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The soil types of the modernized, diagnostic based Hungarian Soil Classification System and their correlation with the World reference base for soil resources

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Abstract

The traditional genetic-based Hungarian Soil Classification System (HSCS) was elaborated during the 1960s. The concept and the units were developed before sufficient data and modern data processing tools became available. The 39 soil types were defined as group of soils developed under similar soil forming factors and processes, resulting in similar morphogenetic properties. The allocation of soils in the system included some subjective elements, even with substantial knowledge and experience of the classifier. The modernized "diagnostic" system was developed based on the accumulated data and experiences with the genetic system as well on the application of new pedometric tools. The definitions and limits of the diagnostic categories (horizons and properties) correspond with the World reference base for soil resources (WRB), but are not identical, they are much simpler, and adopted for the environmental setting of the Carpathian Basin. The 15 soil types (central units) are defined by the newly introduced classification key, based on diagnostic criteria, assuring a more objective result of the classification process. This paper is presenting the rational of the diagnostic system, gives a summary description of the 15 new soil types and discusses the successful correlation with the (WRB).

Keywords: soil classification, genetic approach, diagnostic approach, World Reference Base for soil resources (WRB), correlation

Introduction

In the past few decades the understanding of the global nature of environmental problems created a need for international, harmonized maps and database. The long-term target is a global classification system (Hempel, J. *et al.* 2013; Michéli, E. *et al.* 2016; Hughes, P. *et al.* 2017), however, for the time being, correlation of the units of national systems is essential. Most international databases, maps and related publications, including the European Soil Database (ESDB) (Panagos, P. 2006) and the Soil Atlas of Europe (Jones, A. *et al.* 2005) are based on the World reference base for soil resources, the accepted correlation tool for soil scientists (IUSS Working Group WRB, 2006). Since most systems have their own principles and definitions, simple one to one translation of national units to the WRB is not possible. Generally, reclassification of original data, expert knowledge and, or pedometric applications (mostly taxonomic distance calculations) are applied for the correlation (Minasny, B. *et al.* 2009; Láng, V. *et al.* 2010).

The traditional genetic-based Hungarian Soil Classification System (HSCS) was elaborated during the 1960s. The concept and the units were developed before sufficient data and modern data processing tools became available. The 39 soil types were defined as group of soils developed under similar soil forming factors and processes, resulting in similar morphogenetic properties

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(Stefanovits, P. 1963; Szabolcs, I. 1966). The allocation of soils in the system included some subjective elements even with substantial knowledge and experience of the classifier. Michéli, E. *et al.* (2006) reported also correlation problems of certain units with international standards. The modernized "diagnostic" system was developed based on the accumulated data and experiences with the genetic system as well on applications of new pedometric tools (Fuchs, M. *et al.* 2011; Láng, V. *et al*. 2013; Michéli, E. *et al.* 2014). The definitions and limits of the diagnostic categories (horizons, properties and materials) are based on stronger and numerical criteria than the previous system. Although the categories are not identical with, but most of them correspond with the World reference base for soil resources (WRB) (IUSS Working Group WRB, 2015). Furthermore, the definitions are, much simpler (as simplicity was among the principles of the modernization) and adopted for the environmental setting of the Carpathian Basin. The new 15 soil types are defined by the newly introduced classification key, based on the diagnostic criteria, assuring a more objective result of the classification and correlation processes (Michéli, E. *et al.* 2014). In this paper we provide and discuss the correlated WRB units for the soil types of the modernized, diagnostic-based Hungarian Soil Classification System to help better communication and data exchange on international forums.

Materials and methods

The methods of the modernization efforts of the Hungarian Soil Classification System included: linking the processes to diagnostics (Michéli, E. *et al.* 2011), review and pedometric evaluation of the taxonomic relationships of the genetically defined units (Fuchs, M. *et al.* 2011; Láng, V. *et al*. 2013), the development of the new central units (15 soil types), the development of the classification key, and the definition of the methodology to derive the lower level (subtype and variety) units. The 15 new soil types are the result of merging similar genetic soil types and introducing new soil types, not existing in the genetic system (Michéli, E. *et al.* 2014).

The current official correlation system and the tool for development of harmonized soil information products is the WRB 3rd edition (IUSS Working Group WRB, 2015). On the highest level 32 reference soil groups (RSG) are distinguished and defined by the key, based on the required diagnostic criteria. The RSG level was applied for the correlation of the HSCS soil types. The lower level combinations with the qualifiers are countless and are not in the scope of the present paper. For the definition of the correlated HSCS soil types with the WRB RSGs, simple reviews, expert knowledge and in some cases pedometric tools were applied (Láng, V. *et al.* 2010; Michéli, E. *et al.* 2016).

