Relating Extent of Colluvial Soils to Topographic Derivatives and Soil Variables in a Luvisol Sub-Catchment, Central Bohemia, Czech Republic

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Abstract

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Colluvial soils, resulting from accelerated soil erosion, represent a significant part of the soil cover pattern in agricultural landscapes. Their specific terrain position makes it possible to map them using geostatistics and digital terrain modelling. A study of the relationship between colluvial soil extent and terrain and soil variables was performed at a morphologically diverse study site in a Luvisol soil region in Central Bohemia. Assessment of the specificity of the colluviation process with regard to profile characteristics of Luvisols was another goal of the study. A detailed field survey, statistical analyses, and detailed digital elevation model processing were the main methods utilized in the study. Statistical analysis showed a strong relationship between the occurrence of colluvial soil, various topographic derivatives, and soil organic carbon content. A multiple range test proved that four topographic derivatives significantly distinguish colluvial soil from other soil units and can be then used for colluvial soil delineation. Topographic wetness index was evaluated as the most appropriate terrain predictor. Soil organic carbon content was significantly correlated with five topographic derivatives, most strongly with topographic wetness index (TWI) and plan curvature. Redistribution of the soil material at the study site is intensive but not as significant as in loess regions covered by Chernozem. Soil mass transport is limited mainly to the A horizon; an argic horizon is truncated only at the steepest parts of the slope.

Keywords: digital elevation model; digital soil mapping loess; soil erosion; soil organic carbon

Colluvial soils form part of a mosaic of soil units in the soilscape, influenced by long-term erosion. Sedimentation of eroded humus-rich material forms deep fertile soils with more or less evident stratification of layers. Their close relationship with specific terrain units makes them a good object for digital soil mapping. Although their real spatial extent is not known, the ubiquitous occurrence of soil transport indicates that the extent of colluvial soils may be large (Zádorová *et al*. 2011). Formation of these soils is tightly connected with agricultural exploitation of the landscape and intensification of agriculture production. So far, a method for mapping of colluvial soil was developed for small catchments in Chernozem regions (Zádorová *et al*. 2008, 2011), using geostatistics and fuzzy methods based on detailed terrain analysis. Colluvial soil mapping in loess-derived Luvisols is another step in the delineation of this soil unit and should be studied namely due to the large area of Luvisols and their generally high agricultural productivity. Luvisols, in comparison with e.g. loess-derived Chernozems, have a highly heterogeneous soil profile, namely in terms of the particle size distribution and soil structure. Thus, a different and more complex functioning of soil removal and sedimentation can be presumed. The presence of a dense, clay-rich argic horizon with highly developed and stable soil structure can represent a significant threshold in erosive intensity and influence the resulting area and form of colluvial soils. The effect of soil aggregate stability, clay content, and soil organic matter on erosion vulnerability was studied by Le Bissonnais (1996), Bronick and Lal (2005), Cantón *et al.* (2009). Aggregate stability is a critical component of soil erodibility since it controls the soil dispersion and surface seal development. The level of aggregation and stability of aggregates increases concurrent with increasing organic matter content, surface area of clay minerals, and cation exchange capacity (Bronick & Lal 2005).

Soil organic carbon (SOC) distribution due to soil erosion is intensively studied (e.g. Lal 2001; Ritchie *et al.* 2007). The general distribution of humus and its content in the colluvial profile reflects the specific sedimentation processes at the study plot. Increase in SOC in the colluvial horizon indicates preferential transport of material from A horizon. Decrease in SOC, on the other hand, indicates sedimentation of subsoil material and thus more intensive erosion (Zádorová *et al.* 2013).

Research on Central European loess colluvial soils is extensive. Soil redistribution in Luvisols as a result of erosion was described e.g. by Terhorst (2000), Klimowicz and Uziak (2001), or Wolf and Faust (2013). Most of the studies concentrate on the structure of soil profiles along the studied transects. Other studies in Luvisol areas use colluvial soils as geoarchives due to their wide distribution and continuous presence for at least 7000 years (Lang & Hönscheidt 1999; Leopold & Völkel 2007; Kadereit *et al.* 2010; Klimek 2010; Poreba *et al.* 2011).

Mapping of colluvial soils is based on topography and digital terrain modelling (Zádorová *et al.* 2011). Quantitative terrain data are widely applied in studies concerning how landscape position influences soil properties. Slope, curvature, catchment area, and topographic wetness index (TWI) are the most frequent variables. The various properties investigated include: soil depth (Odeh *et al.* 1995; Penížek & Borůvka 2006), thickness of horizons (Florinsky *et al.* 2002; Vanwalleghem *et al.* 2010), particle size distribution (Odeh *et al.* 1995; Penížek & Borůvka 2004), organic carbon content (Schwanghart & Jarmer 2011), soil unit delineation (Zádorová *et al.* 2008, 2011). In Luvisols, few studies focus on soil depth and horizonation using terrain predictors. Young and Hammer (2000) studied a number of attributes and their relationship with the depth of Bt horizon in a loess-mantled landscape in Missouri. The A horizon depth was studied by Moore *et al.* (1993) or Martin and Timer (2006). Vanwalleghem *et al.* (2010) studied the spatial variability of soil horizons in a natural forested area.

