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The effects of slope and altitude on soil organic carbon and clay content in different land-uses: A case study in the Czech Republic

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Abstract: Soil organic carbon (SOC) and clay, as indicators of soil fertility, are mainly used to determine the ability of soil to retain water and store the nutrients that are necessary for plant growth. However, the distribution of SOC and clay is influenced by topography and land-use. In the present study, the relationships between SOC, clay, altitude, and slope in the topsoil of two different districts in the Czech Republic including the Liberec (71 samples) and Domažlice (67 samples) districts were investigated. To analyse the relationships between slope and SOC, linear regression was used. Results showed that SOC content increased when slope, clay, or altitude increased; however, there were no significant correlations between SOC and clay in both districts. Clay increased with decreasing slope, but clay and altitude were not correlated well in both areas. Then, study areas were divided into three land-use types including arable land, forest, and complex system of agriculture, parcels, and forests. Consequently, the correlations between SOC and slope and clay and slope were generally improved, indicating the importance of land-use on SOC and clay content. Additionally, using multiple regression with several topographic factors can provide a better prediction of SOC and clay content in each land-use for both districts, indicating the complex effects of topography on SOC and clay.

Keywords: ANOVA; coefficient of determination; correlation coefficient; linear regression; multiple regression; SOC

The largest global stock of organic carbon on land is estimated in the soil at 2 500 Pg to 2-m in-depth and is approximately twice as large as the atmospheric carbon stock (Adhikari et al. 2019). Soil organic carbon (SOC) is known as the main indication of soil quality and fertility because soil chemical properties such as pH and nutrients availability, soil physical properties such as structure and hydraulic conductivity, and soil biological activities such as microbial activity are substantially influenced by SOC (Nisha et al. 2007).

Slope and altitude are two important variables that affect the intensity and frequency of erosion, and subsequently, SOC and clay contents (Wei et al. 2017; Khan et al. 2019; Baltensweiler et al. 2020). Additionally, the relationship between SOC and clay is vital for the investigation of changes in SOC stocks. Many studies revealed that SOC level increases with increasing clay content (Zhong et al. 2018; Gruba & Socha 2019). This is because clay particles adsorb great amounts of SOC and clay soils are less aerated, so the decomposition of soil organic matter (SOM) is low (Hartati & Sudar-

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madji 2016). Inadequacy of information on variation of SOC and clay contents with changes in slope and altitude in different land uses are major bottlenecks for predicting the SOC and clay contents.

This study aims to evaluate the relationship between slope, altitude, SOC, and clay content as well as the effects of land-use type on SOC stock. Moreover, similarities and/or differences in SOC and clay distribution in two different districts including Liberec and Domažlice districts, Czech Republic were investigated.

Literature review. Topographical factors, such as slope and altitude, and different land uses substantially influence SOM content by affecting soil erosion and geological deposition processes as well as by controlling soil water, and subsequently, plant litter production and decomposition (Birkeland 1984; Thai et al. 2021).

It has been shown that increasing slope increases flow velocity leading to an increase in erosion intensity and frequency (Liu et al. 2015). In other words, a land with a steeper slope is expected to lose soil leading to SOC loss. However, Hontoria et al. (1999) reported a positive correlation between SOC and slope in Peninsular Spain. It indicates that in addition to slope itself, the position on the slope is also important, as at the upper parts erosion can cause SOC loss, while at the bottom of the slope, sedimentation can lead to SOC increase.

The behaviour and distribution of SOC on the slope is modified by clay. Clay can control SOC dynamics by protecting SOM from decomposition. It has been shown that SOC content increases with increasing clay and finer soil (containing more clay content) has higher SOC content (Gao et al. 2014). Several studies have indicated that the prediction of SOC loss depends on clay content. Olson et al. (2012) indicated that SOC can be predicted by flow dynamics when the clay content is low, however, SOC loss should be predicted by slope when clay content is high.

Altitude is another main factor that influences soil properties. Generally, SOC increases with increasing altitude (Griffiths et al. 2009). Altitude variation mainly affects climatic variables and vegetation types that have major impacts on SOC content (Zhu et al. 2010).

It has been also found that different land use classes affect the soil quality indicators such as SOC and, to smaller extent, clay. This is because land use is one of the main factors controlling soil capacity to retain water and nutrients as well as providing other ecosystem services (Wang et al. 2009; Ngatia et al. 2021). Xiaojun et al. (2013) also reported that land use can affect SOC content even in a region with the same parent material and climate. They showed that different land uses (with different plant covers and soil management practices) had substantially different SOC contents.

Other researchers also found that changing grassland to cropland led to a significant soil degradation through loss of fine soil particles, SOC, and nutrients. However, SOC gradually increased after returning to grassland (Zhao et al. 2005; Wei & Fang 2009). Wiesmeier et al. (2012) also indicated that grassland soils had considerably more SOC content compared to that of forest and cropland soils in southeast Germany. However, the differences between grassland and forest with cropland in this region were lower than the results observed from other researchers in central European countries (Gingrich et al. 2007; Martin et al. 2011; Wiesmeier et al. 2012).

MATERIAL AND METHODS

Study areas and sample collection. As shown in Figure 1, the study areas are Liberec (989 km^2) and Domažlice (1 123 km^2) districts that are located in the north and west parts of the Czech Republic, respectively. Liberec district is covered by 42.4% forest and 47.2% agricultural land while Domažlice district is covered by 38.2% forest and 53.0% agricultural land, indicating that Domažlice district is covered mostly by agricultural land and by a slightly smaller proportion of forest area than Liberec district (Miko & Hošek 2009). The third category considered in this paper, the complex systems of agriculture, parcels, and forests, forms less than 6% of the area in each of the two districts.

