Redistribution of erosion triggered soil organic carbon at the field scale under subhumid cilmate, Hungary

Journal:	*Pedosphere*
Manuscript ID:	Draft
Manuscript Type:	General Paper
Keywords:	Cambisol, Carbon sequestration, Diffuse reflectance, Intensive cultivation, Selective erosion, Soil organic matter compound
Speciality:	Soil Degradation Control, Remediation and Reclamation

Abstract

Soil organic carbon (SOC) has primary importance in terms of soil physics, fertility and even of climate change control. An intensively cultivated Cambisol was studied in order to quantify SOC redistribution under subhumid climate. One hundred soil samples were taken from the representative points of the solum along the slopes from the depth of 20-300 cm with a mean 1.2 % SOC content. They were measured by the simultaneous application of diffuse reflectance (240–1900 nm) and traditional physico-chemical methods in order to compare the results. On the basis of the results hierarchical cluster analyses were performed. The spatial pattern of the groups created were similar, and even though the classifications were not the same, diffuse reflectance has proven to be a suitable method for soil/sediment classification even within a given arable field. Both organic and inorganic carbon distribution was found a proper tool for estimations of past soil erosion process. Results show SOC enrichment on two sedimentary spots with different geomorphological positions. Soil organic matter compound also differs between the two spots due to selective deposition of the delivered organic matter. The components of low molecular weight reach the bottom of the slope and there can leach into the profile, while the more polymerised organic matter compounds are delivered and deposited even before, on a higher segment of the slope in an aggregated form. This spatial difference appears below the uppermost tilled soil layer as well; referring the lower efficiency of conventional ploughing tillage in spatial soil homogenisation.

Keywords: Cambisol; Carbon sequestration; Diffuse reflectance; Intensive cultivation; Selective erosion; Soil organic matter compound

1 Introduction

Soil organic carbon (SOC) content is one of the most important qualifying property in soil description. Soil fertility is generally given as a function of some kind of SOC content. Increasing conservation of SOC content has become a symbol of sustainable agriculture. Since SOC has a pivotal role in structuring soil particles it has primary importance in soil physical properties such as porosity, aggregate stability and infiltration (Stavi and Lal, 2011). Lal (2004) estimated that global soils contain 2500 Gt carbon (1550 Gt SOC) in their uppermost 1 m thick horizon hence this is one of the largest terrestrial pool second only to the geologic stock. In native soils SOC content generally decreases with depth, while tillage homogenises SOC content in the uppermost horizon (Lee *et al*., 2009).

Among uniform climatic, floristic and land use conditions, SOC content does not change significantly. Tillage operations on a native land considerably reduce SOC content until it is stabilised at a lower value controlled by the new circumstances (Häring *et al*., 2013a). On intensively cultivated arable fields the oxidation caused by soil tillage is considered to be an effective factor reducing SOC (Häring *et al*., 2013b), however, there are also data presented on SOC sequestration due to accelerated soil erosion and deposition generated by tillage (Lal, 2004). Although their effects are closely correlated, tillage triggers chemical degradation while erosion controls spatial distribution of SOC (Polyakov and Lal, 2008). Small soil particles are especially prone to erosion while larger aggregates are less affected. Enrichment of the clay fraction and SOC related colloids in soil loss might reach 2.5 times (Farsang *et al*., 2012; Nagy *et al*., 2012; Wang *et al*., 2010). There are also data reported on the erosion of selective soil organic matter (SOM) that proved differences in organic matter of the soil loss compared to the native SOM (Jakab *et al*., 2014). Even though soils have already lost 20–50 t C ha^{-1} due to soil erosion (Lal, 2003) there are still ambiguities concerning the fate of eroded organic carbon whether it sequestrates or mineralizes (Lal and Pimentel, 2008).

In general SOC redistribution was investigated mainly by soil loss sampling and analysis from runoff plots at field or catena scale (Polyakov and Lal, 2008). There are also results on SOC erosion under simulated precipitation events at point scale (Zhang *et al*., 2011; 2013), but up- or downscaling the results is still a problematic issue (Chaplot and Poesen, 2012). Whereas there are estimations about carbon sequestration in buried horizons of lakes and reservoirs exceeding terrestrial carbon stocks by two orders of magnitude in Central Europe (Hofmann *et al*., 2013), still little is known about the deposition and burial processes at the field scale.

A simple way of SOM analyses could be using extraction indexes derived from ultraviolet (UV) and visible (VIS) absorbance spectra (Chin *et al*., 1994; Her *et al*., 2008; Tan, 2003). The application of UV, VIS and near infrared (NIR) reflectance of the soil is also a widespread method for the survey of soil properties by remote sensing (Aichi *et al*., 2009; Conforti *et al*., 2013). This method is applicable only to establish the soil surface parameters (Gomez *et al*., 2008). Diffuse reflectance is a suitable method for the study of buried horizons as well (Viscarra Rossel *et al*., 2006). The UV-VIS-NIR spectra (200–2500 nm wavelength) include all the information on the soil material, the measurement being simple and inexpensive. Many studies report about the accuracy of predictions based on reflectance as for SOC, clay, carbonate content, pH etc. (Brodsky *et al*., 2011; Lee *et al*., 2009; Viscarra Rossel *et al*., 2009). These studies compared many soil samples from very different environmental circumstances using partial least squares regression method and resulted in relatively high R^2 values. However, it is not clear if the determination of chemical properties based on diffuse reflectance works with very similar soil samples at slope scale.

The aim of this study is to survey accelerated erosion and soil redistribution due to erosion triggered by tillage on an intensively cultivated arable land on Cambisol under subhumid climate, Hungary. The main questions are whether (I) the deposited part contains information of the origin of the sediment (II) the SOC enrichment measured in trapped soil losses in previous surveys (Farsang *et al*., 2012; Kuhn *et al*., 2012; Wang *et al*., 2010) still exist in the in situ buried horizons. An additional goal is (III) to compare the SOM compound of the tilled layer with those of the deposited and buried horizons in order to prove selective erosion processes and (IV) to test the prediction of physico-chemical properties based on diffuse reflectance in similar soil samples at slope scale.

2 Material and methods

2.1 Study area

The investigated area is located at Ceglédbercel, SE of Budapest, Hungary (Figure 1). It is an intensively tilled arable field on sandy loess parent material. Soil cover varies among the differently eroded and deposited types of eutric calcaric Cambisol loamic and eutric calcaric ochric Regosol. The crest and the upper third of the slope is occupied by an orchard and have a very shallow solum. This part is separated from the lower one by a road and a ditch therefore it is excluded from the investigation. The slope steepness of the lower, studied part varies between 5 and 17 %, the average value is 12 %. The investigated part forms a valley with Regosol spots on the surface at the steepest points and 3 m deep deposition on the bottom. The area is 3.2 ha. The elevation is between 154 and 170 m a.s.l., mean annual temperature is 10.8 °C while annual precipitation is around 600 mm (Dövényi, 2011). Prevalent crops for the last decades are winter wheat, maize and sunflower. Conventional tillage with autumn mouldboard ploughing was applied with NW–SE tillage direction (Figure 1).

2.2 Field work

Topography of the study site was surveyed by a Trimble 3300DR laser total station. The surface was measured along the mesh with 10 m distances. Boreholes were deepened using Edelman augers in order to reach the parent material along a net with 25 m distance. Altogether 46 drillings (Figure 1) were carried out during the summer of 2013 under sunflower. Each drilling was described in detail, the depth of the parent material was recorded. Horizons were determined on the basis of field observations, such as colour, $CaCO_3$ (Soil Inorganic Carbon; SIC) and moisture content. All descriptions and predictions were applied using the Fieldbook for describing and sampling soils (Schoeneberger *et al*., 2012). Soil colour was determined using the Munsell soil chart, SIC content was predicted on the bases of HCl solution drop treatments. Soil samples were taken from each horizon of the representative drillings. Altogether 100 soil samples were collected.

2.3 GIS support

The soil surface and the predicted surface of the parent material were interpolated using the ordinary linear Kriging method (based on spherical semivariogram model) on the basis of the boring data with Baker Hughes JewelSuite™ 2013 geologic modelling software. The idea for using geological modelling software was to reckon the soil horizons as geological layers, so that the horizons with various depths could be modelled. Interpolating soil and parent material surfaces among the measured points the spatial variation of solum depth was also established with JewelSuite 2013, using the Kriging method mentioned above (Oliver and Webster, 1990).

