Szent István University

# Development of the classification of high swelling clay content soils of Hungary based on diagnostic approach

Thesis of Ph. D. dissertation

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Gödöllő

2012

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## Introduction and objectives

*Background and significance*

Shrinking and swelling clay soils with deep, wide cracks when dry, while sticky and plastic when moist are well known for farmers, and distinguished from other soil types because of their tillage problems since the first agricultural systems has developed.
Due to their widespread geographical coverage, and unique morphological, physical, chemical and management properties, the modern international soil classification systems (like US Soil Taxonomy, or the IUSS accepted international correlations system, the World Reference Base for Soil Resources) and most national (i.e. Russian, French, German, Czech, Slovak, Romanian, Chinese and Australian) soil classification systems as well define the swelling clay soils at the first level of the classification, as Vertisols.
Clayey soils cover 630 000 ha, about 6-9% of the territory of Hungary, and further 1,7 million ha is covered by clay loam soils (STEFANOVITS, 1972). Their significant extension and unique properties resulted early scientific recognition in Hungary too, thus swelling high clay soils can be found in the Hungarian soil science literature since its beginning, from József Szabó's scientific work. On the contrary to their distinctive characteristics, in the recent Hungarian Soil Classification System these soils belong to several different soil taxonomic units, as there is no separate unit for high clay content soils. The high clay, mostly smectite containing soils can be found in the meadow-, salt affected-, parent material influenced-, and alluvial main soil types of the Hungarian Soil Classification System, often together with significantly different soils, making the differentiation and definition of taxa difficult (MICHÉLI et al., 2005).

*Objectives*

My Ph.D. research is connected to the improvement and modernization of the Hungarian soil classification system, with the following objectives:

1. Detailed documentation of high smectite clay content, shrinking and swelling soils of Hungary, developed on different substrates, topographical positions and geographical areas.
2. To prove that my reference profiles, following international standards based soil description and WRB classification satisfy the criteria of Vertisols.
3. To study the taxonomic relationship between the recent Hungarian classification units of my reference profiles, to numerically express the similarities and differences with Vertisols.
4. To develop suggestions for the differentiation criteria of the Hungarian swelling clay soils.
5. To develop suggestions for the highest, and lower levels of classification of the Hungarian swelling clay soils.

## Materials and Methods

*Method of selection of the Hungarian soil types involved in the study*
The soil types of the Hungarian Soil Classification System were studied in order to select the ones that can have high, shrinking and swelling clay content. The soil types were selected based on document analysis of the Hungarian soil classification related literatures (SZABOLCS, 1966; JASSÓ, 1989; STEFANOVITS, 1999).

*Method of selection of the reference profiles*

The selection of the reference profiles was performed based on the results of detailed review of the Hungarian soil classification and mapping related literature.

Based on my objectives, the major criteria of the final selection were the following:

- Inclusion of different Hungarian soil types according to the recent Hungarian Soil Classification System, having high, shrinking and swelling clay content,
- inclusion of profiles with different lithological origin and parent materials,
- inclusion of profiles from different topographic positions, and
- demonstration of the diverse geographical distribution in Hungary.

*Method of on-site description of the reference profiles*

The on-site descriptions of the reference profiles were performed from soil pits according to international standards published as “Guidelines for soil description” by FAO (2006).

*Method of soil sampling and laboratory analysis*

Soil samples were collected from each genetic horizon of the reference profiles. Undisturbed soil samples (2 samples from each genetic horizon) were collected by Eijkelkamp soil sampler. As a summary, 65 genetic horizons of 18 soil profiles were sampled and analysed during this study.

Measured chemical soil parameters:

- pH($H_2O$) and pH(KCl) (MSZ–08–0206/2:1978; BUZÁS, 1988)
- Carbonate content ($CaCO_3$%) (MSZ–08–0206/2:1978; BUZÁS, 1988).
- Soil organic matter content (SOM), Walkley – Black method (VAN REEUWIJK, 1995)
- Cation exchange capacity (CEC) (MSZ-08-0215:1978, BUZÁS, 1988)
- Exchangeable basic cations (MSZ–08–0214/2:1978; BUZÁS, 1988).
- Base saturation (B%): Sum of exchangeable basic cations / CEC *100 (STEFANOVITS et al., 1999)
- Electric conductivity (EC) (MSZ-08-0206/2:1978; BUZÁS, 1988)
- Total salt content (Σsalt%) (MSZ-08-0206/2:1978, BUZÁS, 1988)

Measured physical soil parameters:

- Particle size analysis (MSZ-08-0205:1978; BUZÁS, 1993)
- Bulk density (BUZÁS, 1993)
- Arany-type texture coefficient (MSZ- 21470/51-83; BUZÁS, 1993)
- Coefficient of Linear Extensibility (COLE) (SCHSFFER & SINGER, 1976). The COLE values were not determined in case of the Bodrogköz soil samples (Vajdácska, Dorkó-tanya, Bodroghalom, Nagyrozvágy, Szenna Tanya profiles).

Additional (complementary) studies:

- Mineral composition of Szirák 1 and Szirák 2 reference profiles was determined by X-Ray Diffraction method (NÁRAY-SZABÓ & PÉTERNÉ, 1964) (Hungarian Academy of Sciences, Institute for Geological and Geochemical Research)
- Scanning Electron Microscope (SEM) pictures were made from undisturbed samples of the ABcilg (20-55 cm) and Bikl (55-95 cm) genetic horizons of the Kisújszállás reference profile by a Hitachi S-4700 SEM.
- Archaeomalacological studies from the loessy parent material of the Szirák 1 reference profile (Dr. Krolopp Endre †, University of Szeged, Department of Geology and Paleontology)

*Classification of the reference profiles*

The classification of the reference profiles were performed according to the genetic based Hungarian Soil Classification System (SZABOLCS, 1966; JASSÓ, 1989; STEFANOVITS, 1999), and the international soil correlation system, the World Reference Base for Soil resources (WRB) (IUSS WORKING GROUP WRB, 2006; 2007) based on field and laboratory data.