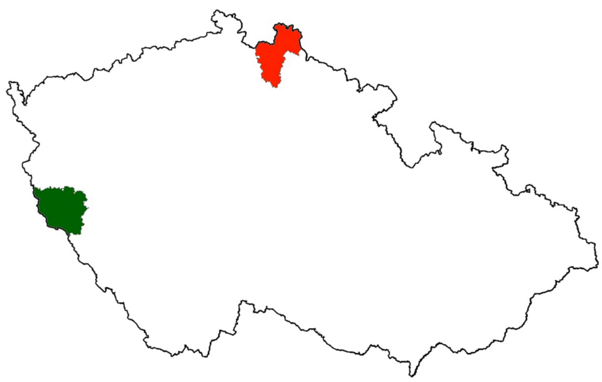

Figure 1. Location of the Liberec (red) and Domažlice (green) districts in the Czech Republic

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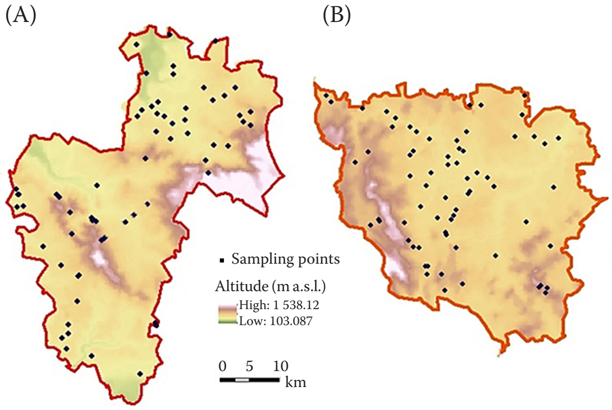

Figure 2. Distribution of sampling locations maps in Liberec (A) and Domažlice (B) districts with altitudes

As shown in Figure 2, simple random sampling design was used; the altitude of sampling locations ranged between 337 to 436 m for the Liberec district (71 samples) and 383 to 691 m for the Domažlice district (67 samples). Composite samples were created from 3 subsamples from an area of several square meters at each location. These subsamples were collected using a steel soil sample probe. Initially, each sample location was navigated by means of a handheld GPS tracker after clearance of debris (e.g. grasses, twigs, etc.) at each point. The probe was inserted in the mineral topsoil at the depth of 0–30 cm. This depth was selected because the 0–30 cm depth indicates the plough depth and SOC estimation in this depth is an important factor in farm management. Organic horizons (forest floor) were omitted and not sampled to get corresponding layers from all land use types. It should be noted that the top 100 cm soil depth shows a rooting depth for many field crops (Adhikari et al. 2014).

The soil was classified according to the Czech taxonomic soil classification system and WRB system (Němeček & Kozák 2002; IUSS 2015). Six major reference soil groups were recognized in the Liberec district including Cambisols, Podzols, Gleysols, Stagnosols, Luvisols, and Fluvisols (Figure 3A). Five dominant reference soil groups were also observed in the Domažlice district: Cambisols, Gleysols, Stagnosols, Luvisols, and Fluvisols (Figure 3B).

Laboratory analyses and data processing. The debris, rocks together with plant roots were manually removed from the collected soil samples. For analyses, the soil samples were air-dried, sieved to 2 mm, and thoroughly mixed. For SOC determination, the samples were further ground to pass the 0.25 mm mesh. Then, soil samples were analysed through the oxidimetric modified Tyurin method (Pospíšil 1964). Clay content of each sample was measured using the hydrometer method (Elfaki et al. 2016). Terrain characteristics were calculated by system for automated geoscientific analyses (SAGA) software, (Ver. 7.2.0) (Conrad et al. 2015), using digital terrain model 4G (DTM 4G) acquired from airborne laser scanning (ALS), also commonly known as light detection and ranging (LiDAR) with an original resolution of 5 × 5 m. Variables used in this study were altitude and slope. Both of these variables have the potential to contribute to SOC and clay spatial distribution. Land use categories were obtained from the database CORINE Land Cover 2018 (EEA 2018) at the resolution of 100 m. (Taghizadeh-Mehrjardi et al. 2014; Figure 4).

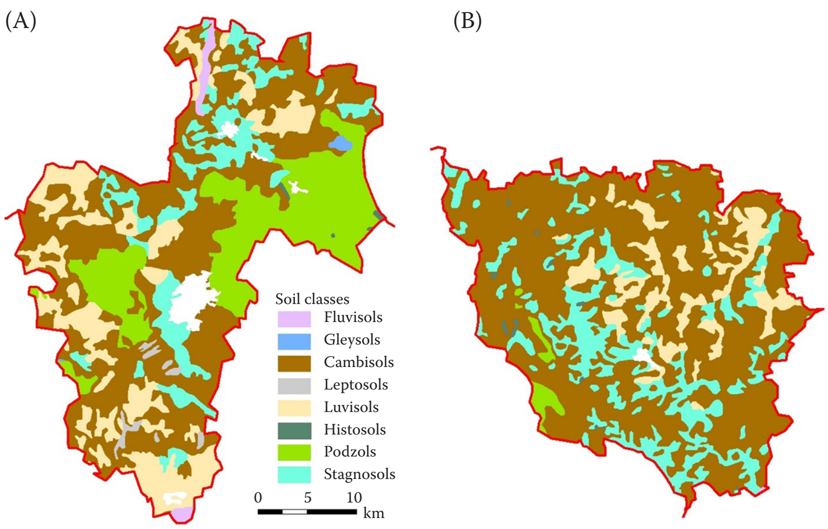

Figure 3. Dominant reference soil groups in Liberec (A) and Domažlice (B) districts

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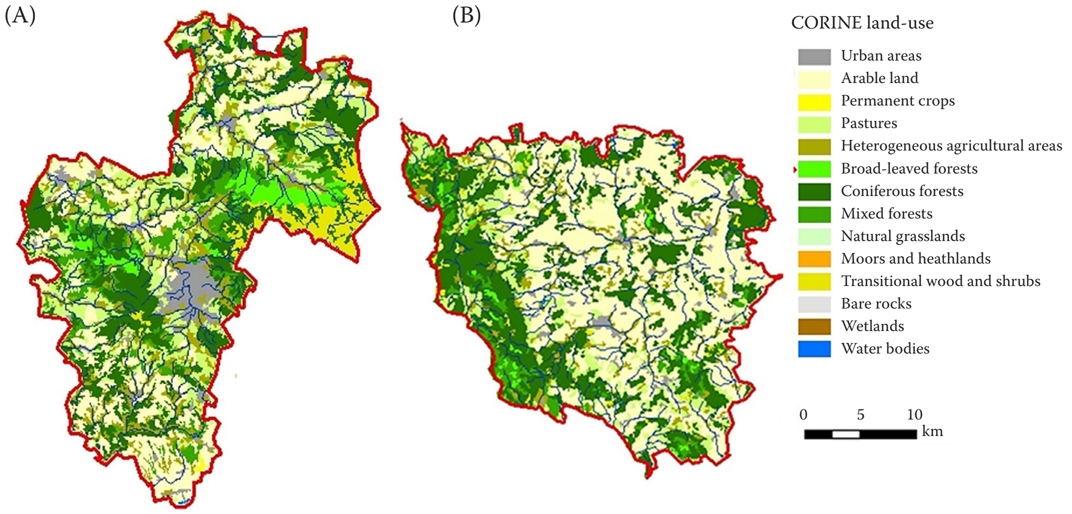

Figure 4. Land-use maps for Liberec (A) and Domažlice (B) districts

RESULTS AND DISCUSSION

Basic statistical terrain analysis

Statistical differences in mean values of SOC and slope were identified by one-way ANOVA using R (Ver. 3.5.1) (The R Foundation for Statistical Computing, 2018) and SPSS (Ver. 11) (SPSS Inc). Additionally, the correlation matrix between the selected variables (SOC, clay, slope, and altitude) was determined using the SPSS software package. Linear regression analysis was conducted using SPSS to identify the relationships between slope, SOC, and clay. The topographic parameters were used as independent variables that were altitude and slope. Summary statistics for SOC, clay, and terrain parameters (altitude and slope) for sampling sites in the Liberec and Domažlice districts are presented in Table 1.