ESRI ArcMap 10.1 and ArcScene 10.1 were used to create soil depth map, and to visualize the soil groups formed on the basis of the reflectance spectra and chemical analyses.

2.4 Laboratory equipment used

SOC and total nitrogen (TN) content were measured by a carbon-nitrogen analyzer (Tekmar Dohrman Apollo 9000N) after the elimination of inorganic carbon (Buurman *et al*. 1996). Samples were pre-treated with 19% HCl in order to eliminate SIC content. C/N ratio was calculated dividing the measured SOC content by TN content. Particle size distribution was determined by laser diffraction analyzer (Horiba LA-950) in a range of 0.2–2000 µm. Samples were disaggregated by 15 min. ultrasonic treatment combined with 0.5 mol sodium pyrophosphate application. SIC content was analyzed by the gas volumetric method of Scheibler (Pansu and Gautheyrou, 2006).

SOC compounds were characterised by UV-VIS spectrophotometry (Shimadzu 3600) using 0.5M NaOH solute sediment samples. E_2/E_3 index as a parameter for the degree of polymerisation (Tan, 2003) as well as Ultraviolet Absorbance Ratio Index (URI, UVA_{210}/UVA_{254}) as an indicator for functional group density (Her *et al*., 2008) were calculated and absorbance values at 280 nm referring to the aromaticity (Chin *et al*., 1994) were recorded to typify SOM compounds. To compare the results of the different methods, the whole absorbance spectra were recorded between the wavelengths of 800–180 nm.

Diffuse reflectance was analyzed using the UV-VIS-NIR spectra. Reflectance values were detected by a Simadzu 3600 spectrophotometer equipped with the LISR-3100 integrating sphere. The recorded range was between 240–2400 nm wavelengths with a resolution of 0.5 nm. Because of the noise caused by humidity in the 1900-2400 nm range, this part of the spectra was excluded from the further data processing (Bradák *et al*., 2014).

Both pH in distilled water and in KCl were determined in a soil suspension 1:5 according to the Hungarian standard (Buurman *et al*. 1996).

2.5 Data evaluation techniques applied

Correlation between variables was established using regression analyses. Since the information of the whole reflectance spectra was too abundant to handle, data filtration was applied. Only each twentieth value (reflectance of each tenth nm) was included into the statistical processes. Hierarchical cluster analysis was used to classify the samples parallel on the basis of diffuse reflectance spectra and of the other measured parameters. Clustering is a kind of coding, as a result of which a certain sampling location originally described with many parameters (runoff, chemical oxygen demand etc.) is now described with only one value, i.e. group code (cluster number). It is important to note that during clustering not the number of parameters but the number of sampling locations is decreased by grouping the similar ones. The main aim is to classify the similar sampling locations into the same category, however this similarity has to be measured by assigning a distance (metrics) to each sampling location which is placed in an *N* dimensional space.

To verify the accuracy of the classification canonical discriminant analysis was applied. It shows to what an extent the planes separating the groups can be distinguished by building a predictive model for group membership. The model is composed of a discriminant function (for more than two groups a set of discriminant functions) based on linear combinations of the predictor variables that provide the most reliable discrimination between the groups. The functions are generated from a sample of cases for which the group membership is known; the functions can then be applied to new cases that have measurements for the predictor variables but their group membership is as yet unknown (Afifi *et al*., 2004).

After the verification of the cluster groups the role of each parameter should be analyzed in determining the formation of the cluster groups. Using Wilks' λ distribution a Wilks' λ quotient is assigned to every parameter. The value of λ is the ratio of the sum of squares within the group to the total sum of squares. It is a number between 0 and 1. If $\lambda=1$, the mean of the discriminant scores is the same in all groups and there is no inter-group variability. In this case the given parameter did not affect the formation of the cluster groups (Afifi *et al*., 2004). If $\lambda=0$, then that particular parameter affected the formation of the cluster groups the most. The lower the quotient value is, the more it determines the formation of the cluster groups (Hatvani *et al*., 2011).

To analyse the parameters within the created clusters a simple statistical method was used such as box and whiskers plots. The boxes show the interquartile range and the black line in the box is the median. Two upright lines represent the data within the 1.5 interquartile range. The data between 1.5 and 3 times the interquartile range are indicated with a circle (outliers), and the ones with values higher than 3 times the interquartile range are considered to be extreme and indicated with an asterisk (Norusis, 1993).

3 Results and discussion

3.1 Variations in the depth of humic horizon

Many authors found correlation between soil depth and redistribution processes (Jakab *et al*. 2010; Kirkels *et al*. 2014; Niu *et al*. 2015; Vona *et al*. 2006; Wiaux *et al*. 2014). The depth of humic horizon varies along the slope sections between 0 cm and 300 cm. On the steepest parts loess is on the surface, however, due to tillage operations some organic matter is continuously mixed into the tilled layer. There is a weak correlation between profile depth and slope steepness (Figure 2), although the deeper profiles tend to occur on the flatter parts.

Spatial distribution of solum depth was estimated by interpolating surfaces among the measured points (Figure 3). Result pattern suggests that solum depth is rather a function of geomorphologic position than that of slope steepness. The deepest profiles are found at the slope bottom (Figure 1) even of an ephemeral gully. Poesen *et al*. (2003) pointed out that soil loss due to ephemeral gullies hardly depends on time, consequently temporary soil deposition occurs at the valley bottoms. Presumably due to these temporary circumstances gully erosion is less effective to deliver sediments than sheet and tillage erosion is (Gong *et al*., 2011).

Under forest sheet erosion is negligible comparing to accelerated erosion. Before forest clearance in the early 18th century a relatively homogeneous soil depth (around 1 m) ruled the district (Stefanovits, 1971), the redistribution took place during the last 300 years as it is typical in Central Europe (Dotterweich *et al*., 2013). Within this period some spots eroded down to the parent material, which means at least 1 m soil loss and 3 mm year^{-1} erosion rate on the average. This value is in accordance with average soil loss reported by Vona *et al.* (2006), Jakab *et al.* (2010) on arable fields with loess as parent material. At the deposition spots more than 2 m thick sediment covers the original surface, which means that most of the delivered soil remained within the field, resulting in reduced net soil loss. As the short time since forest cut was not enough to trace changes due to pedological processes (Schaetzl and Anderson, 2005), the spatial variability of soils is considered to be the combined result of erosion and deposition.

3.2 Results of reflectance spectra

Hierarchical cluster analysis of the reflectance spectra was carried out. The samples were classified into four groups. The results of the canonical discriminant analysis have proven the reliability of the classification: the four groups are definitely divided at least along two functions (dimensions) (Figure 4).

Spatial distribution of the groups reflects their geomorphologic position (Figure 4), that supports the findings of Wiaux *et al.* (2014) concerning SOM and secondary minerals. Accordingly the infiltrated data (reflectance values at only each tenth nm) contain enough information for proper soil sample classification.

Group 1 (red) includes soils with high loess content, high SIC volume and low SOC content. They can be found mainly on the surface of the steepest segments along the slopes where the solum is shallow and loess is close to the surface. Additional members are at the lowest part of the deeper profiles also close to the parent material.

Both Groups 2 and 3 contain samples with high SOC content, but while Group 2 (blue) is generally located in the uppermost 1 m thick layer, Group 3 (green) can be found in the deeper parts and in some spots on the surface as well. Group 4 (purple) contains only four samples of pure loess without SOC and with SIC content higher than 20%.

3.3 Results of physico-chemical analyses

3.3.1 SOC correlation with other parameters

Although SOC is generally reported to migrate attached to fine particles (Centeri, 2006; Fuchs *et al.*, 2010; Wang *et al.*, 2010; Zhang *et al.* 2013) no correlation was found between these two parameters (Figure 5a). Accordingly, SOC is transported and deposited independently from the clay component. A weak relationship could be recorded between SOC amount and SOM compound (Figure 5b–d). Increasing SOC volume raises C/N ratio, that suggests the dominance of lower average molecular weighted, less stable SOM in case of higher SOC content (Figure 5c), although C/N ratio varies within a wide range compared to the results of Watteau et al. (2012). On the other hand aromatic character increases with SOC volume (Figure 5d). In fact, these relations are stronger in case of low SOC content, whereas in the higher range the linkage is getting weaker, that means higher SOC content increases the variability of SOM. This could be the result of selective SOM erosion and/or inhibited SOM formation. In this case the latter is more probable because the formation of high molecular weighted polymerised SOM is impossible on the continuously eroding Regosol spots. Nevertheless, the persistence of SOM can be strongly affected by other physical and biological circumstances as well (Berhe *et al*., 2012; Berhe and Kleber, 2013).