*Numerical analysis*

*Centroid based taxonomic distance calculations*

In my dissertation I studied the taxonomic relationship between my reference profiles and the WRB Reference Soil Groups by the numerical method of *centroid based* taxonomic distance calculation.

The centroids of my reference profiles were calculated based on the measured laboratory soil data presented in the dissertation; while for the calculation of centroids of the WRB Reference Soil Groups (RSGs) the legacy data of the WISE (3.1) international database (BATJES, 2008) was used. Based on data availability, and possible occurrence between the environmental conditions of Hungary, 20 out of the 32 WRB RSGs were selected for the study.

The centroids were defined based on selected *dominant identifiers*, that were determined as sets of soil properties developed due to the dominant soil forming factors and processes, and define the most important characteristics of the particular soil type. These dominant identifiers were attempted to be converted to calculated centroid values in order to numerically express the differences between the studied taxa.

Based on the available data 5 chemical (pH, $CaCO_3$ content, organic carbon content, cation exchange capacity, base saturation) and 2 physical soil parameters (clay content, sand contant) were selected for the calculation of the defined 33 centroids (Table 1.).

Table 1. Derived centroids based on the defined dominant identifiers and available data (numbers express the depth from the mineral soil surface)

| | | | | | |
|---|---|---|---|---|---|
| pH_0-30 | pH_30-100 | pH_50-100 | pH_0-100 | pH_min | |
| $CaCO_3$_0-30 | $CaCO_3$_30-100 | $CaCO_3$_50-100 | $CaCO_3$_0-100 | $CaCO_3$_max | Calcic depth[1] |
| OC_0-30 | OC_30-100 | OC_50-100 | OC_0-100 | | |
| CEC_0-30 | CEC_30-100 | CEC_50-100 | CEC_0-100 | | |
| B%_0-30 | B%_30-100 | B%_50-100 | B%_0-100 | | |
| Sand_0-30 | Sand_30-100 | Sand_50-100 | Sand_0-100 | | |
| Clay_0-30 | Clay _30-100 | Clay _50-100 | Clay _0-100 | Clay _max | Delta Clay [2] |

Mean (centroid) values were calculated weighted on the thickness of the horizon for each examined profiles. When the centroid is referred to a depth of occurrence of a certain property, and the defined criteria were not fulfilled, the maximum value of 200 cm was given - based on the maximum depth criteria occurring in the WRB key. The final centroids were derived as simple arithmetic means and the distance matrix was calculated to study the possible correlation between the selected 20 WRB RSGs and my reference profiles.

On the basis of the matrices, the taxonomic distances between the selected WRB RSGs and my reference profiles were calculated via R software (R Development Core Team, 2009), according to the following:

[1] Depth to a horizon with $CaCO_3$ content > 15%

[2] „Clay_max” diveded by „Clay_0-30” (in order to express the result of clay illuviation)

$$d_{ij} = \sqrt{(x_i - x_j)^T (x_i - x_j)}$$

where $d_{ij}$ is the element of distance matrix $D$ with size $(c \times c)$, c is the number of soil groups. The value of $d_{ij}$ represents the taxonomic distance between soil group $i$ and group $j$, and $x$ refers to a vector of indicators of the soil identifiers (MINASNY et al., 2009).

*Numerical characterization of the representative soil profiles*

To provide a more complete picture about the characteristics of the Hungarian swelling clay soils, basic statistical parameters were calculated from the measured laboratory data of the 18 reference profiles. To avoid statistical distortion caused by different depth and thickness of the sampled horizons, weighted averages were calculated for 20 cm thick sections between the mineral soil surface and 100 cm, and for 25 cm thick sections between 100 and 150 cm from the mineral soil surface. As a summary, 126 layers were created, and the following basic statistical parameters were determined:

- mean
- standard deviation
- minimum
- maximum
- range
- median
- std. error of mean

The data were analyzed by SPSS 15.0 statistical program package.

*Vertical distribution of soil organic matter and soil organic matter stock in heavy clay soils of Hungary based on the TIM database*

My objective was to analyze the vertical distribution of soil organic matter content (SOM), and SOM stock in high clay content soils of Hungary, based on the data (soil organic matter content, clay content, bulk density, depth of sampled horizons) of the database of the Hungarian Soil Information and Monitoring System (TIM). From the 1237 TIM profiles 1117 were selected to study SOM content distribution, and 976 profiles for SOM stock determination. For depth, the central value of the horizon was used. The first sampled horizon (H1) was defined as topsoil (signed as $SOM_{TOP}$), the further horizons (H2-H5) are defined as subsoil ($SOM_{SUB}$), while the combined topsoil and subsoil segment is signed as $SOM_{TOT}$.
Profiles with more than 30% clay in all layers to the depth of 100 cm or deeper were selected, and designated as high clay content soils (HC). Other profiles, with lower clay content than 30% in any horizon to 100 cm depth, were grouped as low clay content soils (LC).
The data were analyzed by SPSS 15.0 statistical program package. Based on the Kolmogorov-Smirnov test the data shown non-parametric distribution, so for the analysis the Mann-Whitney test was used ($\alpha<0{,}05$).

## Results and Discussion

*Hungarian soils types that may satisfy the WRB Vertisol criteria*

My dissertation consists a detailed review of Hungarian and international literature about the unique properties, and classification of swelling clay soils. Based on the analysis of the Hungarian soil classification system, 14 soil types were deteremined, that may correlate with

Vertisols - if the necessary criteria of smectite dominated clay mineral composition and alternating dry-wet climatic conditions are also satisfied (Table 2.).

