substantially more diversity observed in PCs 1-3 (interpreted as with natural origin). That would lead to the interpretation that the human factor is in fact less spatially diversified than natural factors at the deserted strip plots.

The presumption that human activity – agricultural activity in the past and its spatial behaviour – has brought substantial spatial diversity into the environment turned out to be not that obvious. The interpretation should be probably such as the human activity was spatially diversified, but the natural diversity was much higher. Therefore, although there is a diversity among the strip plots in PC4, this situation could be interpreted in a way that human agricultural activity in an 'open-fields' system actually tended to reach the state of unified human indicator signals in its spatial manifestation. Therefore, on the contrary to the diversity, the situation leads to the opposite conclusion that there was probably no (distinctive) individual diversity in the management of the various strip plots in the analysed bundle.

5. Conclusion

This case study has shown that geochemical research in the archaeological contexts can be very variable and that the contexts of the data and their interpretation are closely tied together. The variability can be found even in neighbouring places of the same environmental conditions (comparison of the research in Lovětín and Regenholz).

The geochemical complex at the site Regenholz was characterised by the domination of human-related elements (Mn, Zn, and Cu). Due to the spatial distribution, it was possible to clearly interpret only PC4 linked to Cu and partially to Mn as an indication of past human activity. The interpretation of other PCs connected to the common human indicators (mainly PC1 and PC3 linked to Mn and Zn) was uncertain. The elements like P, Sr, and Cr indicated human activity (P and Sr by the connection to Mn and Cu; Cr by the spatial distribution of its content), although they have been removed from rigorous analyses.

The accuracy of the interpretations could be possibly enhanced by further research of other parts of the village fields to get a broader context and also by other methods, e.g. archaeological (excavations and analysing the spatial patterns of pottery shards distribution – archaeological evidence of manuring). Geochemistry has brought new possible interpretations and questions into the historical and archaeological documentation of historic land use and landscape patterns and surface remains. Geochemically, further research should be focused on more detailed analyses of the elements designated as possible indicators. The interesting characteristics of the anthropogenic signals were defined. They recorded lesser spatial diversity than the natural factors.

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7. References

Abel, W. 1976: Die Wüstungen des ausgehenden Mittelalters. Quellen und Forschungen zur Agrargeschichte 1. Stuttgart. 3rd edition.

Aitchison, J. 1982: The Statistical Analysis of Compositional Data, Journal of the Royal Statistical Society. Series B (Methodological) 44, 139–177.

Antrop, M. 2005: Why landscapes of the past are important for the future, Landscape and Urban Planning 70, 21–34. https://doi.org/10.1016/j.landurbplan.2003.10.002

BAS Rudice spol. s r.o., 2021: https://www.bas.cz/

Bork, H. R. – Bork, H. – Dalchow, C. – Faust, B. – Piorr, H. P. – Schatz, T. 1998: Landschaftsentwicklung in Mitteleuropa. Gotha – Stuttgart.

Canti, M. – Huisman, D. J. 2015: Scientific advances in geoarchaeology during the last twenty years, Journal of Archaeological Science 56, 96–108. https://doi.org/10.1016/j.jas.2015.02.024

Crutzen, P. J. – Stoermer, E.F. 2000: The "Anthropocene", Global Change Newsletter 41, 17–18.

Czech Geological Survey, 2020: https://mapy.geology.cz/geocr50/.

Czech National Geoportal, 2020: https://geoportal.gov.cz/.

Čapek, L. – Holata, L. 2017: General overview of medieval settlement research in the Czech Republic : Emergence and development of the field, main issues and adoption of landscape context. Revista ArkeoGazte Aldizkaria 7, 267–320.

Černý, E. 1992: Výsledky výzkumu zaniklých středověkých osad a jejich plužin. Historicko-geografická studie v regionu Drahanské vrchoviny [Results of the research of deserted medieval villages and their ploughlands: A historical-geographical study in the region of the Drahany Uplands]. Brno.