3.3.2 Clusters on the basis of physico-chemical parameters

A parallel hierarchical cluster analysis of the same samples was carried out on the basis of 14 soil parameters (Table 1). Four groups were created again, and the classification was tested by canonical discriminant analysis that shows an adequate distribution (Figure 6), although in this case four samples were reclassified. Result shows that the groups again are separate units and have the same spatial distribution as the diffuse reflectance related classification had before. The size of the groups has changed compared to the former classification. In this case Group 1(red) contains the same samples as it did in the reflectance case with high SIC content. This group has changed the less. On the depositional surfaces Group 2 (blue) members with the highest SOC content can be found again; however, some samples from the former Group 2 moved to Group 4 (purple). Group 3 represents samples of medium TOC content while this group contains just some part of the former Group 3 (green) which was divided among the newly formed groups of No. 2, 3, and 4. The former Group 4 (pure loess) was merged into Group 1, accordingly Group 4 is a new class including samples of the deepest positions of the deposited profiles, i.e. from the former Group 1 (containing no SIC and minimal SOC).

Even though the two classifications yielded different results, both of them describe very similar main tendencies, consequently total reflectance spectra can be comparable with findings based on the series of physico-chemical measurements. There has been a wealth of studies to identify special wavelengths within reflectance spectra suitable for tracing certain soil components such as iron and clay minerals (Viscarra *et al*., 2009), SOC (Minasny *et al*., 2011; Viscarra *et al*., 2006) and SIC (Ge *et al*., 2014). Nevertheless, because of the polydispersal nature of the system, soils can only be described on the basis of a wider spectrum that can reflect to the interactions. In this way the whole filtered spectrum should be handled as one complex parameter that summarizes the results of each individual physical or chemical measurement. On the other hand even if the filtered spectrum (i.e. reflectance value of only each tenth nm) is enough to classify the soil samples the issue of data filtration methods (range and the starting nm of the filtration) still has ambiguities.

In order to determine the most effective parameters in classification Wilks' λ was calculated (Table 1).

Carbon content has a primary importance in classification. Inorganic, organic and total carbon content respectively determine the way of group formation. The rest of the variables have a minor influence on classification, although group forming factors of similar importance still can be found in the second stage ($0.5<\lambda<0.61$). From textural point of view sand and silt content are important since they represent the main particle sizes in the examined soils. SOM compound parameters do not seem to be an important classifying factor, although C/N ratio and the reflectance value at 280 nm have a definitely stronger influence than URI and E_2/E_3. pH in KCl is a more informative qualifier in this case than that in distilled water, however, there is no exchangeable acidity in the investigated soil. The rest of parameters do not have influence on classification at all.

Differences among the groups concerning the measured parameters are presented using boxplots (Figure 7). SIC content can be a highly suitable parameter to follow erosion and deposition processes on the study site as SIC was leached from the original topsoil/solum and can only appear there again as a result of soil redistribution due to erosion and tillage processes (De Alba *et al*., 2004). Even if it was the main parameter for the classification, only Group 1 has significantly higher SIC content, groups 2, 3 and 4 has a similar low value with decreasing SD values (Figure 7a). Group 4 has the lowest SOC value again while Group 2 has far the highest one (Figure 7b). Many previous studies presented results on SOC enrichment in soil loss (Lal, 2005; Wang *et al*. 2010). Our survey testified to higher SOC value found in the subsurface depositional horizon, consequently selective SOC erosion and deposition exist in spite of the equalizing effect of intensive tillage operations. SOC maximum is near to the surface that could be the result of carbon mineralisation in the underlying layers as it was reported by Olson et al. (2012) or its enrichment in the depositional parts. The four groups have highly different SC values as a result of the mixture of organic and inorganic carbon distribution (Figure 7c). Only the sand content of Group 4 differs significantly from the other groups (Figure 7d), which can be attributed to the appearance of a carbon-free sand layer (Figure 7g) between the solum and the loess. The origin of this sand is unknown but it highlights the importance of spatial diversity in data extrapolation.

Boxplot of absorbance at 280 nm is very similar to that of SOC, as the level of aromaticity is a direct function of SOC content (Figure 7e). This suggests a constant ratio of humic substances within SOM independently from transportation and deposition processes. These results contradict to those reported by Farsang *et al.* (2012) according to which recent deposition was trapped, while our results refer to deposits buried a long time ago. SOC enrichment and SOM compound variations in soil loss strongly depend on initial soil moisture content, precipitation parameters, aggregates and crusting (Kuhn *et al*., 2012; Yamashita *et al*., 2006), consequently results gained from different scales can be compared only with difficulties (Chaplot and Poesen, 2012).

When comparing average values of silt content by group the same phenomenon is observed as in the case of SOC and absorbance at 280 nm. Consequently silt and SOC are closely interrelated (Figure 7f). SOC association with silt instead of clay emphasizes the role of aggregation, because delivered aggregated soil particles contain SOM and have sizes different from the disaggregated soil loss. Differences between groups 2 and 3 are mainly related to SOC content and SOM compound. Group 3 has a higher sand content and a lower SOC volume, absorbance at 280 nm and C/N ratio (Figure 7d, b, e and h). Aromaticity established by the measured absorbance at 280 nm and C/N ratio (Figure 7e, h) seem to be in close correlation that suggests an inverse relationship between aromaticity and polymerisation, although these parameters estimated by URI (Figure 7i) do not prove this trend.

3.4 Modelled spatial distribution

Spatial distribution of the measured parameters was interpolated using Jewel (Figure 8).

A number of studies report about the homogenising effect of persistent tillage operations (Dimassi *et al*., 2014; Lee *et al*., 2009; Zhang, 2013,) on the surface of the study site of various appearance (Figure 8). Low SIC values can be found only on the flatter sedimentary surfaces, while the highest ones are associated with the steeper surfaces. Although as a result of the forest clearance both accelerated and tillage erosion have redistributed SIC content, surface diversity suggests that SIC spread is not that effective. Concerning vertical distribution, the lowest values are on the sedimentary surfaces at 1–2 m depth that is presumed to be the original, leached soil profile before intensive processes of deposition.

Lowest SOC content of the surface can be found on the steepest spots, while the highest values are on the sedimentary surfaces similar to the spatial pattern reported by Navas et al. (2009). The maximum SOC values on the surface are higher than those within the buried *in situ* topsoil probably due to SOC mineralisation in the buried layer or selective SOC deposition at the bottom of the slope. According to the results of Wang *et al.* (2014) and SOC reduction with depth as a rule in the studied area refers to the latter. SOC tends to increase at two morphological spots: "A" at the surface in the middle of the ephemeral gully, and "B" at the surface on the lower end of the ephemeral gully.

Higher N content is associated also with the deposition surfaces, hence TN seems to be a function of SOC content. Even though C/N ratio varies considerably depending on spatial position. Kahle *et al.* (2013) and Marchetti *et al.* (2012) reported much lower C/N values with the decrease of the depth of solum. Spatial changes in polymerisation of SOM have ambiguities. Polymerisation values on the basis of C/N ratio are the inverse to those obtained by E_2/E_3, although the latter has a spatial pattern without horizontal differentiation while C/N varies with depth. Inverse C/N value to the photometric indexes was reported in previous studies. Jakab *et al.* (2014) suppose that in some cases there is no direct correlation between C/N ratio and the degree of SOM polymerisation.

Spatial pattern of the SOM with higher aromaticity (based on URI) is similar to that of modelled on the basis of E_2/E_3, also showing the lack of horizontal variation (Figure 8/3 and 8/7). The lowest and the highest values were found right on the locations of SOC maximums "A" and "B", which suggests the selectivity of SOM deposition.