Table 2. Hungarian soils types that may satisfy the WRB Vertisol criteria based on the analysis of the Hungarian Soil Classification System

| **Main Soil Type** | **Soil Type** |
|---|---|
| Soils influenced by parent materials | Black erubase |
| Brown forest soils | Chernozem brown forest soils |
| Salt affected soils | Meadow solonetz |
| | Steppe meadow solonetz |
| | Secondary salt afftected soils |
| Meadow soils | Solonchak meadow soils |
| | Solonetzic meadow soils |
| | Typic meadow soils |
| | Alluvial meadow soils |
| | Peaty meadow soils |
| | Chernozem meadow soils |
| Soils of alluvial and slope sediments | Soils of slope sediments |
| | Raw alluvial soils |
| | Humic alluvial soils |

*Detailed documentation of the Hungarian shrinking and swelling clay soils*

In my dissertation I performed detailed description and characterization of the environmental conditions, and morphological, chemical and physical properties of 18 reference soil profiles. My findings are supported by a large number of photographs of the described features. Based on the soil descriptions and laboratory data I defined the soil forming factors and processes for each profiles, and classified them based on the genetic based Hungarian Soil Classification System, and the international correlation system of WRB. In case of the Hungarian classification system I evaluated the differences between the definitions of the lower levels according to different classification related literatures (SZABOLCS, 1966; JASSÓ, 1989; STEFANOVITS, 1999), while in case of the WRB I provided a detailed description about the information content of the defined taxa.

*Resalts of the numerical analysis*

*Taxonomic distances of the reference profiles and selected WRB Reference Groups*

Based on the measured data of the Hungarian profiles of this study, and the legacy data from the WISE (3.1) database 33 chemical and physical property based centroid values were calculated for the 19 reference profiles and selected 20 WRB Reference Groups. In order to express the similarities and differences between the examined taxa, and define their taxonomic relationship, taxonomic distance values were calculated from the centroids. The calculation resulted in a 40*40 taxonomic distance matrix. Table 3. shows only the three closest WRB RSGs to each reference profiles based on the taxonomic distance values (lower values represent closer taxonomic relationship).

Based on the taxonomic distance between the "average" Hungarian swelling clay soil – calculated as a simple arithmetic mean from the centroids of the 19 reference profiles – and the selected WRB RSGs, the closest taxonomic relationship is defined with the Vertisol RSG, thus Vertisols are the most similar RSG to the Hungarian swelling clay soils of this study.

The second and third closest WRB RSGs are the Phaeozems and Chernozems, the soils with deep, dark, base saturated and organic matter rich surface horizon.

Table 3. The three closest WRB RSGs to the reference profiles according to the centroid based taxonomic distance calculation

| Reference profile (*Hungarian soil type*) | Three closest WRB RSGs and related taxonomic distance values | | |
|---|---|---|---|
| MEAN of sum of the profiles | Vertisol | Phaeozem | Chernozem |
| | 0,42 | 0,85 | 1,01 |
| Kisújszállás (*Typic meadow soil*) | Vertisol | Chernozem | Kastanozem |
| | 0,90 | 1,17 | 1,32 |
| Gyöngyös (*Black erubase*) | Vertisol | Phaeozem | Gleysol |
| | 0,65 | 1,03 | 1,19 |
| Atkár (*Black erubase*) | Vertisol | Chernozem | Kastanozem |
| | 1,27 | 1,36 | 1,46 |
| Kisnána (*Black erubase*) | Vertisol | Phaeozem | Gleysol |
| | 0,61 | 0,98 | 1,01 |
| Szirák 1_Microlow (*Typic meadow soil*) | Vertisol | Phaeozem | Chernozem |
| | 0,78 | 1,11 | 1,19 |
| Szirák 1_Microhigh (*Typic meadow soil*) | Vertisol | Chernozem | Phaeozem |
| | 0,68 | 0,89 | 0,94 |
| Szirák 2 (*Chernozem brown forest soil*) | Vertisol | Phaeozem | Gleysol |
| | 0,71 | 0,94 | 1,11 |
| Apc (*Chernozem meadow soil*) | Vertisol | Phaeozem | Chernozem |
| | 0,67 | 1,03 | 1,21 |
| Vajdácska (*Solonetzic meadow soil*) | Vertisol | Phaeozem | Chernozem |
| | 0,55 | 1,18 | 1,28 |
| Dorkó-tanya (*Alluvial meadow soil*) | Vertisol | Phaeozem | Gleysol |
| | 0,72 | 0,95 | 1,02 |
| Bodroghalom (*Alluvial meadow soil*) | Vertisol | Phaeozem | Gleysol |
| | 0,77 | 0,92 | 1,05 |
| Nagyrozvágy (*Alluvial meadow soil*) | Phaeozem | Vertisol | Gleysol |
| | 0,74 | 0,77 | 0,89 |
| Szenna Tanya (*Alluvial meadow soil*) | Phaeozem | Gleysol | Cambisol |
| | 0,73 | 0,78 | 0,94 |
| Cibakháza (*Typic meadow soil*) | Phaeozem | Vertisol | Gleysol |
| | 0,70 | 0,85 | 0,90 |
| Törökszentmiklós (*Solonetzic meadow soil*) | Vertisol | Phaeozem | Chernozem |
| | 0,52 | 1,06 | 1,24 |
| Karcagpuszta (*Steppe meadow soil*) | Vertisol | Chernozem | Phaeozem |
| | 0,73 | 1,03 | 1,07 |
| Tiszasas (*Typic meadow soil*) | Vertisol | Phaeozem | Chernozem |
| | 0,51 | 0,82 | 1,04 |
| Kötegyán (*Typic meadow soil*) | Vertisol | Phaeozem | Gleysol |
| | 0,68 | 1,26 | 1,34 |
| Tiszabura (*Typic meadow soil*) | Vertisol | Phaeozem | Gleysol |
| | 0,80 | 1,02 | 1,08 |

Based on the calculated taxonomic distances for each reference profiles separately, Vertisols resulted as the closest RSG to 84% of them too. In case of the Nagyrozvágy and Cibakháza profiles the Phaeozem RSG became first and Vertisols are second, but the calculated taxonomic distance values are very close to each other (distances are 0,03 and 0,15, respectively).
In case of the Szenna-tanya profile, Vertisols resulted just as $4^{th}$ closest. It can be explained with the input data of the TIM database that shows significant sand content in the subsoil (45% below 58 cm, and 62% below 1m from the soil surface).
As a summary, based on the calculated taxonomic distance values I numerically demonstrated the similarity and the close taxonomic relationship between my reference profiles and the WRB Vertisol RSG.