The relationship between slope and SOC content

Tables S1 and S2 in the Electronic Supplementary Material (ESM) present the correlation matrices for Liberec and Domažlice districts. Results show that the distribution of SOC varies with changing the slope (Li et al. 2016). Tables S1 and S2 show that $r = 0.525$ and $P < 0.01$ for Liberec district and $r = 0.444$ and $P < 0.01$ for Domažlice district indicating that there were significant correlations between slope and SOC for both study areas, which is consistent with observations from other studies (Nozari & Borůvka 2020, 2021). A positive correlation between slope and SOC means that there are bigger SOC contents on steeper slopes. Therefore, spots with steeper slopes shown in Figure 5 (slope maps produced by SAGA) may contain more SOC.

Figure 6 also shows a positive linear relationship between slope and SOC for both districts (SOC increases with increasing slope). However, results from the linear model indicated that slope does not explain much the variation of SOC as the dependent variable (small R^2).

The relationship between slope and clay content

As shown in Figure 7, linear models between clay and slope showed a decreasing trend for both districts. This can be attributed to the greater transport of SOC and clay on steeper slopes due to the greater erosion. Also, clay content in the soil was relatively low based on this study dataset, which corresponds to the mostly granitic parent material, particularly in the Liberec district, as well

Table 1. Summary statistics for soil organic carbon (SOC), clay, and terrain parameters (altitude and slope) for sampling sites in the Liberec (71 locations) and Domažlice (67 locations) districts

Variable	Minimum	Maximum	Mean	SD
Liberec district				
SOC (%)	0.42	11.33	2.83	2.50
Clay (%)	2.70	24.32	8.58	3.46
Altitude (m)	239.7	719.1	412.6	98.3
Slope (radian)	0.005	0.534	0.081	0.091
Domažlice district				
SOC (%)	0.00	9.33	2.83	2.39
Clay (%)	2.18	23.71	11.95	4.42
Altitude (m)	356.3	719.7	481.4	77.4
Slope (radian)	0.003	0.158	0.048	0.039

SD – standard deviation

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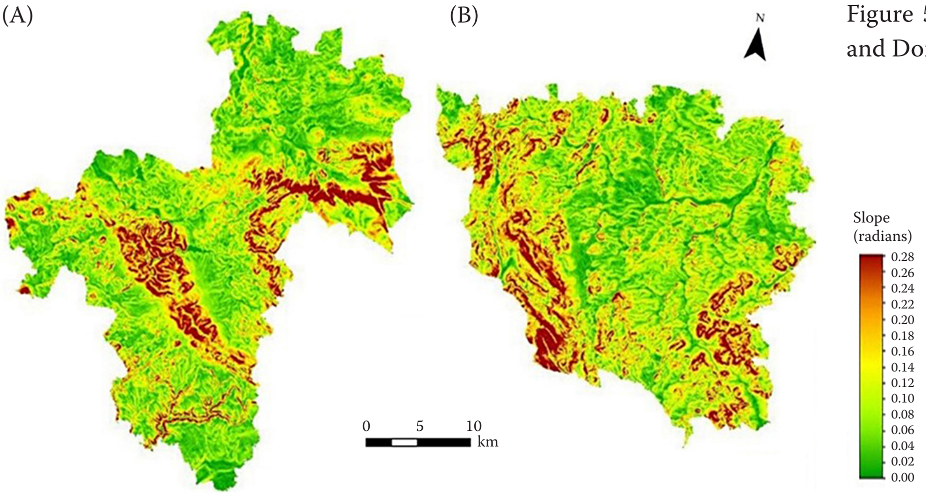

Figure 5. Slope maps for Liberec (A) and Domažlice (B) districts

as Podzols and Cambisols as dominant soil classes. This may explain why there was no significant correlation between slope components and clay. Additionally, logarithmic, exponential, power, and polynomial functions were used, however, similar results were observed.

The relationship between altitude and SOC content

The correlations between altitude and SOC content were identified. Figure 8 shows that SOC increased with increasing altitude. These results showed that the average SOC concentrations increased with al-

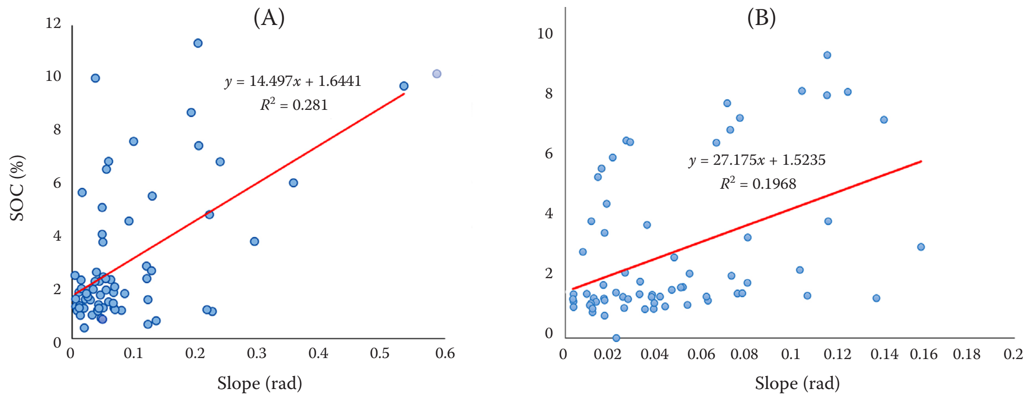

Figure 6. Relationship between slope and soil organic carbon (SOC) (linear regression) in Liberec (A) and Domažlice (B) districts