High molecular weighted, polimerised SOM is typical along the whole solum of location "A" in the upper part of the valley, while in the lower third and at the bottom of the steepest part (location "B") low molecular weighted SOM of higher functional group density dominates the whole profile. The SOM quality on spots of most intensive erosion (Regosol spots) could be the result of locally reduced biological and crop (root and stem) production and of a very rapid soil loss. Since these fulvic acid type SOM components are the most mobile ones they could be delivered by runoff to the bottom where infiltrating water leaches them down into the whole profile as that was presumed by Navas *et al.* (2009). This low molecular weighted SOM surplus could trigger SOC enrichment in this part of the study area. Another SOC increase was observed a little higher on the valley bottom at location "B". Since SOM is much more polymerised here this could be the deposition part of the aggregate transported SOM as presented by Kuhn *et al.* (2012). Here the aggregates are deposited exclusively, while runoff takes the components of lower molecular weight away to the bottom, consequently no intense infiltration is presumed (without SIC sedimentation or leaching into the profile). This phenomenon causes different morphological types of sedimentation and crusting at locations "A" and "B" (Figure 9). The deposited aggregates created a better structured sediment cover on "A" located higher, while on "B" the more mobile elementary particles built a sealed, unstructured sediment cover.

4 Conclusions

The differences measured in SC content and SOM compound are the results of erosion and deposition. Although the highest SOC values were measured in the depositional profiles no direct linkage between geomorphic position and solum depth was found. On the other hand selective SOM sedimentation was observed: the aggregate delivered high molecular weighted SOC was deposited on a higher surface while the most soluble SOM components reached the bottom and leached into the profile there. Consequently the delivery and deposition processes of soil carbon erosion are also selective. Different SOM compounds are transported to different distances and deposited at different geomorpological positions even though tillage continuously homogenize the tilled layer. The long term autumn ploughing based conventional tillage seems to have less importance in topsoil homogenisation than it was believed before. From the soil conservational point of view special care has to be taken to the sedimentation processes since the mobile part of SOM can be transferred easily from the field. For this reason grassed waterways within fields should be an effective tool for soil carbon conservation as well.

The filtered total reflectance spectra provide information sufficient for sample classification, and the results are comparable with those derived from the summary of single physico-chemical parameters. The method is suitable to distinguish between soil samples with similar SOC content and SOM compound. Using this method one recorded spectrum contains all the results of the separate traditional measurements. On the other hand ambiguities still exist as to derive a single quantitative parameter from the reflectance spectra to describe separate soil properties.

Estimations based on classification and spatial modelling did not support the same findings. Classification (sum effects of each parameter) underlined the horizontal dissection among horizons while spatial modelling emphasized the vertical pattern of the separate variables. In order to clarify the role of selective SOC and SOM deposition in the carbon cycle more samples should be analysed and additional statistical methods are to be involved.

Acknowledgement

This study was founded by the Hungarian Foundation (OTKA) 100929, which is kindly acknowledged here. The authors are also grateful to the Egegyümölcs Ltd for providing the study site and to V. Ujházi and K. Fehér for the laboratory support. Special thanks to L. Bassa and Gy. Varga for language improvement.

References

Afifi, A., Clark, V. A., May, S., Raton, B. 2004. Computer-Aided Multivariate Analysis, fourth ed. Chapman & Hall/CRC, USA, p. 489.

Aichi, H, Fouad Y., Walter, C., Viscarra Rossel, R. A., Chabaane Z. L., Sanaa, M. 2009. Regional predictions of soil organic carbon content from spectral reflectance measurements. *Biosystems engineering* **104**: 442–446.

Berhe, A. A. and Kleber, M. 2013. Erosion, deposition, and persistence of soil organic matter: mechanistic considerations and problems with terminology. *Earth Surface Processes and Landforms.* **38**: 908–912.

Berhe, A. A., Harden, J. W., Torn, M. S., Kleber, M., Burton S. D., Harte, J. 2012. Persistence of soil organic matter in eroding vs. depositional landform positions. *Journal of Geophysical Research.* **117** doi:10.1029/2011JG001790

Bradák, B., Kiss, K., Barta, G., Varga Gy., Szeberényi, J., Józsa, S., Novothny, Á., Kovács, J., Markó, A., Mészáros, E., Szalai, Z. 2014. Different paleoenvironments of Late Pleistocene age identified in Verőce outcrop, Hungary: Preliminary results. *Quaternary International* **319**: 119–136.

Brodský, L., Klement, A., Penížek, V., Kodešová, R., Borůvka L. 2011. Building Soil Spectral Library of the Czech Soils for Quantitative Digital Soil Mapping. *Soil & Water Res.* **6**(4): 165–172.

Buurman, P., van Lagen, B., Velthorst, E.J. (eds) 1996 Manual for soil and water analysis. Backhuys Publishers, Leiden, The Netherlands p. 302

Centeri, Cs. 2006: Data on particle size distribution under different rainfall intensities on black fallow plots. Conference Proceedings of the 14th International Poster Day Transport of Water, Chemicals and Energy in the System Soil-Crop Canopy-Atmosphere. CD, pp. 106-111.

Chaplot, V. and Poesen, J. 2012. Sediment, soil organic carbon and runoff delivery at various spatial scales. *Catena.* **88**: 46–56.

Chin, Y. P., Aiken, G., Loughlin, E. O. 1994. Molecular weight, polydispersity, and spectroscopic properties of aquatic humic substances. *Environmental Science & Technology.* **28**: 1853–1858.

Conforti, M., Buttafuoco, G., Leone, A. P., Aucelli, P. P. C., Robustelli, G., Scarciglia, F. 2013. Studying the relationship between water-induced soil erosion and soil organic matter using Vis–NIR spectroscopy and geomorphological analysis: A case study in southern Italy. *Catena.* **110**: 44–58.

De Alba, S., Lindstrom, M., Schumacher, T. E., Malo, D. D. 2004. Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes. *Catena.* **58**: 77–100.

Dimassi, B., Mary, B., Wylleman, R., Labreuche, J. Couture, D., Piraux, F., Cohan, J. P. 2014. Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years. *Agriculture Ecosystems & Environment* **188:** 134–146.

Dotterweich, M., Stankoviansky, M., Minár, J., Koco, S., Papčo, P. 2013. Human induced soil erosion and gully system development in the Late Holocene and future perspectives on landscape evolution - The Myjava Hill Land, Slovakia. *Geomorphology.* **201**: 227–245.

Dövényi, Z. (ed.) 2010. Magyarország kistájainak katasztere. MTAFKI Budapest, Hungary. p. 876. (In Hungarian)

Farsang, A., Kitka, G., Barta, K., Puskás, I. 2012. Estimating element transport rates on sloping agricultural land at catchment scale (Velence mts., NW Hungary). *Carpathian Journal of Earth and Environmental Sciences*. **7**(4): 15–26.

Fuchs, M., Gál, A. Michéli, E. 2010. Depth distribution of SOM stock in fine-textured soils of Hungary. *Agrokémia és Talajtan*. **59**(1): 93–98.

Ge, Y., Thomasson, J. A., Morgan, C. L. S. 2014. Mid-infrared attenuated total reflectance spectroscopy for soil carbon and particle size determination. *Geoderma* **213**: 57–63.

Gomez, C., Viscarra Rossel, R. A., McBratney, A. B. 2008. Soil organic carbon prediction by hyperspectral remote sensing and field vis-NIR spectroscopy: An Australian case study. *Geoderma*. **146**: 403–411.

Gong, J. G., Jia, Y. W., Zhou, Z. H., Wang, Y., Wang, W. L., Peng, H. 2011. An experimental study on dynamic processes of ephemeral gully erosion in loess landscapes. *Geomorphology*. 125: 203–213.

Hatvani, I. G., Kovács, J., Kovácsné Székely, I., Jakusch, P., Korponai, J. 2011. Analysis of long term water quality changes in the Kis-Balaton Water Protection System with time series-, cluster analysis and Wilks' lambda distribution. *Ecological Engineering*. **37**(4): 629–635.

Häring, V., Fischer, H., Cadisch, G., Stahr, K. 2013a. Implication of erosion on the assessment of decomposition and humification of soil organic carbon after land use change in tropical agricultural systems. *Soil Biology & Biochemistry*. **65**: 158–167.

Häring, V., Fischer, H., Cadisch, G., Stahr, K. 2013b. Improved delta C-13 method to assess soil organic carbon dynamics on sites affected by soil erosion. *European Journal of Soil Science*. **64**(5): 639–650.