The presented study forms a part of a complex research concerning colluvial soil delineation in different soil and parent material conditions. This study directly continues from the study of a Chernozem region presented in Zádorová *et al.* (2011).

The particular objectives can be defined as follows: (*i*) to evaluate the relationship between the colluvial soil extent and selected topographic derivatives using different statistical methods, (*ii*) to define topographic derivatives with values specific for colluvial soils, which distinguish them from other soil units, and (*iii*) to assess the specificity of the colluviation process at the study plot with regard to profile characteristics of Luvisols. Soil profile structure and organic carbon distribution will be used for this aim.

MATERIAL AND METHODS

Study site. The study was situated in Central Bohemia (Czech Republic), in the Pšovka River watershed (Figure 1). The wider area is underlain by Cretaceous sandstones covered by a Pleistocene loess layer (Chlupáč *et al.* 2002). Haplic and Albic Luvisols are the original dominant soil units. Detailed research was carried out on a section of an agricultural parcel. The study plot is characterized by intensive topography dominated by two perpendicular side valleys (north-south and east-west) connected in the south-west part of the site (Figure 2). These two concave units

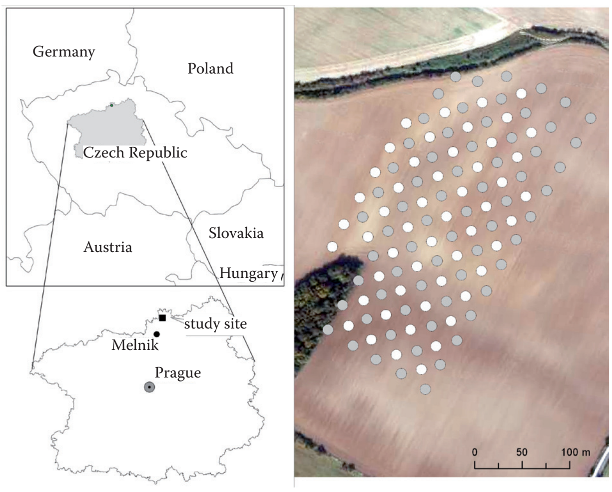

Figure 1. Localization of the study site (left) and the network of borings (white dots – soil profile description, grey dots – soil profile description and soil organic carbon analysis)

together with a significant rill in the east part of the plot represent the main accumulation positions at the plot. The adjacent slopes are relatively steep (up to 12°), while the south, north-east, and north-west parts of the plot are formed by flat terrain.

Methods. The study plot was investigated by soil sampling based on a regular grid (15 × 15 m) with 1 m deep auger observations (in total 119 bores) (Figure 1). The following soil characteristics were determined: soil unit, soil depth, soil profile stratigraphy. Samples for analysis of soil organic carbon content were taken from half of the borings (66 borings, grid 30 × 30 m).

The soil organic carbon content was measured using the dichromate redox titration method (Skjemstad & Baldock 2008).

The topographic derivatives were obtained from the digital elevation model (DEM) derived from the airborne laser scanning procedure. The DEM was provided in 1 × 1 m point grid (provider GEODIS Ltd., Brno, Czech Republic), interpolated and filtered by Gaussian filter in SAGA GIS software. Computed topographic derivatives represent a standard set of terrain variables used for the soil-terrain mapping (Moore *et al.* 1993; Odeh *et al.* 1995). The topographic derivatives were calculated using integrated algorithms implemented in SAGA GIS from the DEM: altitude (ALT), slope, plan, profile, and mean curvature (PLANC, PROFC, MEANC), catchment area (CA), altitude above channel (ALTCHN), and topographic wetness index (TWI). Particular topographic derivatives were selected to be comparable with the study on colluvial soil delineation carried out in a Chernozem region (Zádorová *et al.* 2011).

Correlation between the soil characteristics and terrain derivatives was assessed by Pearson's (normal distribution variables) and Spearman's (other) coefficient. Multiple Range Test (parametrical and non-parametrical) was used for all topographic derivatives to find out which of them are characteristic for the colluvial soil unit. It means that for colluvial soil there exists a unique confidence interval of topographic derivative value that significantly differentiates colluvial soil from other soil units. This analysis enabled the choice of a reasonable number of appropriate topographic derivatives to distinguish the colluvial soil from other units. Principal component analysis (PCA) was applied to display the structure of the data set and reveal possible inter-correlations between the variables. All statistical calculations were performed using the software R.

Names of soil units used in this paper are based on the national classification Czech Taxonomic Classification System of Soils (CTCSS; Němeček *et al.* 2011). Their correlation with World Reference Base for Soil Resources 2006 (WRB 06; IUSS Working Group WRB 2006) and CTCSS is described in Table 1. Detailed information on correlation between CTCSS and WRB 06 is given in Zádorová and Penížek (2011). Soil units defined in the national classification are better suited for the soil cover pattern description after a long-term redistribution as they, opposite to the WRB, reflect the process of soil formation and can be used to differentiate particular erosion and accumulation stages of the soil profile.