*Numerical characterization of the reference profiles*
Table 4. shows the basic statistical parameters of the 18 reference soil profile by the measured chemical and physical parameters, calculated for the 0-150 cm thick segment of the soils. The results are in good agreement with the data published in the international Vertisol related literature.

Table 4. Basic statistical parameters of the 18 reference soil profile by the measured chemical and physical parameters, calculated for the 0-150 cm thick segment of the soils (n=126[3])

| | SOM | $CaCO_3$ | pH | pH | y1 | CEC | Ca | Mg | Na | K | B | Σ salt | EC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | % | $H_2O$ | KCl | | cmol/kg | % of sum cations | | | | % | % | mS/cm |
| Mean | 1,5 | 3,2 | 7,5 | 6,2 | 3,1 | 35,6 | 72,9 | 21,8 | 3,1 | 2,3 | 95 | 0,05 | 0,3 |
| Standard deviation | 1,1 | 6,4 | 0,8 | 0,9 | 6,6 | 10,9 | 11,1 | 7,6 | 6,9 | 1,6 | 6,9 | 0,06 | 0,7 |
| Minimum | 0,2 | 0,0 | 5,4 | 2,3 | 0,0 | 11,2 | 32,1 | 10,0 | 0,0 | 0,2 | 68 | 0,00 | 0,0 |
| Maximum | 5,4 | 35,5 | 9,5 | 7,7 | 35,5 | 56,5 | 87,0 | 47,1 | 44,0 | 7,6 | 102 | 0,28 | 2,5 |
| Range | 5,2 | 35,5 | 4,1 | 5,4 | 35,5 | 45,2 | 54,8 | 37,1 | 44,0 | 7,4 | 34 | 0,28 | 2,5 |
| Median | 1,3 | 0,2 | 7,6 | 6,4 | 0,0 | 35,5 | 75,6 | 20,5 | 0,5 | 2,0 | 98 | 0,03 | 0,0 |
| Std. error of mean | 0,10 | 0,57 | 0,07 | 0,08 | 0,59 | 0,97 | 0,99 | 0,67 | 0,61 | 0,15 | 0,62 | 0,01 | 0,07 |

| | Sand % | Silt % | Clay % | BD | COLE | $K_A$ |
|---|---|---|---|---|---|---|
| | 2-0,02 mm | 0,02-0,002 mm | <0,002 mm | g/cm3 | | |
| Mean | 15,8 | 39,0 | 48,5 | 1,4 | 0,21 | 61 |
| Standard deviation | 14,1 | 14,7 | 12,1 | 0,2 | 0,06 | 9,7 |
| Minimum | 0,2 | 13,8 | 11,8 | 1,2 | 0,08 | 30 |
| Maximum | 61,7 | 80,2 | 74,1 | 2,2 | 0,31 | 82 |
| Range | 61,5 | 66,4 | 62,3 | 1,1 | 0,23 | 52 |
| Median | 12,1 | 38,0 | 50,4 | 1,4 | 0,23 | 64 |
| Std. error of mean | 1,25 | 1,31 | 1,08 | 0,02 | 0,01 | 0,86 |

For more detailed characterization of the Hungarian swelling clay soils, and to provide good basis for the development of the lower levels of its classification, the basic statistical parameters of the 20 cm thick segments were also evaluated for selected parameters.
Based on my results, the average clay content of my reference profiles are high, 48,5% in the 0-150 cm thick segment of the soils, and it stays above 30% in all layers, respectively. To go

[3] In case of the COLE values n=91

into more details, the mean clay content is 50% or more in the upper 80 cm of the soils, and more than 39% in the deeper layers too. The minimum and maximum values show that higher clay contents are characteristic for the upper 60 cm of the profiles, while below this depth the value of less than 30% may occur.

Related to the high clay content, the other examined physical parameters also show high values: the mean bulk density is 1,4 g/cm$^3$, the COLE is 0,21, and the Arany-type textural coefficient is 61.

The mean organic matter content is relatively high among the mineral soils; 1,5% in the 0-150 cm thick segment of the soils. The depth distribution is also favorable: the mean SOM value stays above 2,4% in the upper 40 cm (with the minimum of 1,2%), it is more than 1% in the upper 80 cm, and more than 0,5% at the depth of 150 cm, too.

Considering the significant importance of organic matter in soils, the development of the indication of deep (>50 cm), organic matter rich (>1%) surface horizons is suggested at the lower level of classification.

The mean carbonate content is 3,2% in the 0-150 cm thick segment of the soils, but similarly to the clay content, its distribution can be quite extreme with the range of 35,5%. Based on the evaluation of values determined from the 20 cm thick segments, the mean carbonate content is increasing with depth. Some cases the soils may contain carbonates from the surface, but higher (>15%) $CaCO_3$ content values are characteristic for the layers below 50 cm from the soil surface. Based on my results the indication of presence and depth of carbonate accumulation horizon in swelling clay soils is developed at the lower levels of classification.

The mean pH value is slightly alkaline (pH $H_2O$=7,5) with high base saturation (95%). The detailed evaluation of the two parameters shows good relation with the $CaCO_3$ distribution results: both the mean pH and base saturation values are increasing with depth. Although acidic, slightly acidic pH, and low base saturation values may occur at the surface layers – the indication of these cases is developed at the lower level of classification, too.

Among the exchangeable cations the calcium is dominated (73%), but the mean magnesium content is also significant (22%). The evaluation of the extremes of exchangeable sodium, and the total salt content values (44% and 0,28%, respectively) provides information about the possible sodification and salinization processes. The mean exchangeable sodium content (defined in % of sum of the adsorbed basic cations) is 3,1% in the 0-150 cm thick segment of the soils, significant values of higher than 15% start below 60 cm from the soil surface, with further increasing of the maximum values with depth. The mean total salt content is 0,05% in the 0-150 cm thick segment of the soils, with slight increase of the mean values with depth. Some cases the soils may have high salt content (0,11%) from the surface. Profiles with salt accumulation usually have increasing salt content with depth. The indication of presence and degree of salinization and/or sodification is developed at the lower levels of classification as well.