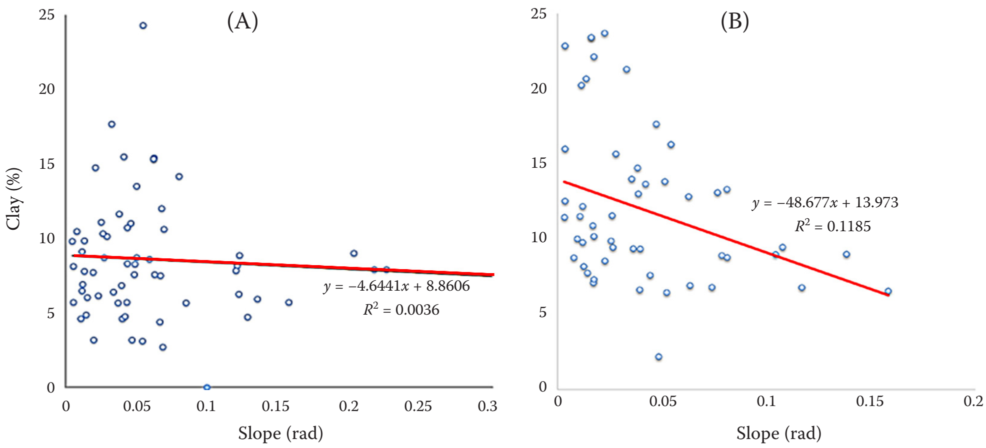

Figure 7. Relationship between slope and clay (linear regression) in Liberec (A) and Domažlice (B) districts

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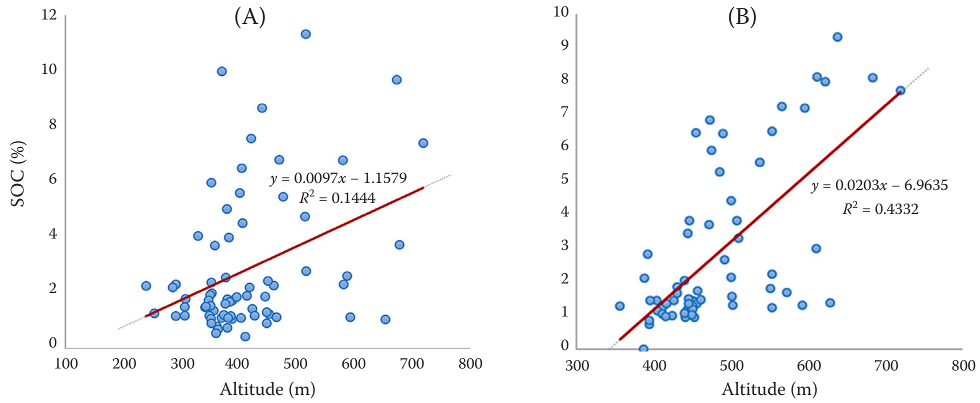

Figure 8. Relationship between altitude and soil organic carbon (SOC) (linear regression) in Liberec (A) and Domažlice (B) districts

titude, even after considering the effects of land-use and landscape position. This suggests that SOC is responding to climatic variables (the most likely temperature that decreases as altitude increases). This may also be confounded by the recent nature of land-use change (i.e. agricultural lands at higher altitudes are more likely to have been recently converted) and higher levels of soil acidity at higher altitudes, which may decrease decomposition rates. Therefore, the effect of altitude on SOC obtained from this study may be due to the combined effects of increased leaching at higher altitudes (subsurface pH change) as well as soil acidification through reduced decomposition and the build-up of a high organic matter litter layer with organic acids. Similar studies showed that SOM and soil nutrients are significantly correlated with altitude (Wu et al. 2016; Massawe et al. 2017; Gebrehiwot et al. 2018). Additionally, the coefficient of determination (R^2) between altitude and SOC was 0.144 and 0.433 for Liberec and Domažlice districts, respectively, indicating that there was a moderate correlation between altitude and SOC. Borůvka et al. (2022) reported that the importance of environmental variables in the models for SOC stock prediction varies in different regions and altitudes.

The relationship between altitude and clay content

Figure 9 shows the correlations between altitude and clay content for both Liberec and Domažlice districts. The R^2 value for the relationship between altitude and clay was 0.002 and 0.039 for Liberec and Domažlice districts, respectively, indicating that altitude and clay content were not correlated in both areas as shown in Figure 9.

The weak correlation between altitude and clay content can be attributed to different factors. Geological processes such as erosion can occur independently of altitude variations, leading to different clay content in areas at different altitudes solely based on local geological conditions, rather than being directly in-

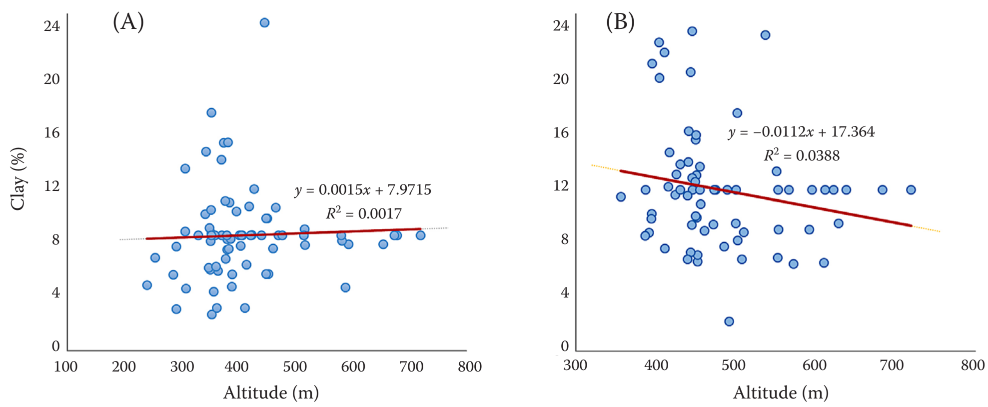

Figure 9. Relationship between altitude and clay (linear regression) in Liberec (A) and Domažlice (B) districts

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fluenced by altitude. Additionally, although climate and parent material affect clay content, only climatic conditions (such as temperature and precipitation) are directly influenced by altitude. Moreover, there can be localized variations in clay content due to factors such microclimates, drainage patterns, and land-use practices that may not directly correlate with altitude. Finally, soil movement through erosion or runoff can cause spatial variations in clay content, irrespective of altitude, as landscape dynamics re-distribute clay particles (Gebrehiwot et al. 2018).