RESULTS AND DISCUSSION

Soil cover pattern. The soil cover pattern exists as a diverse mosaic of soil units due to intensive material redistribution caused by both water and tillage erosion. Five soil units, and/or subunits, were identified (Figure 3). Luvisols cover mainly the upper flat parts of the plot and lower slopes. The A horizon is restricted to the plough layer or reaches a maximum of 5–10 cm below. The eluvial horizon forms part of the plough layer. The argic horizon is well structured

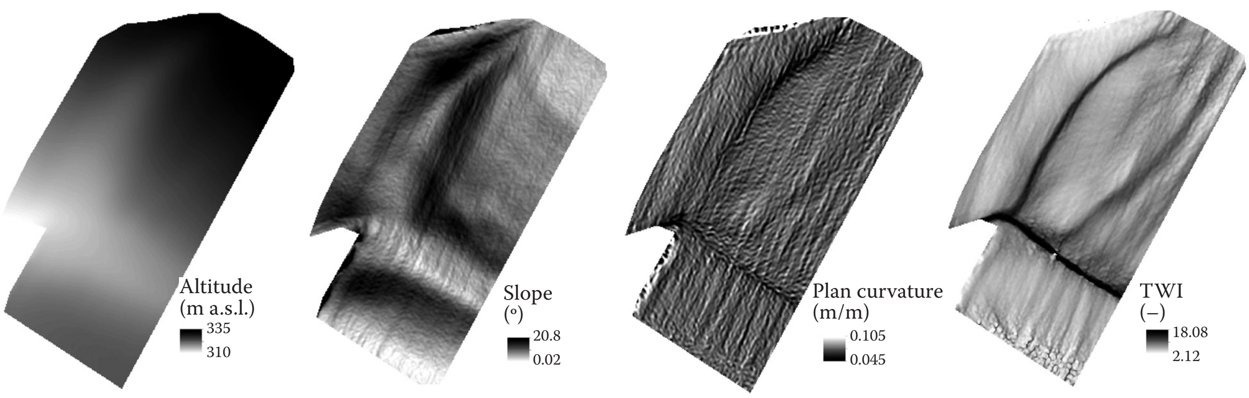

Figure 2. Digital elevation model and selected topographic derivatives; TWI – topographic wetness index

Table 1. Soil units names used in the paper and their correlation in World Reference Base for Soil Resources (WRB 06)

Soil unit	WRB 06	CTCSS	Profile	A horizon depth (cm)
LU	Haplic Luvisol	Hnědozem modální	A–Bt–C	A < 30
LUac	Luvic Phaeozem	Hnědozem modální akumulovaná	A–Bt–C	A > 30, < 60
CO	Luvic Phaeozem Colluvic	Koluvizem modální	A–Bt–C	A > 60
RG	Haplic Calcisol Haplic Regosol	Regozem modální	A–C	A < 30
RGac	Haplic Kastanozem	Regozem modální akumulovaná	A–C	A > 30, < 60

LU – Luvisol; LUac – accumulated Luvisol; CO – colluvial soil; RG – Regosol; RGac – accumulated Regosol; CTCSS – Czech Taxonomic Classification System of Soils

(polyhedric and prismatic structure) but its thickness varies significantly from 10 to 60 cm (Figure 4). Luvisols differ according to their accumulated forms in the concave parts of the terrain, mainly at the outer parts of the main side valleys. The A horizon is deeper (30–60 cm), but the eluvial horizon is not present. Colluvial soils develop exclusively in the bottom parts of the two side valleys. The A horizon exceeds 60 cm in thickness, in majority of profiles it is more than 80 cm thick (Figure 4). In a similar terrain arrangement, the thickness of colluvial horizons is fundamentally smaller than in Chernozems (Zádorová *et al.* 2011), namely because of generally shallower A horizons in Luvisols and the presence of a stable Bt horizon. Colluvial layers bury argic horizons indicating the original presence of Luvisols at the valley bottom. Steep slopes adjacent to the side valleys are covered by Regosols with an eroded profile. Regosols located close to the accumulation area have deep A horizons (up to 60 cm) but lack an argic horizon. This profile evolution corresponds to the consecutive filling of the valleys bottom and accumulation of the soil matter at adjacent slopes. A strong influence of tillage erosion can be assumed in these profiles.

A very similar soil cover pattern was identified by Terhorst (2000) with Albic Luvisol at the flat-topped ridges, Regosols and Rendzinas at the slopes, and thick colluvial layers and buried Luvisols at the valleys bottom. Klimowicz and Uziak (2001) estimated an average colluvial horizon thickness of 90 cm in the wider area of Polish loess-derived Luvisols. Wolf and Faust (2013) reported severe truncation of Luvisol profiles at the slopes and colluvial sediment up to 1 m thick in accumulation positions. In contrast, at a comparable study site in a Chernozem region (Zádorová *et al.* 2011), the area with exposed parent material is negligible.