The high mean CEC values (35,6 cmol/kg in the 0-150 cm thick segment) are related to the high clay and SOM content, and are in good agreement with the literature data.

*Vertical distribution of soil organic matter content in heavy clay soils of Hungary based on the TIM database*

The need to restore soil organic matter stocks in order to preserve soil resources and to promote C sequestration in soils is widely recognized, and will be even more important in the following years. The storage of carbon in soils is influenced by several factors; one of them is soil texture.

Based on the statistical analysis of the data of the TIM dataset, the mean SOM content is significantly higher ($P<0,001$ and $P <0,05$) in all layers of the high clay (HC) content soils compared to low clay content soils (LC) (Table 5.).

Table 5. Mean soil organic matter content (SOM%) in sampled horizons of the Hungarian high clay (HC) and low clay (LC) content soils based on the TIM database

| Horizon | Depth* (cm) | HC | | LC | | P |
|---|---|---|---|---|---|---|
| | | SOM(%)±sd | n (db) | SOM(%)±sd | n (db) | |
| H1 | 15 | 2,80±0,99 | 179 | 2,12±1,35 | 797 | <0,001 |
| H2 | 46 | 1,66±0,82 | 179 | 1,15±0,92 | 797 | <0,001 |
| H3 | 84 | 0,93±0,54 | 179 | 0,67±0,67 | 797 | <0,001 |
| H4 | 126 | 0,61±0,44 | 128 | 0,51±0,60 | 627 | <0,001 |
| H5 | 167 | 0,49±0,24 | 37 | 0,42±0,37 | 183 | <0,05 |

* central depth of a sample horizon

The non-linear decrease of SOM content with increasing depth in HC and LC soils and in the profiles of the TIM dataset are shown in Figure 1.

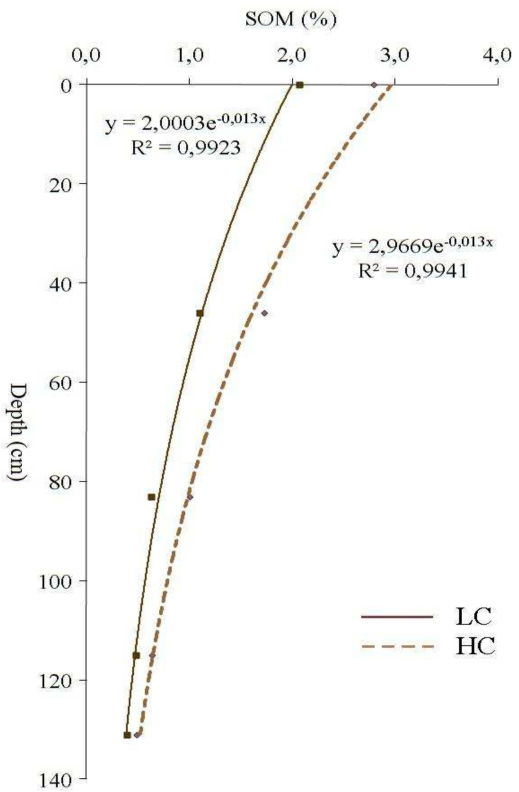


Figure 1. Vertical distribution of mean SOM content
of Hungarian high clay (HC) and low clay (LC) content soils based on the TIM dataset

The HC soils have 2.81% mean SOM content in the surface horizon, and it stays above 1% until the third horizon (with 83 cm central depth). In the 4th and 5th horizons mean SOM is above 0.5%.

The LC soils have 2.09% mean SOM content in the surface horizon, 1.11% in the 2nd and 0.65% in the 3rd horizon, while in the 4th and 5th horizons it is below 0.5%.

Based on the results it can be concluded, that HC soils develop deeper SOM accumulation horizons with significantly higher SOM content than low clay content (LC) soils, the differences are decreasing with depth, but stay significant.

Thus, HC soils are able to contain larger quantities of stable sequestered carbon in the subsoil.

*Vertical distribution of soil organic matter stock in heavy clay soils of Hungary based on the TIM database*

As shown in Table 6., based on the results it can be stated that in both HC and LC soils about 40% of SOM is held in the topsoil, and about 60% is in the subsoil. In case of the LC soils it's 45% in the topsoil, and 55% in the subsoil. HC soils store 25% more SOM in the combined topsoil and subsoil segment than LC soils, the difference is extremely significant ($P<0.001$).

Table 6. Depth distribution of soil organic matter stock (t/ha) in the topsoil and subsoil layers of low clay (LC) and high clay (HC) content soils of Hungary based on the TIM dataset

| | Soil organic matter stock (t/ha) ± SEM | | |
|---|---|---|---|
| | $SOM_{TOP}$ | $SOM_{SUB}$ | $SOM_{TOT}$ |
| Low clay (LC) | 8,69±0,21*** | 10,48±0,29*** | 19,17±0,42*** |
| High clay (HC) | 10,33±0,39*** | 15,25±0,48*** | 25,59±0,69*** |

*Remark:* $SOM_{TOP}$ = topsoil (H1 horizon) $SOM_{SUB}$ = subsoil (H2–H5 horizons); $SOM_{TOT}$ = combined topsoil and subsoil segment (H1-H5 horizons); *** P <0,05

The vertical distribution of SOM stock in t/ha is shown in Figure 2. The differences between SOM stock of HC and LC soils were highly significant ($P<0.001$) in the H1-H4 horizons, and significant ($P<0.05$) in the H5 horizon, based on the Mann-Whitney test.