The relationship between SOC and clay content

As presented in Tables S1 and S2 in the ESM, the correlation between SOC and clay was insignificant in both districts with $r = -0.026$ for Liberec and $r = -0.108$ for Domažlice districts. Additionally, clay content in the soil was mostly less than 20% as presented in Table 1, which could not have significantly minimized mineralization. On the other hand, soils containing lower content of clay may contain lower SOC content due to the high decomposition rate of organo-mineral fractions (Lee et al. 2009; Pronk et al. 2012). This can be due to the parent material in sampling locations (including granites, loamy glacial sediments, micaceous schist, and phyllites) because parent materials influence the organic matter stock. As an example, soils developed from inherently rich materials, such as basalt, are more fertile and have higher SOC than soils formed from granitic materials which include fewer mineral nutrients (Straaten 2011; Hartati & Sudarmadji 2016). Moreover, very acidic reaction of the soils under study can reduce the decomposition rate and thus lead to higher SOC content. In the present study, soil textural classes for the Liberec district included sedimentary coarse-textured rocks, acid granites, similar rocks (coarse textured), polygenetic loams, and loamy glacial sediments. Similarly, soil textural classes for the Domažlice district included polygenetic loams, loamy glacial sediments, micaceous schist, phyllites (medium textured), and a small proportion of acid granites, and similar rocks (coarse textured). The high content of SOC in sandy soils particularly at higher altitudes under coniferous forests can be caused by reduced mineralization due to strong acidity, as it is typical for Podzols and some Cambisols.

Comparing observed and predicted variables (SOC and clay)

Based on the relationships found in this study, multiple linear models were constructed to predict SOC and clay contents from altitude and slope separately for the Liberec and Domažlice districts. Figures 10 and 11 show the relationship (linear regression) between observed and predicted values for two variables including SOC and clay contents, respectively. Results indicate that although correlations between observed and predicted values were better in the Domažlice district than Liberec district, the correlation between observed and predicted SOC is much better than the correlation between observed and predicted clay content in both districts. This can be due to the low content and great variability in observed clay contents that decrease the possibility of creating a regression model with a strong correlation.

Data separation by land use classes and model analysis

Generally, SOC is affected by land-use and increases with increasing altitude within land-use categories

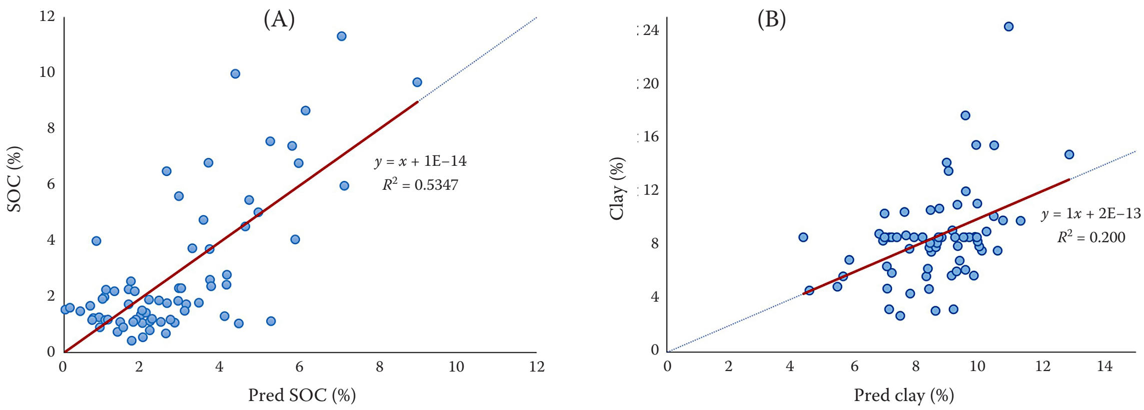

Figure 10. Relationship (linear regression) between observed and predicted soil organic carbon (SOC) content (A) and observed and predicted clay (B) in the Liberec District

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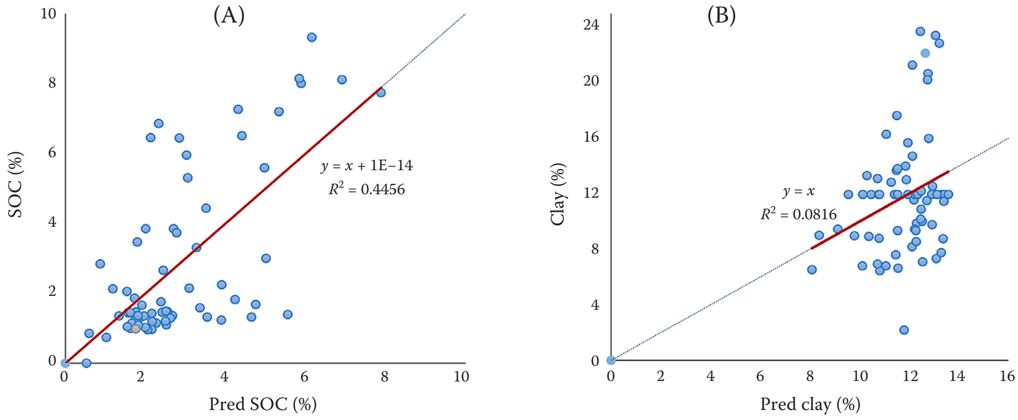

Figure 11. Relationship (linear regression) between observed and predicted soil organic carbon (SOC) content (A) and observed and predicted clay (B) in the Domažlice district

due to the convergent effects of temperature decrease, precipitation changes, acidification, and intactness of native ecosystems. To analyse the correlation between SOC and slope for Liberec and Domažlice districts in more detail, datasets were divided into three subsets based on the land-use including arable land, forest, and complex system of agriculture, parcels, and forests (Figure 4). In the following subsections, the relationship between slope and SOC, across three different land use classes, is evaluated. Additionally, a comprehensive comparison between the observed and predicted variables (SOC and clay) is conducted.

The relationship between slope and SOC content after data separation. As shown in Figures 12A through 14A, SOC and slopes for Liberec district were correlated at arable land with R^2 = 0.353 at $P < 0.05$ (35 samples), at forest land with R^2 = 0.140 (22 samples), and at complex system with R^2 = 0.598 at $P < 0.05$ (14 samples). As shown in Figures 12B through 14B, SOC and slopes for Domažlice district were correlated very little at arable land with R^2 = 0.008 (35 samples), at forest land with R^2 = 0.083 (20 samples), and at complex system with R^2 = 0.386 (12 samples).

Comparing Figure 6 with Figures 12 through 14 shows that the data separation improved the correlations between SOC and slope in some subsets, confirming the effects of land-use on SOC. The correlation for arable areas in the Liberec district increased more than that in the Domažlice district. This is because of the different effects of agricultural systems and management, tillage, slope, soil biology, and erosion on SOC. For instance, agricultural systems with conventional tillage in the Czech Republic have been affected over the years (Šíp et al. 2009).