Relationship between soil units and topographic derivatives. Tables 2 and 3 show the relationship between each of the identified soil units and topographic derivatives. Results of PCA analysis are

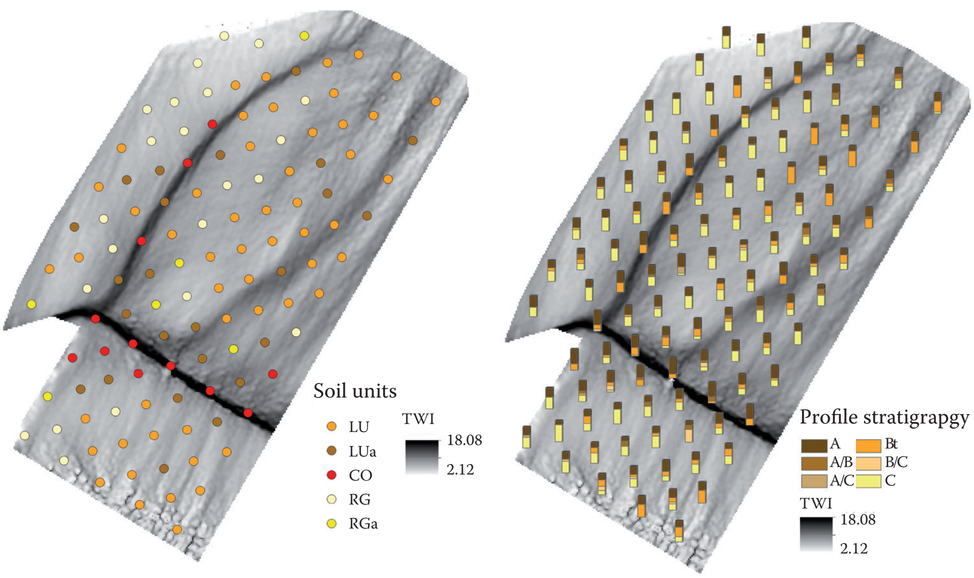

Figure 3. Soil units distribution at the study site (left) and soil profile stratigraphy (right)

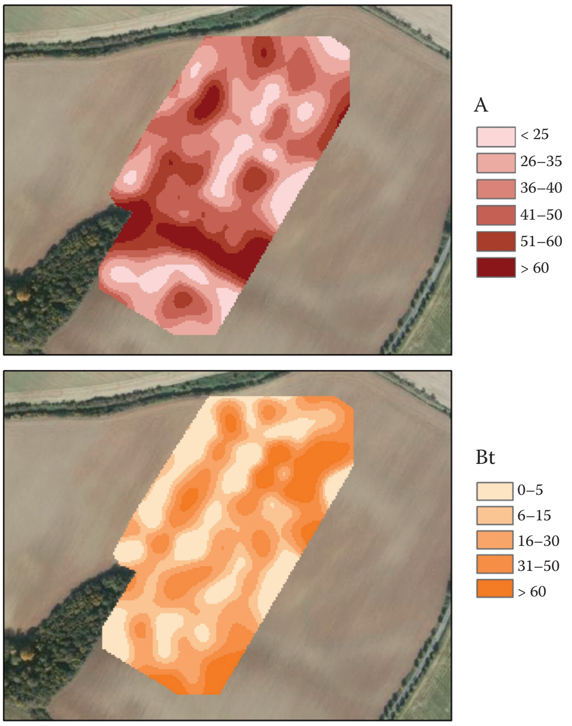

Figure 4. Interpolated soil horizons thickness (cm)
A, Bt – soil profiles

depicted in Figure 5. Component 1 and component 2 explain 77% of the data variability. Mean values for each soil unit were generated for each involved topographic derivative (Table 2). In the majority of cases, mean values for colluvial soil lie in a different part of the interval than other soil units. This is noticeable in the case of ALT, slope, PLANC, CA, TWI, and ALTCHN (Figure 6). As the PCA analysis showed a strong inter-correlation of TWI and CA, only TWI will be used for the next analysis. Multiple range test for aggregated soil units (colluvial soil, Luvisol, and Regosol) proved significant differences between colluvial soil and other soil units in all of the above mentioned variables except for slope (Table 3). Colluvial soils can then be delineated using these topographic variables. The most marked difference was determined in the case of TWI (Figure 6) This is an expected result as TWI has a high potential in the delineation of areas with different intake of sediments (Florinsky 2002; Zádorová *et al.* 2011). The significance of ALT and ALTCHN shows that the occurrence of colluvial soil is restricted to the lowest parts of the relief. PLANC also showed significant differences between colluvial soil and other soil units, indicating their development in the concave side valleys. PCA analysis also shows the isolated position of colluvial soils and their strong relationship with the above mentioned topographic derivatives. On the contrary, mean and profile curvature has no influence on the differentiation of soil units. With accumulated forms included, the differences were not significant for any of the derivatives (Table 3). This is caused mainly by the group of accumulated Luvisols having the properties typical of colluvial soil and Luvisol. PCA analysis shows this polarity as the profiles are aggregated in two distinct groups. Standardized means of topographic derivatives relevant for soil units can be compared with an analogous study conducted in a Chernozem region (Zádorová *et al*. 2011). In colluvial soil, the means of profile and mean curvature are very similar while the mean of slope is markedly lower in the case of the Luvisol area (0.38 in Luvisol area, 0.52 in Chernozem area) and the mean of TWI is higher in the Luvisol area (0.58 in Luvisol area, 0.44 in Chernozem area). The differences are caused mainly by different terrain configuration in both study sites when the colluvial soil in Chernozem region reaches up to the backslope positions with high slope. A relatively high value of slope in the case of Luvisol (0.59) proves that the extent of these soils is not limited to the flat areas and that the Luvisols are stable even at low and middle slopes (in contrast to Chernozems that are preserved exclusively at the flat positions). The MRT revealed