Dambrine, E. – Dupouey, J. L. – Laut, L. – Humbert, L. – Thinon, M. – Beaufils, T. – Richard, H. 2007: Present forest biodiversity patterns in France related to former Roman agriculture, Ecology 88, 1430–1439. https://doi.org/10.1890/05-1314

Davidson, D. A. – Wilson, C. A. – Meharg, A. A. – Deacon, C. – Edwards, K. J. 2007: The legacy of past manuring practices on soil contamination in remote rural areas, Environment International 33, 78–83. https://doi.org/10.1016/j.envint.2006.07.001

Dick, R. P. 1992: A review: long-term effects of agricultural systems on soil biochemical and microbial parameters, Agriculture, Ecosystems & Environment 40, 25–36. https://doi.org/10.1016/0167-8809(92)90081-L

Dick, R. P. – Sandor, J. A. – Eash, N. S. 1994: Soil enzyme activities after 1500 years of terrace agriculture in the Colca Valley, Peru, Agriculture, Ecosystems & Environment 50, 123–131. https://doi.org/10.1016/0167-8809(94)90131-7

Diedhiou, A. G. – Dupouey, J. L. – Buée, M. – Dambrine, E. – Laüt, L. – Garbaye, J. 2009: Response of ectomycorrhizal communities to past Roman occupation in an oak forest, Soil Biology and Biochemistry 41, 2206–2213. https://doi.org/10.1016/j.soilbio.2009.08.005

Droogers, P. – Bouma, J. 1997: Soil Survey Input in Exploratory Modeling of Sustainable Soil Management Practices, Soil Science Society of America Journal 61, 1704–1710. https://doi.org/10.2136/sssaj1997.03615995006100060023x

Dupouey, L. J. – Dambrine, E. – Laffite, J. D. – Moares, C. 2002: Irreversible impact of past land use on forest soils and biodiversity, Ecology 83, 2978–2984.

Egozcue, J. J. – Pawlowsky-Glahn, V. – Mateu-Figueras, G. – Barceló-Vidal, C. 2003: Isometric Logratio Transformations for Compositional Data Analysis, Mathematical Geology 35, 279–300. https://doi.org/10.1023/A:1023818214614

Ellis, E. – Maslin, M. – Boivin, N. – Bauer, A., 2016: Involve social scientists in defining the Anthropocene, Nature 540, 192–193. https://doi.org/10.1038/540192a

Entwistle, J. A. – Abrahams, P. W. – Dodgshon, R. A. 1998: Multi-Element Analysis of Soils from Scottish Historical Sites: Interpreting Land-Use History Through the Physical and Geochemical Analysis of Soil, Journal of Archaeological Science 25, 53–68. https://doi.org/10.1006/jasc.1997.0199

Entwistle, J. A. – Abrahams, P. W. – Dodgshon, R. A. 2000: The Geoarchaeological Significance and Spatial Variability of a Range of Physical and Chemical Soil Properties from a Former Habitation Site, Isle of Skye, Journal of Archaeological Science 27, 287–303. https://doi.org/10.1006/jasc.1999.0453

Gojda, M. – Hejcman, M. 2012: Cropmarks in main field crops enable the identification of a wide spectrum of buried features on archaeological sites in Central Europe, Journal of Archaeological Science 39, 1655–1664. https://doi.org/10.1016/j.jas.2012.01.023

Goodman-Elgar, M. 2008: Evaluating soil resilience in long-term cultivation: a study of pre-Columbian terraces from the Paca Valley, Peru, Journal of Archaeological Science 35, 3072–3086. https://doi.org/10.1016/j.jas.2008.06.003

Hejcman, M. – Karlík, P. – Ondráček, J. – Klír, T. 2013a: Short-Term Medieval Settlement Activities Irreversibly