Her, N., Amy, G., Sohn, J., Gunten, U. 2008. UV absorbance ratio index with size exclusion chromatography (URI-SEC) as an NOM property indicator. *Journal of Water Supply: Research and Technology*. AQUA **57**(1): 35–44.

Hoffmann, T., Schlummer, M., Notebaert, B., Verstraeten, G., Korup, O. 2013. Carbon burial in soil sediments from Holocene agricultural erosion. *Central Europe Global Biogeochemical Cycles*. **27**(3): 828–835.

Jakab, G., Kiss, K., Szalai, Z., Zboray, N., Németh, T., Madarász, B. 2014. Soil Organic Carbon Redistribution by Erosion on Arable Fields. In: Hartemink, A. and McSweeney, K. (eds.) Soil Carbon Dordrecht: Springer, pp. 289–296. (Progress in Soil Science)

Jakab, G., Kertész, Á., Madarász, B., Ronczyk, L., Szalai Z. 2010. The role of relief in soil erosion with special emphasis on tolerable soil loss. *Tájökológiai Lapok*. **8**(1): 35–45. (In Hungarian with English abstract)

Kahle, P., Möller, J., Baum, C., Gurgel, A. 2013. Tillage-induced changes in the distribution of soil organic matter and the soil aggregate stability under a former short rotation coppice. *Soil & Tillage Research*. **133**: 49–53.

Kirkels, F. M. S. A., Cammeraat, L. H., Kuhn, N. J. 2014. The fate of soil organic carbon upon erosion, transport and deposition in agricultural landscapes — A review of different concepts. *Geomorphology*. **226**: 94-105.

Kuhn, N. J., Armstrong E. K., Ling A. C., Connolly K. L., Heckrath G. 2012. Interrill erosion of carbon and phosphorus from conventionally and organically farmed Devon silt soils. *Catena*. **91**: 94–103.

Lal, R 2004. Soil Carbon Sequestration Impacts on Global climate change and food security. *Science*. **304**: 1623–1627.

Lal, R. 2003. Soil erosion and the global carbon budget. *Environment International* **29**(4): 437–450.

Lal, R. 2005. Soil erosion and carbon dynamics. *Soil & Tillage Research*. **81**: 137–142.

Lal, R., Pimentel, D., 2008. Soil erosion: a carbon sink or source? *Science* **319**: 1040–1042.

Lee, J., Hopmans, J. W., Rolston, D. E., Baer, S. G., Six J. 2009. Determining soil carbon stock changes: Simple bulk density corrections fail. *Agriculture, Ecosystems and Environment* **134**: 251–256.

Lee, K. S., Lee, D. H., Sudduth, K. A., Chung, S. O., Kitchen, N. R., Drummond, S. T. 2009. Wavelength identification and diffuse reflectance estimation for surface and profile soil properties. *American Society of Agricultural and Biological Engineers*. **52**(3): 683–695.

Marchetti, A., Piccini, C., Francaviglia, R., Mabit, L. 2012. Spatial distribution of soil organic matter using geostatistics: A key indicator to assess soil degradation status in central Italy. *Pedosphere*. **22**(2): 230-242.

Minasny, B., McBratney, A. B., Bellon-Maurel, V., Roger, J. M., Gobrecht, A., Ferrand, L., Joalland, S. 2011. Removing the effect of soil moisture from NIR diffuse reflectance spectra for the prediction of soil organic carbon. *Geoderma*. **167–168**: 118–124.

Nagy, R., Zsófi, Zs., Papp, I., Földvári, M., Kerényi, A., Szabó, Sz. 2012. Evaluation of the relationship between soil erosion and the mineral composition of the soil: a case study from a cool climate wine region of Hungary. *Carpathian Journal of Earth and Environmental Sciences.* **7**(1): 223–230.

Navas, A., Gaspar, L., López-Vicente, M., Machín, J. 2009. Patterns of soil carbon and nitrogen in relation to soil movement under different land uses in mountain farmland fields (South Central Pyrenees). *Geophysical Research Abstracts* 11.

Niu, X. Y., Wang, Y. H., Yang, H., Zheng, J. W., Zou, J., Xu, M. N., Wu, S. S. and Xie, B. 2015. Effect of land use on soil erosion and nutrients in Dianchi Lake watershed, China. *Pedosphere*. **25**(1): 103-111.

Norušis, M. J. 1993. SPSS for Windows Advanced Statistics Release 6.0. Englewood Cliffs: Prentice Hall, USA

Oliver, M. A. and Webster, R. 1990. Kriging: a method of interpolation for geographical information systems. *International Journal of Geographical Information Systems* **4**(3): 313–332.

Olson, K. R., Gennadiyev, A. N., Zhidkin, A. P., Markelov, M. V. 2012. Impacts of Land-Use Change, Slope, and Erosion on Soil Organic Carbon Retention and Storage. *Soil Science*. **177**(4): 269–278.

Pansu, M. and Gautheyrou, J. 2006. Handbook of Soil Analysis. Mineralogical, Organic and Inorganic Methods. Springer, Berlin, Deutschland p. 993.

Poesen, J., Nachtergaele, J., Verstraeten, G., Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. *Catena*. **50**: 91-133.

Polyakov, V. O. and Lal, R. 2008. Soil organic matter and CO_2 emission as affected by water erosion on field runoff plots. *Geoderma*. **143**: 216–222.

Schaetzl, R. and Anderson, S 2005. Soils Genesis and Geomorphology. Cambridge University Press, New York, USA p. 821.

Schoeneberger, P. J., Wysocki, D. A., Benham, E. C. and Soil Survey Staff 2012. Field book for describing and sampling soils, Version 3.0 Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE, USA

Stavi, I. and Lal, R., 2011. Variability of soil physical quality in uneroded, eroded, and depositional cropland sites. *Geomorphology* **125**: 85–91.

Stefanovits, P. 1971. Brown forest soils of Hungary. Akadémiai kiadó, Budapest, Hungary p. 261.

Tan, K. H. 2003. Humic Matter in Soil and the Environment Principles and Controversies. Marcel Dekker Inc., New York, USA p. 181.

Viscarra Rossel, R.A., Cattle, SR, Ortega, A., Fouad, Y. 2009. In situ measurements of soil colour, mineral composition and clay content by VIS–NIR spectroscopy. Geoderma 150, 253–266

Viscarra Rossel, R. A., Walvoort, D. J. J., McBratney, A. B., Skjemstad, J. O. 2006. Visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties. *Geoderma*. **131**(1–2): 59-75.

Vona, M., Centeri, Cs., Penksza, K., Malatinszky, Á., Pottyondy Á., Helfrich, T., Barczi, A. 2006. Soil and nutrient loss in Galgahéviz, Hungary. Proceedings of the 14th Conference of ISCO, Marrakech, Morocco, May 14–19, 2006. (CD), pp. 1-4.

Wang, Z., Govers, G., Steegen, A., Clymans, W., Van den Putte, A., Langhans, C., Merckx, R., Van Oost, K. 2010. Catchment-scale carbon redistribution and delivery by water erosion in an intensively cultivated area. *Geomorphology*. **124**: 65–74.

Wang, Z., Van Oost, K., Govers, G. 2015. Predicting the long-term fate of buried organic carbon in colluvial soils. *Global Biogeochem. Cycles*. **29**: doi: 10.1002/2014GB004912

Watteau, F., Villemin, G., Bartoli, F., Schwartz, C., Morel J. L. 2012. 0–20 µm aggregate typology based on the nature of aggregative organic materials in a cultivated silty topsoil. *Soil Biology & Biochemistry*. **46**: 103–114.

Wiaux, F, Cornelis, J. T., Cao, W., Vanclooster, M., Van Oost, K. 2014. Combined effect of geomorphic and pedogenic processes on the distribution of soil organic carbon quality along an eroding hillslope on loess soil. *Geoderma*. **216**: 36-47.

Yamashita, T., Flessa, H., John, B., Helfrich, M., Ludwig, B. 2006. Organic matter in density fractions of water-stable aggregates in silty soils: Effect of land use. *Soil Biology & Biochemistry*. **38**: 3222–3234.

Zhang, G. H., Liu, G. B., Wang, G. L. and Wang, Y. X. 2011. Effects of vegetation cover and rainfall intensity on sediment-bound nutrient loss, size composition and volume fractal dimension of sediment particles. *Pedosphere*. **21**(5): 676-684.