Table 2. Standardized means of topographic derivatives for each soil unit

Soil unit	ALT	SLOPE	MEANC	PLANC	PROFC	CA	TWI	ALTCHN
LU	0.593	0.513	0.378	0.344	0.575	0.001	0.248	0.206
LUac	0.428	0.495	0.323	0.302	0.625	0.007	0.340	0.084
CO	0.263	0.3848	0.365	0.275	0.506	0.149	0.585	0.040
RG	0.547	0.6428	0.432	0.412	0.514	0.001	0.196	0.216
RGac	0.344	0.706	0.425	0.367	0.592	0.001	0.226	0.117

LU – Luvisol; LUac – accumulated Luvisol; CO – colluvial soil; RG – Regosol; RGac – accumulated Regosol; ALT – altitude; SLOPE – slope; MEANC – mean curvature; PLANC – plan; PROFC – profile; CA – catchment area; TWI – topographic wetness index; ALTCHN – altitude above channel

Table 3. Differentiation of soil units based on topographic derivatives (Multiple Range Test Method: 95.0% LSD)

Soil unit	ALT	SLOPE	MEANC	PLANC	PROFC	CA	TWI	ALTCHN
Aggregated soil units								
LU	A	A	A	A	A	A	A*	A
CO	B*	A	A	B*	A	B*	B*	B*
RG	A	B*	A	AC	A	A	C*	A
Soil units and subunits								
LU	A	AB	A	AB	A	A	A	A
LUac	B	AB	A	A	A	B	AB	AB
CO	BC	A	A	A	A	B	B	B
RG	AB	B	A	B	A	A	AC	A
RGac	ABC	B	A	AB	A	AB	AC	AB

LU – Luvisol; LUac – accumulated Luvisol; CO – colluvial soil; RG – Regosol; RGac – accumulated Regosol; ALT – altitude; SLOPE – slope; MEANC – mean curvature; PLANC – plan; PROFC – profile; CA – catchment area; TWI – topographic wetness index; ALTCHN – altitude above channel; *soil unit forms a distinguished group

the most important difference in the case of curvature (mean and profile); it was one of the most significant derivatives for the distinction of colluvial soils in the Chernozem region but it had a very low potential in the Luvisol area. Catchment area and TWI showed high potential for colluvial soil delineation in both study areas. Opposite from the Luvisol area, altitude was not a significant parameter in the Chernozem area where colluvial soils also reached higher parts of the study plot. In the Chernozem region, colluvial soil could be unified with accumulated Chernozem using some topographic derivatives and thus a wider accumulation area could be delineated. At the Luvisol study site, the colluvial soil and accumulated Luvisol do not form a homogeneous group in any case. The wider accumulation area defined by colluvial soil and accumulated Luvisol cannot be properly defined using the topographic derivatives.

Not only the mean values but also the variability and range of the values of each soil unit are important. The variability of values in colluvial soils, Luvisols, and Regosols is rather low as these soil units are dependent on particular landform units. On the contrary, the accumulated sub-units have a high variability of terrain attributes as they occur in transitional positions where both mass transport and deposition can occur. Very similar results in variability have been reported from the Chernozem region (Zádorová *et al.* 2011).

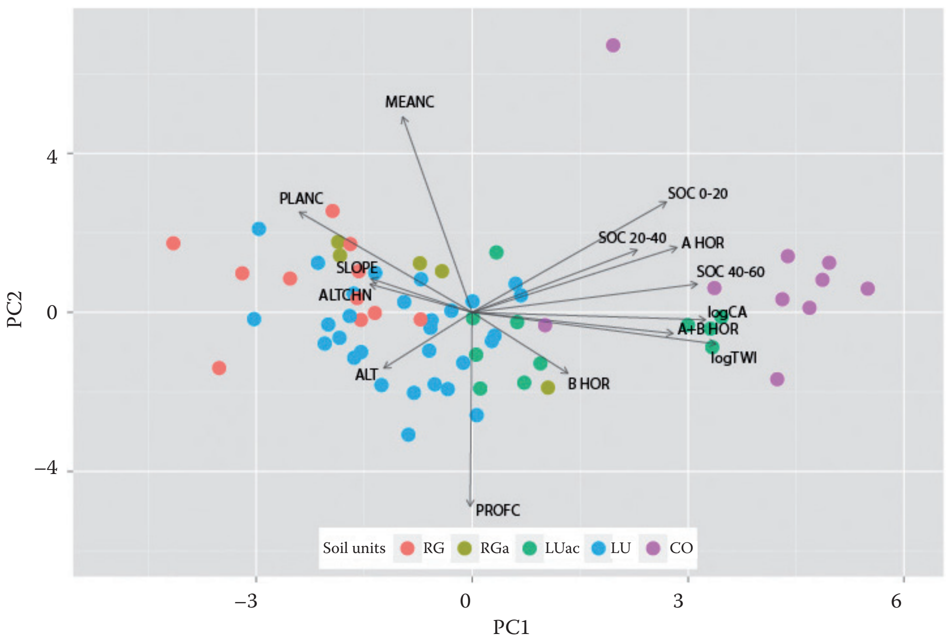

Figure 5. Principal component analysis biplot LU – Luvisol; LUac – accumulated Luvisol; CO – colluvial soil; RG – Regosol; RGac – accumulated Regosol; ALT – altitude; SLOPE – slope; PLANC – plan; PROFC – profile; MEANC – mean curvature; CA – catchment area; ALTCHN – altitude above channel; TWI – topographic wetness index; SOC – soil organic carbon