Results and discussion

The simplified classification key for the 15 soil types and the most likely correlated WRB RSGs are given in *Figure 1.* (The HSCS soil type names are written in bold.) For the correlated WRB RSGs the most likely correlated unit is given. Additional less common options are given in bracket. Short discussion for the correlation of each soil type is coming below.

Peat soils

Peat soils of Hungary are organic soils that commonly developed in local water-logged depressions. As a result of long-term water saturation undecomposed or partially decomposed biomass of the wetland habitats has been accumulated. In higher altitude locations, with cool climate, the peat material may consist of undecomposed moss fibres. The defined thickness (≥ 40 cm), depth (starts from 40 cm from the surface) and organic carbon content (OC ≥ 20%) are criteria of the organic layer(s), provide easy correlation with the *WRB Histosols*. Peats overlying ice, or

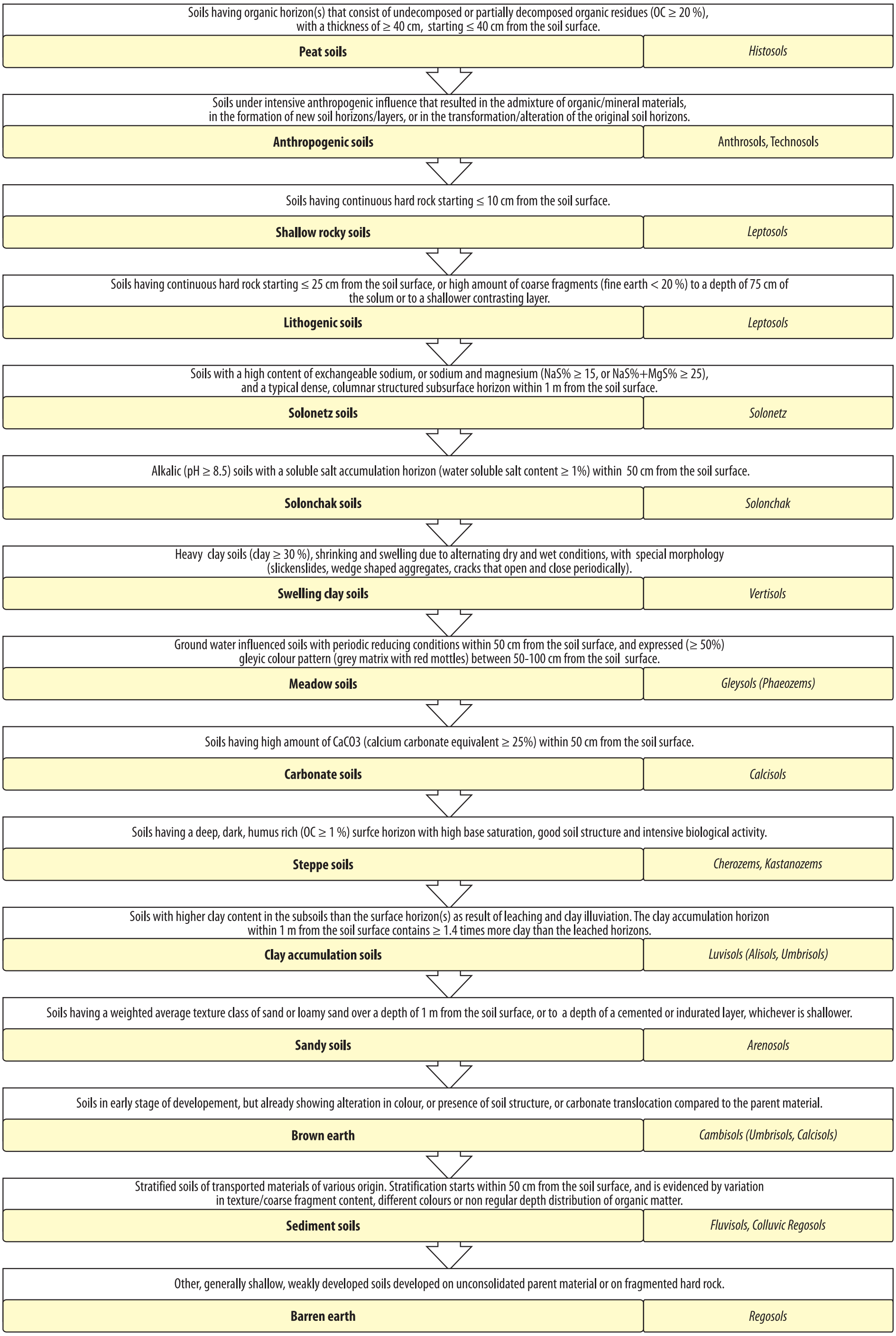

Fig. 1. The simplified classification key for the 15 soil types of the modernized, diagnostic based HSCS and the most likely correlated WRB (2015) RSGs.