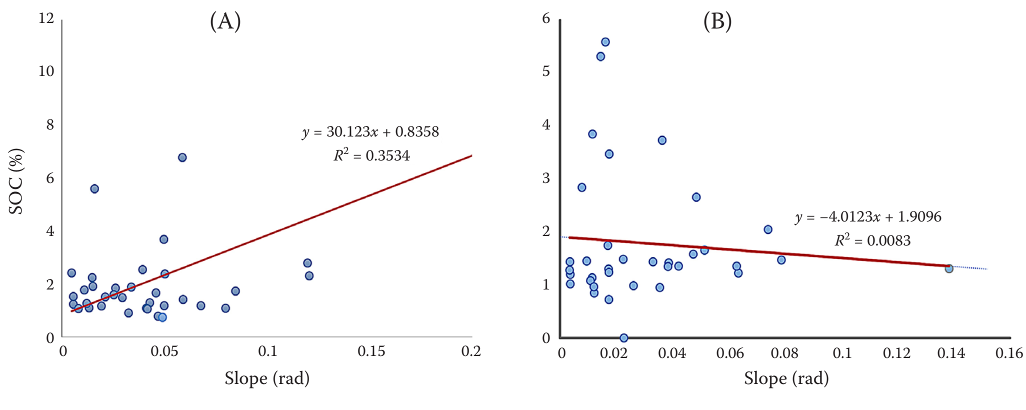

Figure 12. Relationship between slope and soil organic carbon (SOC) (linear regression) in arable lands in Liberec (A) and Domažlice (B) districts

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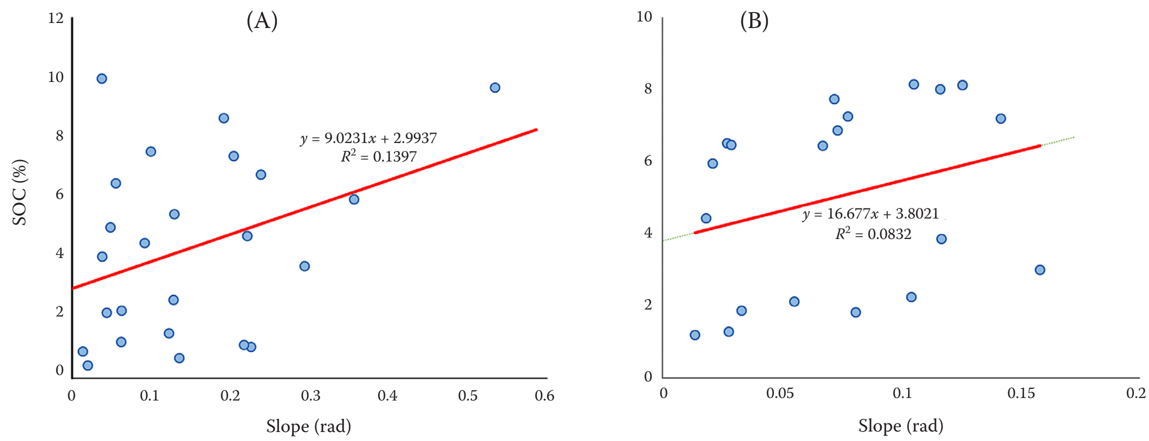

Figure 13. Relationship between slope and soil organic carbon (SOC) (linear regression) in forest areas in Liberec (A) and Domažlice (B) districts

The results of the surface runoff speed corroborate the significant benefits of soil conservation tillage technology. Also, tillage typically reduces mean SOC content and homogenizes the horizontal and vertical distribution of SOC (Dornbush & Von Haden 2017). Additionally, the spatial distribution of biologically mediated soil ecosystem services is impacted by agricultural practices, changing SOC, because most of the soil biological communities are dependent on SOC substrates. A reduction in SOM decomposition and thus increased SOC concentration is due to an increase in acidity and consequent reduction of biological activities. Soil compaction is another problem due to intensive conventional farming. The original causes of the decrease in SOC are conventional farming without using organic fertilizer or other SOM (Šíp et al. 2009). This shows the necessity for sustainable land management practices, mostly those that reduce erosion and build SOM. As shown in Figure 13, the correlation between SOC and slope in forests of the Liberec district was similar to the Domažlice district while both correlation values were low. This can be due to the effects of forest tree species on soil layers. Generally, the soil of coniferous stands, which constituted the largest group in the forests group, contained significantly less stored carbon than the soil of other species, as a large part of SOC is stored in the forest floor that is not considered in this study. Also, carbon stocks can potentially be affected by soil disturbance events depending on forest type or topographic parameters.

It appears that changes in SOC are affected by a range of soil-management practices relating to tillage management, a total of crop residues, fer-

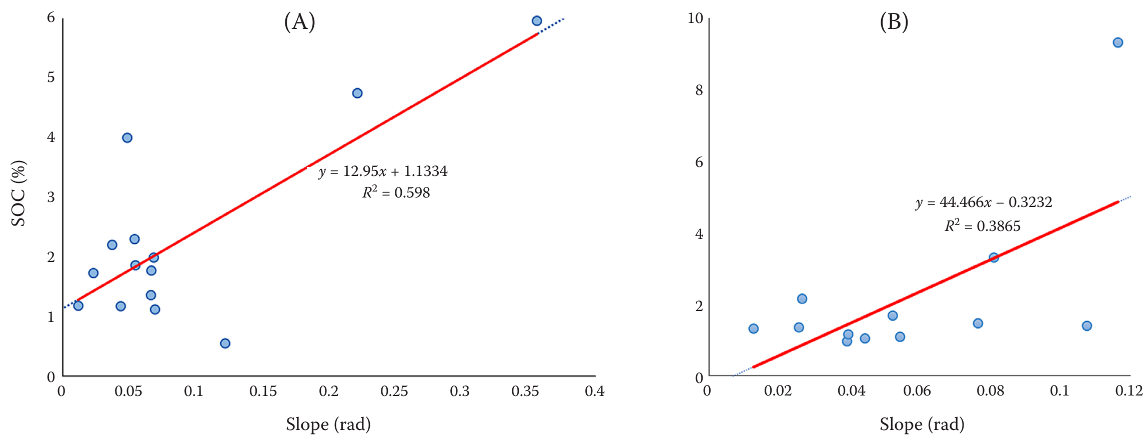

Figure 14. Relationship between slope and soil organic carbon (SOC) (linear regression) in complex systems in Liberec (A) and Domažlice (B) districts

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Table 2. Regression coefficients of multiple regression models for soil organic carbon (SOC) and clay (dependent variable) prediction based on altitude and slope (independent variables) in different land-uses and for the entire dataset

Source	Liberec district				Domažlice district			
	arable	forest	complex	entire dataset	arable	forest	complex	entire dataset
SOC								
Altitude	0.421	0.142	–0.177	0.380	0.373	0.594	0.622	0.658
Slope	0.595	0.374	–0.306	0.525	–0.091	0.289	0.622	0.444
Clay								
Altitude	–0.019	–0.154	0.688	0.042	–0.161	–0.293	–0.257	–0.197
Slope	0.056	–0.061	–0.085	–0.025	–0.267	–0.599	0.180	–0.276

tilizer, organic losses, and different crop rotation programs (Ghimire et al. 2012).