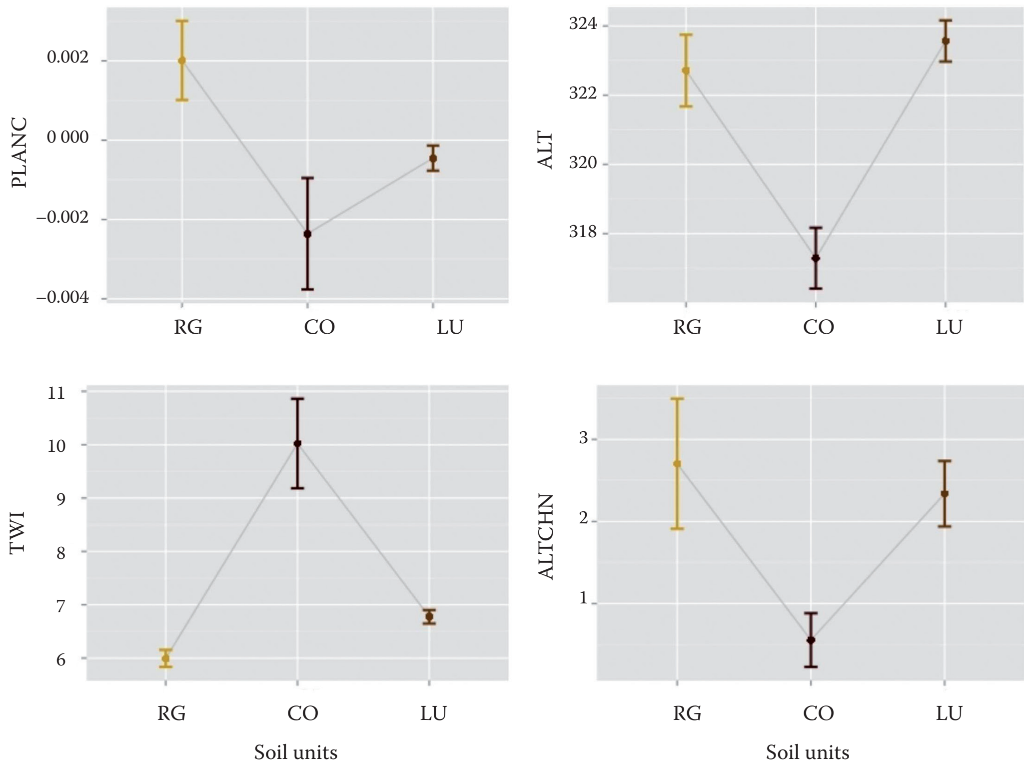

Figure 6. Mean values of selected topographic derivatives with confidence intervals for soil units (Multiple Range Test – LSD: 95% confidence interval)
LU – Luvisol; CO – colluvial soil; RG – Regosol; ALT – altitude; PLANC – plan; ALTCHN – altitude above channel; TWI – topographic wetness index;

Correlation of soil depth and horizon thickness with topographic derivatives was performed (Table 4). Soil depth and horizon thickness are closely linked with the soil unit. However, soil units with different erosional stages can have a similar thickness of some soil horizons; e.g. a deep A horizon is typical not only of colluvial soil and accumulated Luvisol, but also of accumulated Regosol. A shallow A horizon can occur not only in Regosol, but also in stable Luvisol. A horizon thickness significantly correlates with a number of topographic derivatives: ALT, PLANC, TWI, and ALTCHN. The strongest relationship in the case of ALTCHN (–0.47) and TWI (0.38) clearly shows the accumulation of humus material at the bottom of the side valleys. On the contrary, correlation of A horizon depth and slope is not significant. Such a weak correlation has been reported also in Florinsky *et al.* (2002) or Zádorová *et al.* (2011). A very weak relationship between MEANC (–0.14) and PROFC (0.08) and A horizon thickness is surprising and is in contrast with the findings of Zádorová *et al.* (2011). Thickness of B horizon correlates only with three topographic derivatives: TWI, PLANC, and slope. In this case, the closest correlation was found in the case of slope (–0.44). This can be explained by the presence of a deep undisturbed Bt horizon in the upper flat parts of the study plot covered by the most developed Luvisols. Lastly, soil depth is related significantly to PLANC, TWI, and slope. Low dependency on altitude and ALTCHN corresponds with the occurrence of deep soils both in the low parts of the valleys bottom and at the upper flat parts of the study plot.

The above-mentioned results confirmed known facts about topographic influence on the thickness of the horizons and soil depth at the agricultural areas (e.g. Moore *et al.* 1993; Florinsky *et al.* 2002; Zádorová *et al.* 2011). The fact that the very close relationship between Luvisol profile stratification and topography is a specificity of agricultural land was reported by Vanwalleghem *et al.* (2010). Their research situated in a natural forest area showed that the dependence of soil depth on terrain units is very low and that the variability of soil horizon thickness is not related to the variability of topography.