Zhang, H. 2013. Soil Organic Carbon Stocks as Affected by Tillage Systems in a Double-Cropped Rice Field. *Pedosphere*. **23**(5): 696–704.

Zhang, X., Li, Z., Tang, Z., Zeng, G., Huang, J., Guo, W., Chen, X., Hirsh A. 2013. Effects of water erosion on the redistribution of soil organic carbon in the hilly red soil region of southern China. *Geomorphology*. **197**: 137–144.

Table 1 Wilks' λ values of the examined parameters (lower values refer to a more dominant role in classification)

	Wilks' Lambda
Soil Inorganic Carbon	0.18
Soil Carbon	0.31
Soil Organic Carbon	0.35
Sand (2-0.02 mm) content	0.53
Reflectance at 280 nm	0.58
Silt (0.02-0.002 mm) content	0.58
pH in KCl	0.59
Carbon / Nitrogen ratio	0.60
Total Nitrogen content	0.71
Ultraviolet Ratio Index	0.74
pH in distilled water	0.75
Clay (<0.002 mm) content	0.76
pH difference[1]	0.82
E_2/E_3	0.85

---

[1] difference between ph in distilled water and KCl

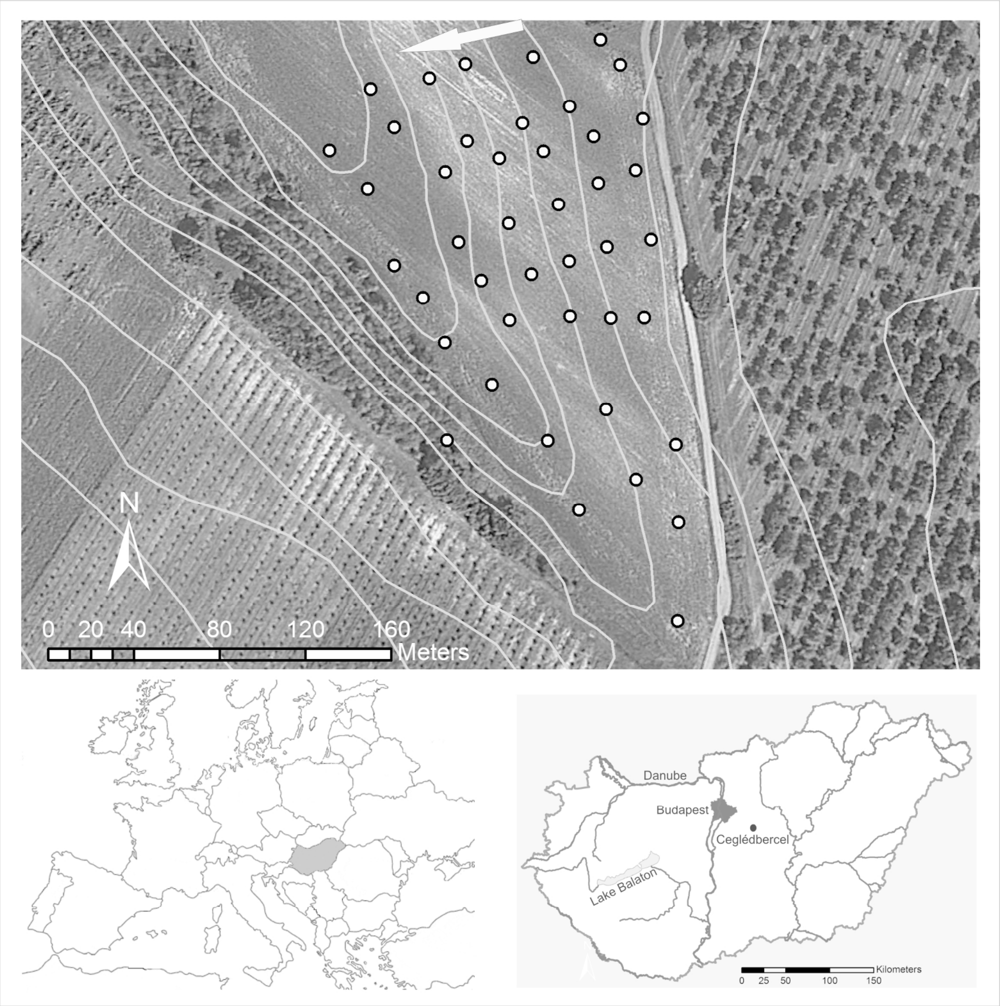

Figure 1 Location of the study site with 2.5 m contour lines. Dots indicate boreholes, arrow indicates slope direction

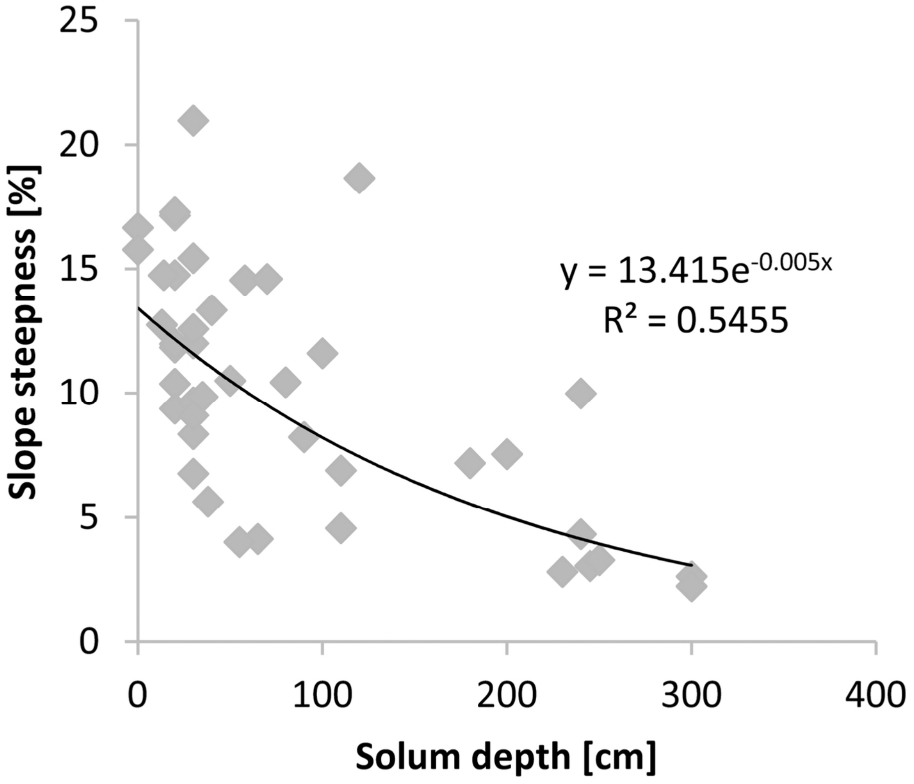

Figure 2 Relationship between slope steepness and solum depth on the study site (n=41)
67x57mm (600 x 600 DPI)