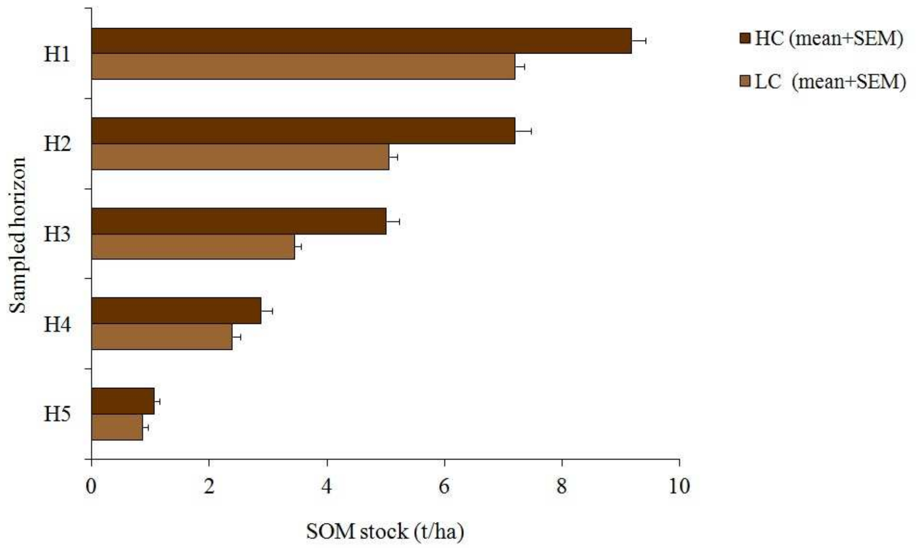


Figure 2. Vertical distribution of soil organic matter content (%) in the high clay content (HC) and low clay content (LC) soils of the TIM profile dataset (P<0,001)

Under the climatic conditions of Hungary, high swelling clay content can significantly determine SOM content distribution in soils. The special features and soil forming processes that characterize the Hungarian swelling clay soils, such as surface mulch development and opening of deep cracks seem to have a high impact on depth distribution of SOM. Based on my results I concluded, that HC soils develop deeper SOM accumulation horizons with significantly higher SOM content than LC soils, thus HC soils are able to contain larger quantities of stable sequestered carbon in the subsoil.

## Conclusions and Suggestions

My Ph.D. research is connected to the diagnostic based improvement and modernization of the Hungarian Soil Classification System (HSCS). Its basic principles and suggested structure has been first introduced as part of the final report of the "Improvement and international correlation of the Hungarian Soil Classification System" project supported by the Hungarian Research Fund (OTKA T 046513, 2008), and as a presentation (FUCHS et al., 2008) at the 2008. meeting of the Hungarian Soil Science Society.

The development of the system is based on diagnostic approach, thus the classification of soils is made according to *basic definitions*, the presence or absence of strictly and (if possible) numerically defined soil horizons, soil properties and/or materials.

The central taxa is the *soil type*, that are distinguished and defined by a *classification key*. The development of the key and names of the taxa is based on the recent 9 main soil types and 32 soil types of HSCS, with introduction of new units in well established cases. The suggested structure of the classification key, and possibly correlated WRB Reference Groups (in brackets) are shown in Table 7.

Table 7. The suggested structure of the classification key
(possibly correlated WRB Reference Soil Groups in brackets)

Peat soils (WRB: Histosols)
↓
Antropogenic soils (WRB: Technosols, Anthrosols)
↓
Stony skeletal soils (WRB: Leptosols)
↓
Gravelly skeletal soils (WRB: Leptosols)
↓
Parent material determined soils (WRB: Leptosols)
↓
Sandy soils (WRB: Arenosols)
↓
Barren earths (WRB: Regosols, Calcisols)
↓
Humus-carbonate soils (WRB: Calcisols, Chernozems, Kastanozems)
↓
Alluvial soils (WRB: Fluvisols)
↓
Solonetz soils (WRB: Solonetz)
↓
Solonchak soils (WRB: Solonchaks)
↓
**Swelling clay soils** (WRB: Vertisols)
↓
Meadow soils (WRB: Chernozem, Phaeozem, Kastanozem, Gleysol)
↓
Chernozems (WRB: Chernozem, Phaeozem, Kastanozem)
↓
Soils with clay illuviation (WRB: Luvisols, Alisols)
↓
Brown earths (WRB: Cambisols)

The suggested classification key consists of 16 soil types (Table 7.), that are clearly distinguishable from other soil types by strict definitions and numerical criteria, and has significant geographic distribution in Hungary. International correlation and harmonization with the World Reference Base for Soil Resources (WRB) was important during the development as well.
The order of soil types was defined based on the Hungarian conditions, thus it differs from the key of the WRB in some parts. One of the major differences is the position of Vertisol correlated *swelling clay soils* (topic of this dissertation) that is situated after the salt affected soils, thus giving priority to the salinization and sodification processes and related soil properties.
However I feel important to declare that the final priority order of the key can be defined just after detailed research of all taxa of the first level of the classification.
The classification key is built up from general description and from classification criteria. At the lower level of the classification *subtypes* and *varieties* are defined in order to provide further characterization of other important (transitional, chemical, physical and genetic) properties of the soil types.
Based on my results I suggest to define the high clay content soils with unique morphological, physical and chemical properties due to alternation moisture conditions governed shrinking and swelling processes at the first level of classification in the new Hungarian Soil Classification System.
I suggest the name of *swelling clay soil* for the new soil type, but the final nomenclature and names (for soil types, basic definitions, and also for the subtype and variety levels) should be defined just after widespread arrangement between Hungarian soil scientists.
During the development of definitions and criteria the most determining point of view is the respect to Hungarian conditions but correlation and harmonization with international systems is important as well.
In the following I present my suggestions according to the structure and basic principles of the previously introduced new HSCS under improvement.

I propose the following definition of *swelling clay soils* in the classification key:

*General description:*

Other soils that shrinking and swelling due to alternating dry-moist conditions.

*Classification criteria:*

1. *Swelling horizon* starting within 100 cm of the soil surface, *and*
2. clay content (particle size < 0,002 mm) of 30% or more between the soil surface and the horizon defined in criteria 1, *and*
3. cracks that open and close periodically.