Soil organic carbon distribution. The process of erosion and the following sedimentation of eroded material cause a significant redistribution of the organic carbon within the studied plot. The three maps (Figure 7) show the distribution of SOC content at

Table 4. Differentiation of soil units based on soil organic carbon (SOC) content at various depths (Multiple Range Test Method: 95.0% LSD)

Soil unit	SOC (depth, cm)		
	0–20	20–40	40–60
Aggregated soil units			
LU	A	A	A
CO	B*	B*	B*
RG	A	A	A
Soil units and subunits			
LU	A	A	A
LUac	AB	AB	AB
CO	B	B	B
RG	A	A	A
RGac	AB	AB	A

LU – Luvisol; LUac – accumulated Luvisol; CO – colluvial soil; RG – Regosol; RGac – accumulated Regosol; *soil unit forms a distinguished group

three different soil depths. The highest SOC concentration at all of the three depths was observed in the two side valleys. However, differences can be seen in these two accumulation units. In the first 40 cm, high organic matter content (more than 2%) is described in the majority of the north-south valley while the SOC content in the east-west valley is lower. At the depth of 60 cm and more, the SOC content is higher in the east-west valley proving the deeper A horizon in this part (shown also in Figure 4). Another isolated area of high SOC content is formed at the flat undisturbed part of the study plot. The soils covering steeper slopes have significantly lower SOC content in both topsoil and deeper horizons. The SOC distribution indicates the erosional-sedimentation processes at the study plot. Soil mass is primarily eroded from the slopes adjacent to the side valleys. The erosion is more intensive at the southern part of the plot; the soil profiles in the east-west valley are deeper and the plough layer contains less humus. In the late phase of erosion the colluvial horizon is built also by the material eroded from subsurface soil horizons poor in organic matter which are successively excavated by erosion. However, this process leading to retrograde soil development is weak in comparison with subsequent burying of A horizons known from Chernozem or Cambisol regions (Zádorová *et al.* 2008, 2011).

The relationship between SOC content, soil units, and topographic derivatives was statistically evaluated. Colluvial soil is distinguished by its SOC content at all three profile depths in the case of aggregated soil units. This means that the SOC content in colluvial

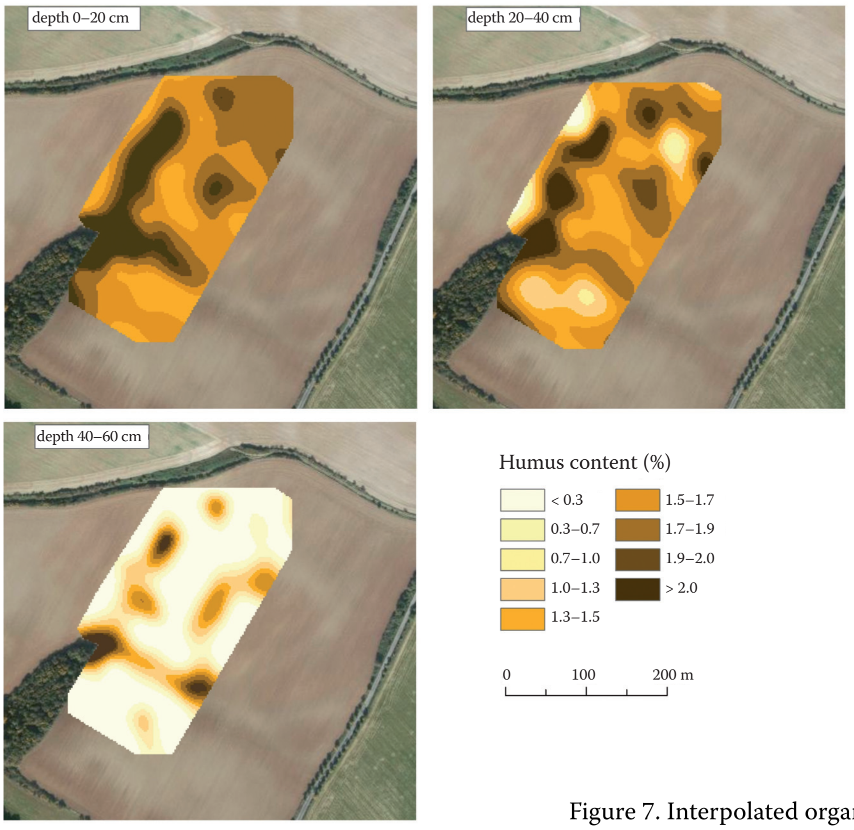

Figure 7. Interpolated organic matter content at various depths

Table 5. Correlation analyses between soil and topographic variables (Pearson's and/or Spearman's correlation coefficient)