Changed Forest Soils and Vegetation in Central Europe, Ecosystems 16, 652–663. https://doi.org/10.1007/s10021-013-9638-3
Hejcman, M. – Součková, K. – Gojda, M. 2013b: Prehistoric settlement activities changed soil pH, nutrient availability, and growth of contemporary crops in Central Europe, Plant and Soil 369, 131–140. https://doi.org/10.1007/s11104-012-1559-y
Hopcroft, R. L. 1999: Regions, institutions, and agrarian change in European history. Ann Arbor.
Horák, J. – Janovský, M. – Hejcman, M. – Šmejda, L. – Klír, T. 2018: Soil geochemistry of medieval arable fields in Lovětín near Třešť, Czech Republic, Catena 162, 14–22. https://doi.org/10.1016/j.catena.2017.11.014
Horák, J. – Klír, T. 2017: Pedogenesis, pedochemistry and the functional structure of the Waldhufendorf field system of the deserted medieval village Spindelbach, the Czech Republic, Interdisciplinaria Archaeologica – Natural Sciences in Archaeology 8, 43–57. https://doi.org/10.24916/iansa.2017.1.4
Hijmans, R. J. 2016: raster: Geographic Data Analysis and Modeling. R package version 2.5-8. https://CRAN.R--project.org/package=raster
Holliday, V. T. – Gartner, W. G. 2007: Methods of soil P analysis in archaeology, Journal of Archaeological Science 34, 301–333. https://doi.org/10.1016/j.jas.2006.05.004
Jones, R. 2009: Manure and the Medieval Social Order. In: J.A. Allen – N. Sharpless – T. O`Connor (eds.): Land and People. Papers in memory of John G. Evans. Prehistoric Society Research Paper 2, Oxbow Books, Oxford and Oakville, 215–225.
Klápště, J. 2012: The Czech Lands in Medieval Transformation. East Central and Eastern Europe in the Middle Ages, 450–1450, 17. Europe Leiden – Boston.
Klápště, J. 2016: The Archaeology of Prague and the Medieval Czech Lands, 1100-1600. Studies in the Archaeology of Medieval Europe Series, Equinox Publishing.
Klír, T. 2008: Osídlení zemědělsky marginálních půd v mladším středověku a raném novověku – The Settlements and Agriculture of the Margins in the Later Middle Age and Early New Age. Dissertationes Archaeologicae Brunenses / Pragensesque 5. Praha.
Klír, T. 2016: Zaniklé středověké vsi ve výzkumném záměru Ústavu pro archeologii Univerzity Karlovy v Praze. Zaniklý Spindelbach (Krušné hory), Kří a Hol (střední Čechy) – Research of Deserted Medieval Villages Conducted by the Institute of Archaeology at Charles University in Prague. Deserted Spindelbach (Ore Mountains), Kří and Hol (Central Bohemia). In: P. Nocuń – K. Fokt – A. Przybyła-Dumin, (eds.), Wieś zaginiona. Stan i perspektywy badań, (= Monografie i materiały MGPE 5) Chorzów, 17–58.
Kristiansen, S. M. 2001: Present-day soil distribution explained by prehistoric land-use: Podzol – Arenosol variation in an ancient woodland in Denmark, Geoderma 103, 273–289. https://doi.org/10.1016/S0016-7061(01)00044-1
Mazáčková, J. – Doležalová, K. – Těsnohlídek, J. 2016: Zaniklé středověké vesnice na Moravě, dějiny bádání a stav výzkumu – Deserted Medieval Villages in Moravia, History and the Current State of Research. In: P. Nocuń – K. Fokt – A. Przybyła-Dumin, (eds.), Wieś zaginiona. Stan i perspektywy badań, (= Monografie i materiały MGPE 5) Chorzów, 59–92.
Misarti, N. – Finney, B. P. – Maschner, H. 2011: Reconstructing site organization in the eastern Aleutian Islands, Alaska using multi-element chemical analysis of soils, Journal of Archaeological Science 38, 1441–1455. https://doi.org/10.1016/j.jas.2011.02.007
Navrátil, V. 1986: K povrchovému průzkumu zaniklých středověkých osad a jejich plužin na jihozápadní Moravě [On the surface research of deserted medieval villages and their ploughlands in southwest Moravian], Historická geografie 25, 201–228.
Nielsen, N. H. – Kristiansen, S. M. 2014: Identifying ancient manuring: traditional phosphate vs. multi-element analysis of archaeological soil, Journal of Archaeological Science 42, 390–398. https://doi.org/10.1016/j.jas.2013.11.013
Pebesma, E. J. 2004: Multivariable geostatistics in S: the gstat package, Computers & Geosciences 30, 683–691. https://doi.org/10.1016/j.cageo.2004.03.012
Poschlod, P. 2017: Geschichte der Kulturlandschaft. 2nd edition. Ulmer.
R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
Reimann, C. – Filzmoser, P. – Garrett, R. – Dutter, R. 2008: Statistical Data Analysis Explained. Applied Environmental Statistics with R. John Wiley and Sons.
Salisbury, R. B. 2013: Interpolating geochemical patterning of activity zones at Late Neolithic and Early Copper Age settlements in eastern Hungary, Journal of Archaeological Science 40, 926–934. https://doi.org/10.1016/j.jas.2012.10.009
Sklenička, P. – Molnárová, K. – Brabec, E. – Kumble, P. – Pittnerová, B. – Pixová, K. – Šálek, M. 2009: Remnants of medieval field patterns in the Czech Republic: Analysis of driving forces behind their disappearance with special attention to the role of hedgerows, Agriculture Ecosystems & Environment 129, 465–473. https://doi.org/10.1016/j.agee.2008.10.026
Smetánka, Z. 1988: Život středověké vesnice. Zaniklá Svídna. Památníky naší minulosti 13. [The life of a medieval village: The abandoned village of Svídna. The monuments of our history 13]. Praha.
Smetánka, Z. – Klápště, J. 1981: Geodeticko-topografický průzkum zaniklých středověkých vsí na Černokostelecku. [Geodetical-topographical survey of deserted medieval villages in the Kostelec nad Černými Lesy region], Památky archeologické 73, 416–458.
Součková, K. – Hejcman, M. – Klír, T. 2013: Medieval Farming Practices in Deserted Villages Can be Determined Based on the Nitrogen Isotopic Signature in Recent Forest Soils, Interdisciplinaria Archaeologica – Natural Sciences in Archaeology 4/1, 63–71. https://www.iansa.eu/papers/IANSA-2013-01-souckova.pdf
Templ, M. – Hron, K. – Filzmoser, P. 2011: robCompositions: an R-package for robust statistical analysis of compositional data. In: V. Pawlowsky-Glahn – A. Buccianti (eds.): Compositional Data Analysis. Theory and Applications. Chichester, John Wiley & Sons, 341–355.
Tolasz, R. et al. 2007: Climate atlas of Czechia. Praha – Olomouc.
Uhlig, H. – Lienau, C. (eds.) 1978: Flur und Flurformen – Types of Field Patterns – Le Finage agricole et sa structure parcellaire. Materialen zur Terminologie der Agrarlandschaft, Vol. I. Giessen. 2nd edition.
Vařeka, P. – Auchrechtová, A. – Hnízdilová, P. – Novák, R. – Rožmberský, P. – Veselá, R. 2006: Archeologie zaniklých středověkých vesnic na Rokycansku 1. [Archaeology of Deserted Medieval Villages in the Rokycany Region (West Bohemia) 1]. Plzeň.
Walkington, H. 2010: Soil science applications in archaeological context: A review of key challenges, Earth-Science