In complex systems, correlations were better than the arable land and forest. Francaviglia et al. (2019) showed that variated arable cropping systems and various management plans in selected European areas had positive effects on SOC.

Multiple linear regression models for SOC and clay content prediction. To achieve more appropriate results, multiple regressions were conducted on different land-use types to assess the relationship between SOC and other environmental variables (altitude and slope) as well as the relationship between clay and other parameters (altitude and slope) in both districts. The results showed the multicollinearity between environmental variables and predicting SOC and clay with these variables using simple regression would not be reliable while using multiple regression could effectively improve the results. The results also illustrated that the multiple regression was significantly changed by dividing the study area into various land-use types because the distribution of SOC and clay varies with land-use. Similarly, Lettens et al. (2005) separated the regions into 289 landscape units and predicted the SOC stocks for each landscape unit in Belgium. They reported that SOC stocks were continuously influenced by some external characteristics, mainly land-use history and usual land management and climate.

Table 2 presents the distribution of SOC and clay as dependent variables, respectively, based on the altitude and slope for different land-uses and entire dataset in both districts. It can serve as a basis for multiple regression model for the selection of the predictors. For instance, multiple Pearson correlation coefficients of 11 different variables for arable land in the Liberec district are also presented in Table S3 (in ESM). SOC was mostly positively correlated with altitude and slope, while clay was mostly negatively correlated with altitude and slope (Table 2).

Figures 15 through 20 show multiple regression (linear trend) of the relationship between observed

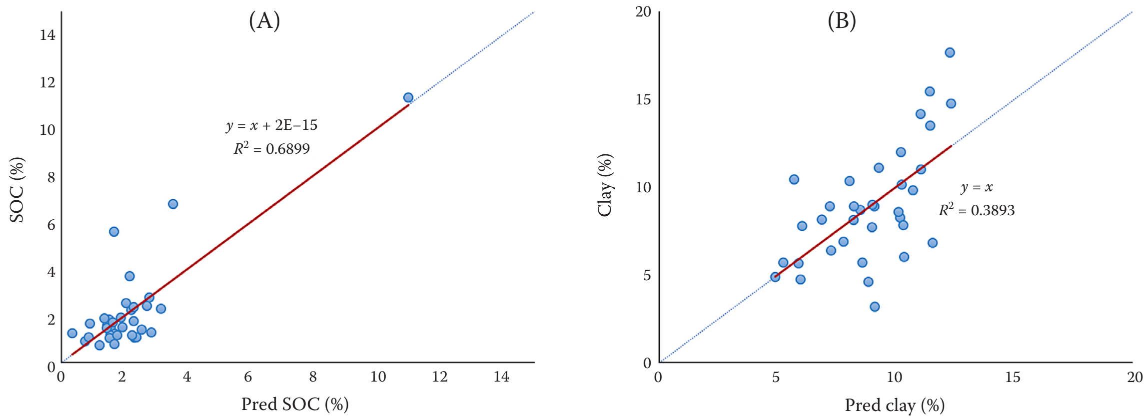

Figure 15. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the arable land (B) (Liberec district)

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and predicted SOC as well as observed and predicted clay for arable land, forest, and complex system in both districts. Results showed that the correlations obtained from multiple regression (linear trend) for separate land-uses were more significant (greater R^2) compared to the correlations obtained from simple regression (linear trend) without land-use separation. For instance, the re-

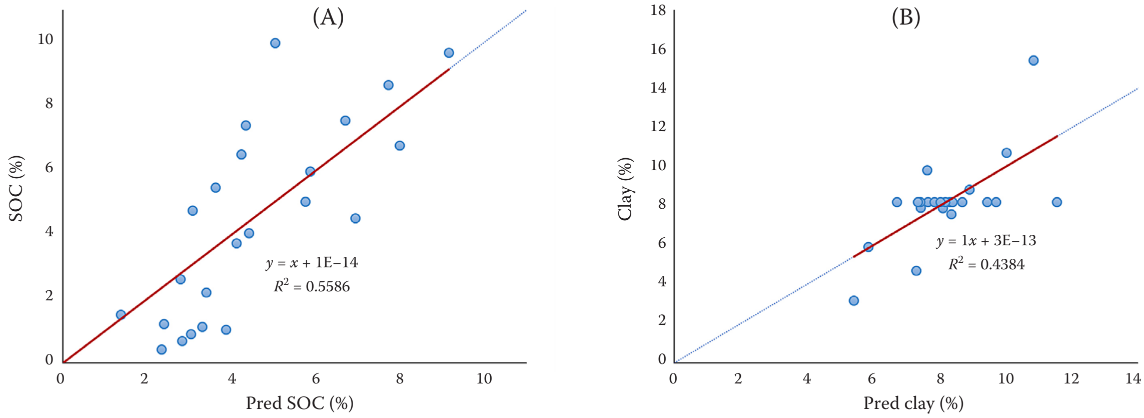

Figure 16. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the forest (B) (Liberec district)

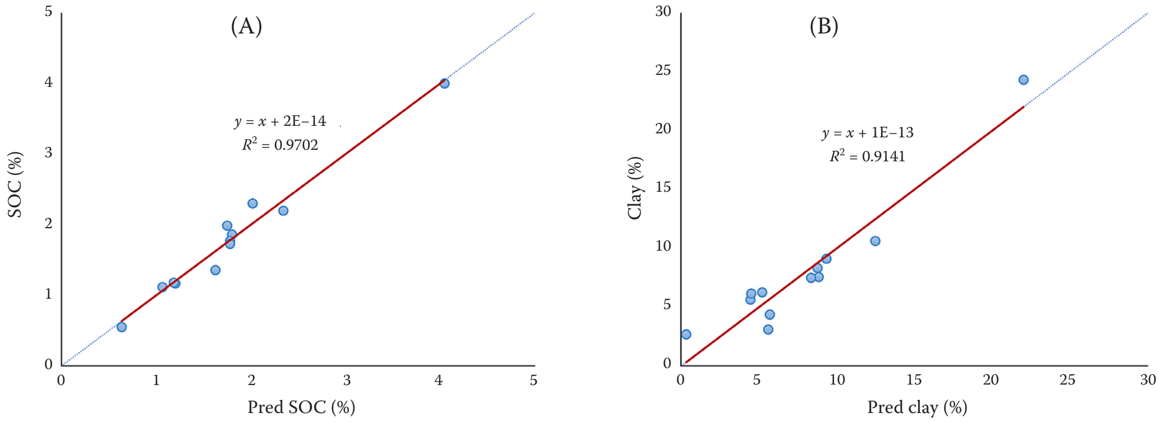

Figure 17. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the complex system (B) (Liberec district)