		SOC (depth, cm)			HOR			ALT	MEANC	PLANC	PROFC	CA	TWI	ALTCHN	SLOPE
		0–20	20–40	40–60	A	A + B	B								
SOC (depth, cm)	0–20		0.78**	0.56*	0.57**	0.49**	0.23	–0.19	0.05	–0.47**	–0.15	0.43**	0.48**	–0.41**	–0.34*
	20–40	0.78**		0.53**	0.50**	0.32*	0.10	–0.07	–0.12	–0.43**	0.00	0.38*	0.47**	–0.40**	–0.32*
	40–60	0.56**	0.53**		0.66**	0.58**	0.28	–0.25	–0.28	–0.56**	0.05	0.56**	0.57**	–0.53**	–0.29
HOR	A	0.57**	0.50**	0.66**		0.49**	0.10	–0.36**	–0.14	–0.30**	0.08	0.36**	0.38**	–0.47**	–0.21
	A + B	0.49**	0.32*	0.58**	0.49**		0.82**	–0.06	–0.20	–0.39**	0.13	0.34**	0.51**	–0.28*	–0.50**
	B	0.23	0.10	0.28	0.10	0.82**		0.10	–0.14	–0.29*	0.06	0.17	0.35**	–0.06	–0.44**
ALT		–0.19	–0.07	–0.25	–0.36**	–0.06	0.10		0.08	0.07	–0.04	–0.34**	–0.20	0.21	–0.14
MEANC		0.05	–0.12	–0.28	–0.14	–0.20	–0.14	0.08		0.40**	–0.81**	–0.36**	–0.36**	0.25*	0.07
PLANC		–0.47**	–0.43**	–0.56**	–0.30**	–0.39**	–0.29*	0.07	0.40**		–0.24*	–0.65**	–0.65**	0.55**	0.07
PROFC		–0.15	0.00	0.05	0.08	0.13	0.06	–0.04	–0.81**	–0.24*		0.18	0.20	–0.08	–0.05
CA		0.43**	0.38*	0.56**	0.36**	0.34**	0.17	–0.34**	–0.36**	–0.65**	0.18		0.88**	–0.73**	–0.04
TWI		0.48**	0.47**	0.57**	0.38**	0.51**	0.35**	–0.20	–0.36**	–0.65**	0.20*	0.88**		–0.64**	–0.42**
ALTCHN		–0.41**	–0.40**	–0.53**	–0.47**	–0.28*	–0.06	0.21	0.25*	0.55**	–0.08	–0.73**	–0.64**		0.00
SLOPE		–0.34*	–0.32*	–0.29	–0.21	–0.50**	–0.44**	–0.14	0.07	0.07	–0.05	–0.04	–0.42**	0.00	

SOC – soil organic contents; HOR – horizon; ALT – altitude; MEANC – mean curvature; PLANC – plan; PROFC – profile; CA – catchment area; TWI – topographic wetness index; ALTCHN – altitude above channel; SLOPE – slope; *, **$P < 0.05, 0.01$

soil is markedly higher than in other soil units (Table 4). This is in contradiction with findings from the Chernozem region, where the SOC content in the upper parts of the colluvial horizon was significantly lower than in the undisturbed Chernozem (Zádoro-vá *et al.* 2013). All units and subunits included, colluvial soil cannot be reliably distinguished as the accumulated Luvisol stands between colluvial soil and Luvisol.

SOC content is significantly correlated with several variables (Table 5). The strongest relationship was indicated between SOC content and A horizon thickness and soil depth. This is comprehensible as the greatest soil depth represents the accumulated soils. TWI and PLANC are positively correlated with the SOC content at all three depths while SLOPE and ALTCHN are negatively correlated.

The results showing SOC as a function of soil redistribution and topography correspond with long-term studies on SOC distribution in the landscape (e.g. Ritchie *et al.* 2007). TWI showed the highest potential for the SOC mapping as it delineates areas with high potential accumulation and soil moisture. Findings of Schwanghart and Jarmer (2011) and Wiesmeier *et al.* (2013) correspond with our results.

CONCLUSION

The statistical relationship between colluvial soil extent and terrain and soil parameters was studied at a diversified study plot in a Luvisol region with the aim of finding topographic variables suitable for colluvial soil delineation.

Colluvial soils cover a significant part of the soil mosaic at the study site in the Luvisol area. Colluvial horizons reach a maximum thickness of 80 cm and their extent is limited to two perpendicular side valleys. Luvisols with a fully developed soil profile occur not only at the flat parts of the plot but also at low and middle slopes (up to 9°). The steepest parts of the plot are covered by Regosols.

Statistical analysis showed a significant relationship between colluvial soil extent and various terrain and soil variables. Multiple range test proved that four topographic derivatives (TWI, ALT, PLANC, ALTCHN) significantly distinguish colluvial soil from other soil units and can be then used for colluvial soil mapping. The most marked difference was determined in the case of TWI. TWI and ALTCHN also showed the strongest correlation with A horizon thickness and soil depth.

Soil organic matter redistribution is strongly dependent on erosion processes and shows a significant relationship with numerous topographic derivatives (PLANC, TWI, ALTCHN, slope). SOC content distinguishes colluvial soil from other soil units proving intensive accumulation in the concave positions.

Redistribution of the soil material at the study site is intensive but not as pronounced as in Chernozem areas. The soil removal is limited mainly to the A horizon; the argic horizon is truncated only at the steepest parts of the slope where the parent material is exposed. This finding is supported by relatively shallow colluvial horizons, a high SOC content in the plough layer of colluvial soils meaning a weak admixture of mineral soil material and also by a large extent of undisturbed or weakly disturbed Luvisols at the study plot. These results can be attributed to the specific profile of Luvisols with the well-structured argic horizon representing a stable and hardly erodible layer.

The study showed that the colluvial soils developing in Luvisol areas can be delineated using topographic derivatives as the relationship between colluvial soil and topography is significant. The delineation model proposed in the Chernozem region will be applied in the next step of the research.

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