Reviews 103, 122–134. https://doi.org/10.1016/j.earscirev.2010.09.002
Wilson, C. A. – Cresser, M. S. – Davidson, D. A. 2006: Sequential element extraction of soils from abandoned farms: an investigation of the partitioning of anthropogenic element inputs from historic land use, Journal of Environmental Monitoring 8, 439–444. https://doi.org/10.1039/B516614D
Wilson, C. A. – Davidson, D. A. – Cresser, M. S. 2005: An evaluation of multielement analysis of historic soil contamination to differentiate space use and former function in and around abandoned farms, The Holocene 15, 1094–1099. https://doi.org/10.1191/0959683605hl881rr
Wilson, C. A. – Davidson, D. A. – Cresser, M. S. 2008: Multi-element soil analysis: an assessment of its potential as an aid to archaeological interpretation, Journal of Archaeological Science 35, 412–424. https://doi.org/10.1016/j.jas.2007.04.006
Wilson, C. A. – Davidson, D. A. – Cresser, M. S. 2009: An evaluation of the site specificity of soil elemental signatures for identifying and interpreting former functional areas, Journal of Archaeological Science 36, 2327–2334. https://doi.org/10.1016/j.jas.2009.06.022
Yu, Y. – Guo, Z. – Wu, H. – Finke, P. A. 2012: Reconstructing prehistoric land use change from archeological data: Validation and application of a new model in Yiluo valley, northern China, griculture, Ecosystems & Environment 156, 99–107. https://doi.org/10.1016/j.agee.2012.05.013

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