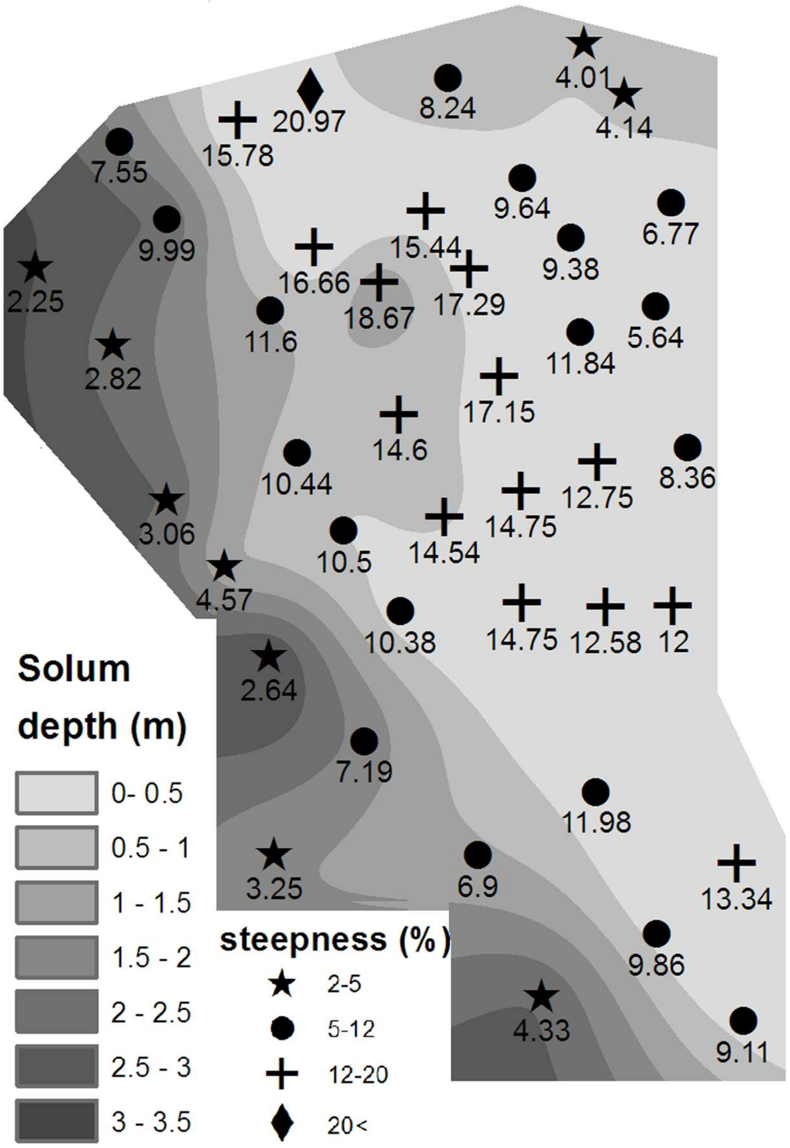

Figure 3 Slope steepness and solum depth on the examined slope section (numbers refer to surface steepness at the borehole)
241x343mm (300 x 300 DPI)

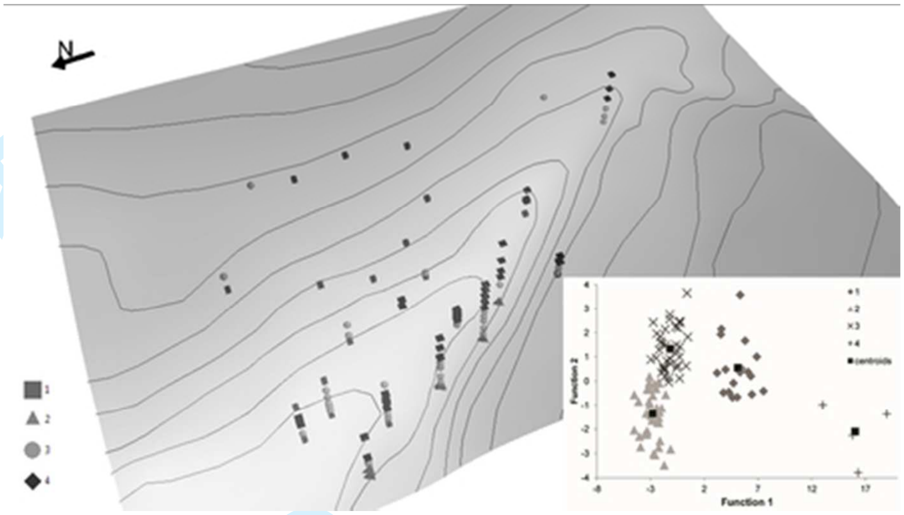

Figure 4 Canonical discriminant analysis of the soil samples classified into four groups on the basis of their reflectance spectra and the spatial location of the groups n=100 (8× vertical distortion)
37x21mm (300 x 300 DPI)

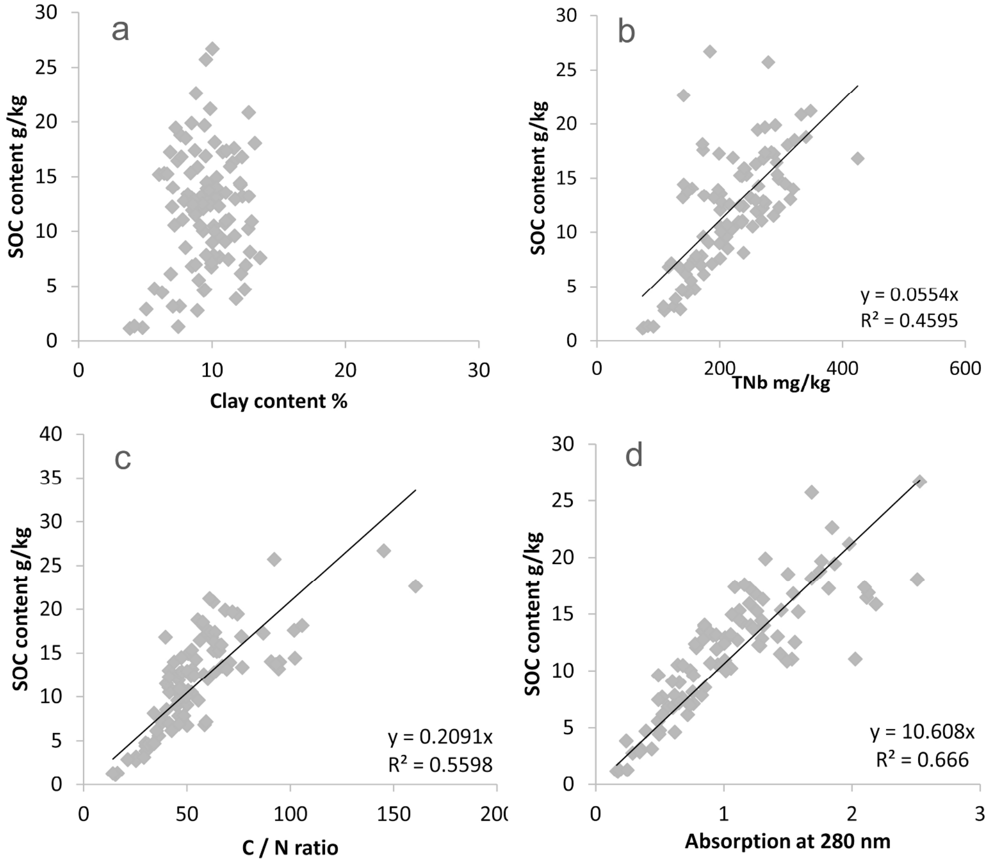

Figure 5 SOC relations to other (a: Clay (<0.002 mm) content; b: Total Nitrogen; c: Carbon / Nitrogen ratio and d: Absorption at 280 nm) measured parameters n=100
132x116mm (600 x 600 DPI)

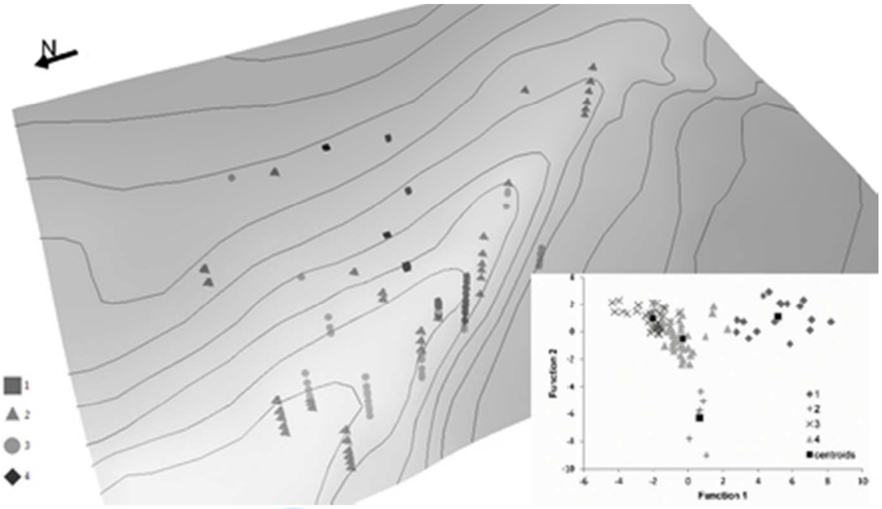

Figure 6 Canonical discriminant analysis of the soil samples classified into four groups on the basis of their chemical properties and the spatial location of the groups n=100 (8× vertical distortion)
37x21mm (300 x 300 DPI)