→ „Swelling clay soils"

The suggested definition of *"Swelling horizon"*:

The *swelling horizon* has:

1. 30% of clay content or more, *and*
2. slickensides and wedge-shaped structural units, *and*
3. a thickness of 25 cm or more.

Based on my results, I propose the following subtypes and varieties at the lower level of classification of swelling clay soils:

Subtypes:

- meadow
- stagnating
- alluvial
- calcic
- solonchacic
- saltic
- sodic
- typic

Varieties:

- humic
- acidic
- unsaturated
- mazic
- ferric
- reddish

According to the basic principles of the system, all subtype and variety properties have the same interpretation and definition for all taxa thus the final development of definitions will be the task of a delegated working group.

Suggested definitions for the *subtype properties*:

**Alluvial**: Having *alluvial soil material* of 25 cm or more thick within 100 cm of the soil surface.
*Alluvial soil material*:
Shows stratification of alluvial or lacustrine origin, with

1. fluctuation in coarse fragment content (particle size > 2 mm) of 5-10% or more, *or*
2. sand content (particle size of 2-0,02 mm) of the strata differs with 10% or more, *or*
3. irregular decrease of soil organic matter content with depth.

**Meadow**: Having within 100 cm of the mineral soil surface a layer, 25 cm or more thick that has *reducing conditions* in some parts of the matrix, and a *gleyic colour pattern* throughout.
*Gleyic colour pattern*:
Developing due to periodic groundwater saturation, and shows one or both of the following:

1. 90% or more grayish reductimorphic colours (Munsell 2.5Y, 5Y, 5G, 5B), *and/or*
2. 5% or more reddish oximorph mottles (presence of iron mottles, nodules), primarily along root channels or other biological channels.

**Stagnating**: Having within 100 cm of the mineral soil surface a *stagnic colour pattern* in 25 percent or more of the soil volume, and for some time during the year *reducing conditions* in some parts of the matrix.
*Stagnic colour pattern*:
Developing due to periodic water saturation of surface origin, and shows mottling in such a way that parts of the soil matrix (primarily the surfaces of the peds) are lighter (at least one Munsell value unit more) and paler (at least one chroma unit less), while other parts of the soil matrix (primarily the interiors of the peds) are more reddish (at least one hue unit) and brighter (at least one chroma unit more) than the non-redoximorphic parts of the layer.

**Calcic**: Having *calcic horizon* or evidences of *secondary carbonate* accumulation starting within 100 cm of the soil surface.
*Calcic horizon:*
A horizon in which secondary calcium carbonate ($CaCO_3$) has accumulated which has

1. a $CaCO_3$ content of 15% or more in the fine earth fraction, *and*
2. 5% or more secondary carbonates, *and*

3. a thickness of 15 cm or more.

**Solonchacic:**
Having *solonchacic soil horizon* starting within 100 cm of the soil surface.
*Solonchacic soil horizon:*
A surface or subsurface horizon that contains a secondary enrichment of readily soluble salts, and has:

1. during some parts of the year the electrical conductivity of the saturation extract ($EC_e$):
    a. of 15 dS /m or more (at 25 °C), *or*
    b. 8 dS /m or more (at 25 °C), if the pH ($H_2O$) of the saturation extract is 8.5 or more, *and*
2. thickness of 15 cm or more.

**Salty**: Having 0,15% or more total salt content.

**Sodic**: Having 15 percent or more exchangeable Na plus Mg on the exchange complex within 50 cm of the soil surface throughout.

**Typic**: Typical – only used if none of the subtype properties is satisfied.

Suggested definitions for the *variety properties*:

**Humic**: Having *humic soil horizon*.
*Humic soil horizon*:
A surface horizont hat has:

1. favorable soil structure, *and*
2. dark colour (Munsell value/chroma of 3/3 or less when moist, 5/5 or less when dry), *and*
3. 1% soil organic matter or more, *and*
4. 50% base saturation or more, *and*
5. thickness of 25 cm or more.

**Acidic**: Having a pH($H_2O$) of 5,5 or less.

**Unsaturated**: Having a base saturation (by 1M NH4OAc) of 50 to 80%:

1. in the major part between 20 and 100 cm from the soil surface, *or*
2. between 20 cm and continuous rock or a cemented or indurated layer, *or*
3. in a layer, 5 cm or more thick, if the solum is less than 20 cm thick.

**Mazic**: Massive and hard to very hard in the upper 20 cm of the soil with very coarse (>30 cm in size) structural units without any secondary structure.

**Ferric**: Having *ferric soil horizon* starting within 100 cm of the soil surface.
*Ferric soil horizon*:
A subsurface horizon that has:

1. 15% or more of the exposed area occupied by coarse mottles with a Munsell hue redder than 7.5 YR and a chroma of more than 5, moist; *or*
2. 5% or more of the volume consisting of discrete nodules/concretions with a diameter of 2 mm or more that are at least weakly cemented, *and*
3. has a thickness of 15 cm or more

**Reddish**: Having within 150 cm of the soil surface a subsurface layer, 30 cm or more thick, that has red colour (defined by a Munsell hue color of redder than 7,5 YR, or a hue of 7.5 YR and a chroma, moist, of more than 4).

To indicate the depth of occurrence the following *specifiers* may be used (similarly to the subtype and variety properties the specifiers have the same interpretation and definition for all taxa):

- at the surface: Occurrence of a subtype or variety property in the surface layer between 0 and 20 cm from the soil surface.
- from the surface: Occurrence of a subtype or variety property from the soil surface to at least 1m depth, or to continuous rock or a cemented or indurated layer, whichever is shallower.
- close to the surface: Occurrence of a subtype or variety property between 20 to 50 cm from the soil surface.
- at middle depth: Occurrence of a subtype or variety property between 50 to 100 cm from the soil surface.
- at deep depth: Occurrence of a subtype or variety property below 100 cm from the soil surface.

To express the intensity of soil characteristics the following *specifiers* may be used (similarly to the subtype and variety properties the specifiers have the same interpretation and definition for all taxa):

- strongly: Having a stronger expression of certain features than as defined at the subtype or variety level.
- weakly: Having a weaker expression of certain features than as defined at the subtype or variety level.