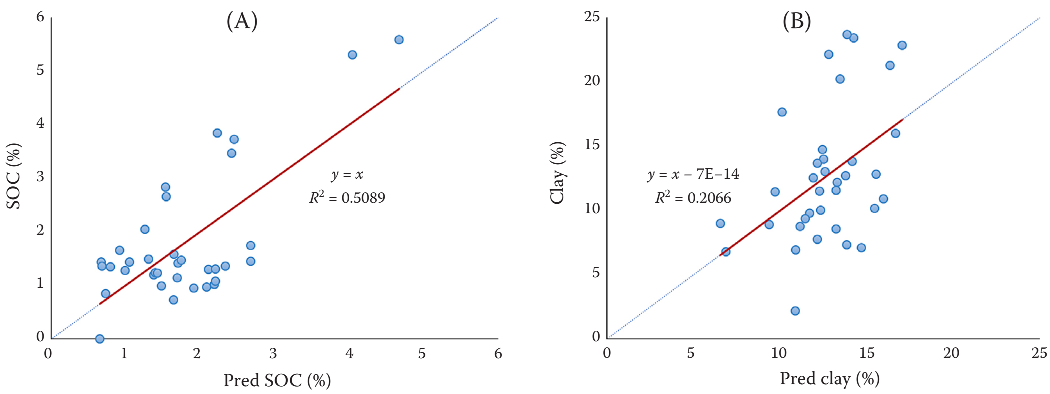

Figure 18. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the arable land (B) (Domažlice district)

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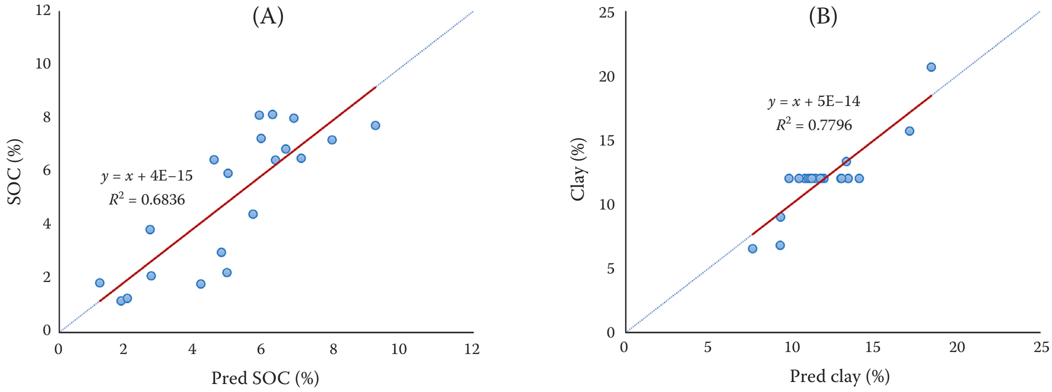

Figure 19. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the forest (B) (Domažlice district)

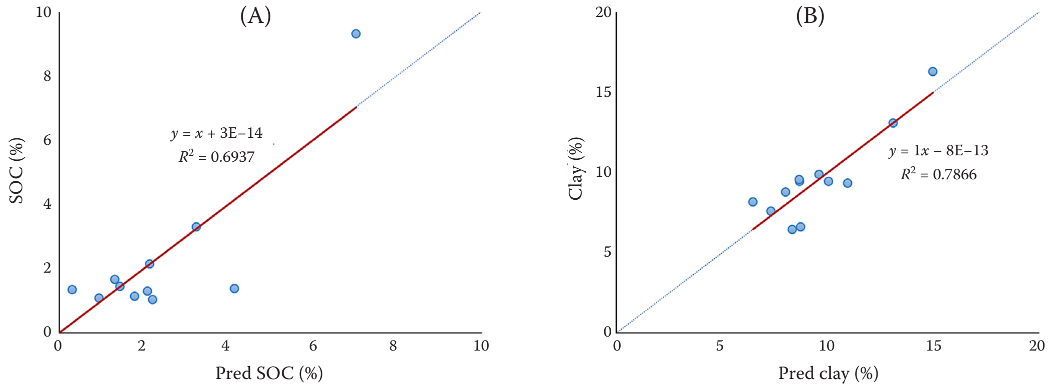

Figure 20. Linear trend of the relationship between observed values and values predicted by multiple regression for soil organic carbon (SOC) (A) and clay in the complex system (B) (Domažlice district)

lationship between observed and predicted SOC in the Liberec district improved with increasing R^2 = 0.535 (Figure 10A) to R^2 = 0.970 (Figure 17A) when considering only complex system. As another example, R^2 value for the relationship between observed and predicted clay increased from 0.200 (Figure 10B) to an impressive 0.914 (Figure 17B) by exclusively considering complex systems within the Liberec district.

CONCLUSION

From the results of this study, the following conclusions can be drawn:

(1) Although SOC content increases when slope or clay increase, the correlation between SOC and clay was not significant in both districts.

(2) SOC increases with increasing altitude, most likely due to the combined effects of increased leaching at higher altitudes and soil acidity leading to reduced decomposition. However, there was only a moderate correlation between SOC and altitude.

(3) Clay increases with decreasing slope for both districts.

(4) Clay and altitude were not correlated well in both areas, most likely due to the effects of erosion and runoff which transported sediments from higher altitudes and accumulated them in the lower parts of the basin.

(5) The correlation between observed and predicted SOC is much better than the correlation between observed and predicted clay content in both districts, due to the low content and great variability in observed clay contents.

(6) Multiple linear regression models based on topographical variables were constructed for SOC and clay content prediction separately for each district. A better correlation between observed and predicted values (SOC and clay) was observed

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in the Domažlice district than in the Liberec district. This can be due to the low content and great variability in observed clay contents in Liberec district that decreases the possibility of creating a linear model with a strong correlation.

(7) Data separation by land-use types improved the correlations between SOC and slope in some subsets, showing the significant effects of land-use on SOC.

(8) Overall, it can be concluded that the variation of land uses was influential in SOC distribution of the study areas and should be taken into consideration when evaluating the effects of future land use changes on SOC and clay content on a regional scale. Additionally, a combination of slope and altitude could provide a better understanding of the effect of topography on SOC and clay.

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