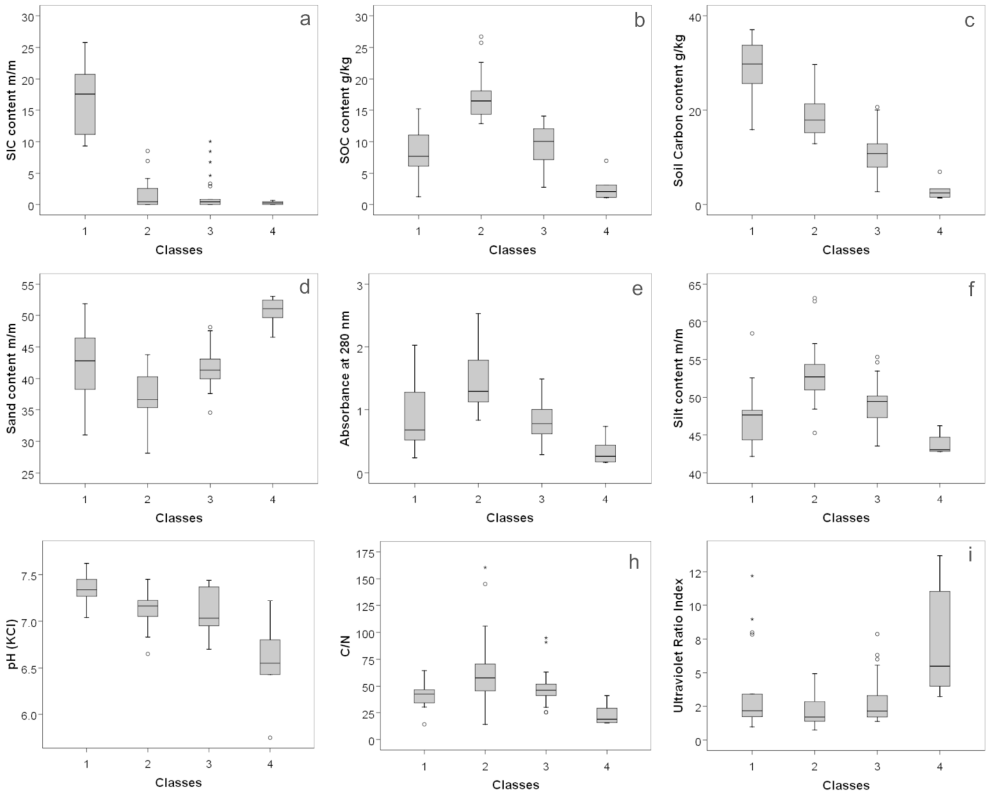

Figure 7 Chemical and physical parameter boxplots of the four groups classified by cluster analysis (a: SIC content; b: SOC content; c: Soil Carbon content; d: Sand (2-0.02 mm) content e: Absorbance at 280 nm; f: Silt (0.02-0.002 mm) content; g: pH(KCl); h: Carbon / Nitrogen ratio; i: Ultraviolet Ratio Index)

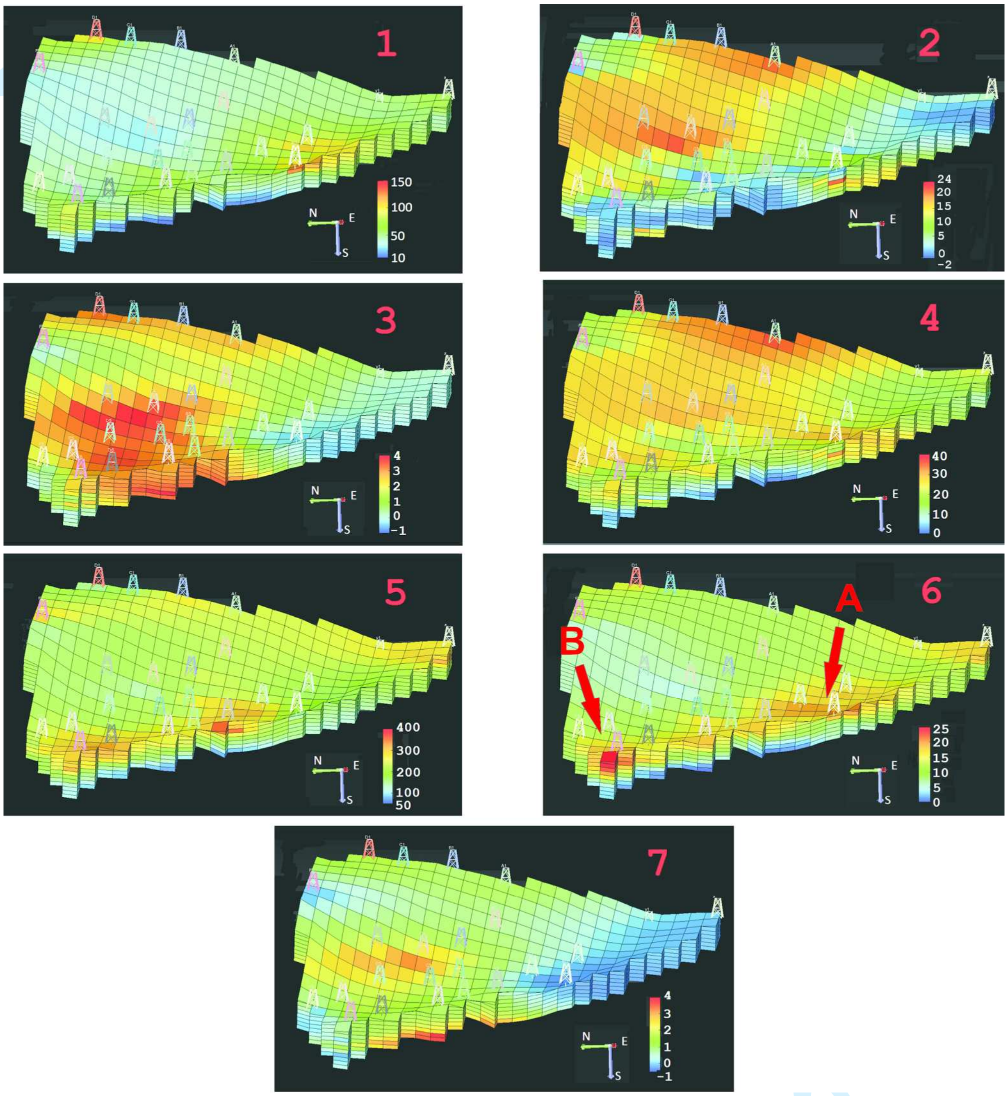

Figure 8 Modelled spatial distribution of the measured parameters (1 Carbon / Nitrogen ratio; 2 SIC content; 3 E2/E3 value; 4 Soil Carbon content; 5 Total Nitrogen content; 6 SOC content [SOC maximum highlighted by locations "A" and "B"]; 7 Ultraviolet Ratio Index value; towers represent the investigated boreholes)
184x201mm (300 x 300 DPI)

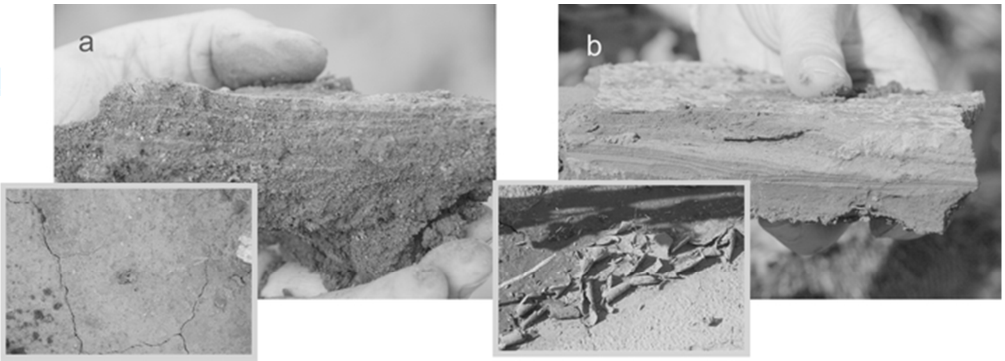

Figure 9 Deposited sediment in aggregated form at location ("A") and created by individual particles at location ("B")
60x21mm (300 x 300 DPI)