To indicate greater thickness than as defined at the subtype or variety level the following *specifiers* may be used (similarly to the subtype and variety properties the specifiers have the same interpretation and definition for all taxa):

- moderately thick: Subtype or variety property two times thicker than as defined in the classification criteria
- very thick: Subtype or variety property three times thicker than as defined in the classification criteria

Based on the previously introduced suggestions, the new classification of my reference profiles is the following:

| | |
|---|---|
| Szirák 1_Microlow: | Calcic at deep depth, meadow, swelling clay soil (very thick and strongly humic) |
| Szirák 1_Microhigh: | Calcic close to the surface, meadow, swelling clay soil (strongly humic) |
| Szirák 2: | Calcic at deep depth, swelling clay soil (moderately thick and strongly humic) |
| Kisnána: | Calcic at middle depth, swelling clay soil (very thick and strongly humic) |
| Gyöngyös: | Calcic at middle depth, swelling clay soil (strongly humic) |
| Atkár: | Calcic at middle depth, swelling clay soil |
| Apc: | Calcic from the surface, meadow at middle depth, swelling clay soil (moderatley thick, strongly humic) |
| Vajdácska: | Calcic, sodic and meadow at middle depth, swelling clay soil (moderatley thick, strongly humic) |
| Dorkó-tanya: | Alluvial, meadow at middle depth, swelling clay soil (very thick strongly humic, ferric) |
| Bodroghalom: | Stagnating and meadow at middle depth, swelling clay soil (moderatley thick, strongly humic, weakly acid at the surface, ferric) |
| Nagyrozvágy: | Calcic at deep depth, alluvial, meadow close to the surface, swelling clay soil (moderately thick and strongly humic) |
| Szenna tanya: | Calcic and meadow at middle depth, swelling clay soil (moderatley thick, strongly humic, weakly acid at the surface) |
| Kisújszállás: | Calcic, sodic and weakly salty at middle depth, stagnating and meadow close to the surface, swelling clay soil (moderatley thick, strongly humic, ferric) |
| Törökszentmiklós: | Calcic and salty at middle depth, sodic from the surface, meadow at at middle depth swelling clay soil (mazic) |
| Karcagpuszta: | Calcic at middle depth, sodic close to the surface, salty at middle depth, swelling clay soil (mazic) |
| Tiszasas: | Calcic at middle depth, sodic from the surface, meadow close to the surface, swelling clay soil (moderately thick and strongly humic) |
| Cibakháza: | Calcic, stagnating and meadow close to the surface, swelling clay soil (strongly humic) |
| Kötegyán: | Calcic at middle depth, alluvial, meadow close to the surface, swelling clay soil (very thick and strongly humic) |
| Tiszabura: | Calcic at deep depth, meadow close to the surface, swelling clay soil (very thick and strongly humic, acidic at the surface) |

## Summary of new scientific results

1. A detailed documentation is made of the high smectite clay content, shrinking and swelling soils of Hungary, developed on different substrates, topographical positions and geographical area

2. Following international standards based soil description and World Reference Base for Soil Resources (WRB) classification of my reference profiles I confirmed that they satisfy the criteria of Vertisols.

3. By the application of the centroid based taxonomic distance calculation method I numerically certified that my reference profiles are taxonomically closest to the WRB Vertisol Reference Soil Group based on measureable physical and chemical soil parameters as well.

4. Based on the analysis of the TIM dataset I concluded that Hungarian high clay content soils (>30% clay content to 100 cm depth from the soil surface) have significantly higher mean organic matter content ($P<0,001$ ill. $P <0,05$) in all horizons, and store 25% more SOM in the combined topsoil and subsoil segment than low clay content soils ($P<0.001$). Based on my results Hungarian high clay content soils differs from low clay content soils in morphological and chemical parameters as well.

5. I developed suggestions for the differentiation criteria and definition of the Hungarian swelling clay soils at the first level of classification based on its clay content and special morphological features related to shrinking and swelling processes.

6. I developed suggestions for the definition of the lower, subtype and variety levels of the classification of the Hungarian swelling clay soils based on its further morphological, physical and chemical properties.

## Related publications

## ARTICLES

### 1. Peer-reviewed research articles

#### 1.1. With impakt factor (according to WEB OF SCIENCE), in English

##### 1.1.2. International publisher

LÁNG, V., FUCHS, M., WATNER, I. & MICHÉLI, E., 2013. Taxonomic distance metrics, a tool for soil correlation. *Geoderma* **192**, 269-276.
http://dx.doi.org/10.1016/j.geoderma.2012.07.023
Impact factor: 2,318

#### 1.2. Without impakt factor, in English

##### 1.2.1. Hungarian publisher

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.

LÁNG, V., FUCHS, M., WALTNER, I. & MICHÉLI, E., 2010. Taxonomic distance measurements applied for soil correlation. *Agrokémia és Talajtan*, **59**, 1. 57-64.

***Citation:***
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#### 1.3. Without impakt factor, in Hungarian

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## CONFERENCE PROCEEDINGS

### 4. Conference proceedings with ISBN, ISSN or other certification

#### 4.1. Full text, peer-reviewed, in English

LÁNG, V., FUCHS, M., WALTNER, I. & MICHÉLI, E., 2010. Pedometrics applications for correlation of Hungarian soil types with WRB. In: Gilkes R.J., Prakongkep N. (eds.), Proceedings of the 19$^{th}$ World Congress of Soil Science; Soil Solutions for a Changing World; ISBN 978-0-646-53783-2; Published on DVD; http://www.iuss.org; Symposium WG 1.1; The WRB ®evolution; 2010 Aug 1-6. Brisbane, Australia, IUSS; 2010, pp. 21-24.

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***Citation:***
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## Acknowledgement

This research received funding from the „Kocsis Károly Young Researcer Scholarship" supported by the TÁMOP 4.2.2. B-10/1-2010-0011 project.

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