continuous hard rock are not documented in Hungary, hence such situations are not part of the definition of peat soils and have no relevance for correlation with the WRB shallow Histosol options (criterion 1. in the WRB key).

Anthropogenic soils

The group of anthropogenic soils is a newly introduced soil type in the modernized HSCS. The soil type combines soils under intensive anthropogenic influence that resulted in the admixture of organic/mineral materials (> 20%), in the formation of new soil horizons/layers, or in the transformation/alteration of the original soil horizons within 100 cm from the soil surface. The HSCS Anthropogenic soils may correlate with the *Anthrosols* and/or *Technosols* reference soil groups of WRB. The precise correlation, however, is only possible with the application of the qualifiers in both systems (eg. Terric, Linic etc.). Farsang, A. *et al.* (2015) contributed to the development of the concept and definitions of the anthropogenic soils. Since these soils were not part of the traditional Hungarian system, experiences with application are limited.

Shallow rocky soils

Typical soils of the steep, highly eroded surfaces of mountainous regions of Hungary, where continuous hard rock is starting ≤ 10 cm from the soil surface, and rock outcrops are common. The depth criteria provide a one-to-one correlation with *Lithic* or *Nudilithic* "versions" of the WRB *Leptosols*. Since these soils occupy less than 0.5 per cent of the country it is considered to combine them with the Lithogenic soils of the HSCS.

Lithogenic soils

Lithogenic soils include the Rendzinas, Rankers and Erubase soils of the former genetic system (Stefanovits, P. 1963), in which no specific depth criteria are defined. The modified definition of these shallow, rocky soils fully corresponds with the WRB *Leptosols* definition (having continuous hard rock, starting ≤ 25 cm from the soil surface; or high amount of coarse fragments (fine earth < 20%) over a depth to 75 cm or to the bedrock). The traditional names are preserved on the lower level of the classification with the application of the subtype qualifiers.

Solonetz soils

Both Solonetz and Solonchak soils are typical for lowland areas with high evaporation rate. Their characterization, classification and mapping have long traditions in Hungary, and the achievements of Hungarian scientists influenced the classification of salt-affected soils globally (Szabolcs, I. 1989; Tóth, T. and Várallyay, G. 2002). Solonetz soils are defined by the presence of high amount of adsorbed sodium and/or magnesium, and the strongly structured columnar subsurface horizon. In the WRB the natric horizon is defined on 2 pages with several alternatives and sub-criteria. The HSCS has a simplified definition, however, the criteria for the exchangeable sodium percentage ESP ≥ 15, or Na + Mg > 25 per cent, and the similar morphological criteria provides easy correlation with the WRB *Solonetz* soils.

Solonchak soils

Solonchaks are alkaline (pH ≥ 8.5) soils with high accumulation and concertation of soluble salts at, or close to the surface. Due to the limited biological activity and bioturbation, Solonchaks show moderate genetic horizon development in the subsoil. The original stratification of the fluvial or lacustrine sediments is commonly preserved. The criteria for the salt accumulation horizon (water soluble salt content ≥ 1% within 50 cm from the soil surface) is defined by using the standard Hungarian unit for salt content, but with the application of a conversion factor developed by Filep, G. (1999) successful correlation with the WRB *Solonchak* RSG is possible. Soils that do not meet the salt criterion, hence the EC requirement may correspond with other WRB RGSs (eg. *Gleysols* or *Fluvisols*), however, the salt accumulation can be indicated with the *Protosalic* (EC ≥ 4 dS/m) qualifier in the correlation.

Swelling clay soils

"Swelling clay soils" are newly introduced to the modernized HSCS. They may form in different landscapes from fluvial depositions to mountain pediments and were allocated in different genetic soil types (alluvial soils, meadow soils, "erubaz" soils (soils of volcanic origin), however, the common characteristics are the high clay content (≥ 30%), and shrinking and swelling properties due to alternating dry and wet conditions. The corresponding criteria for the clay content and for the special morphology (slickensides, wedge shaped aggregates, cracks that open and close periodically) within 1 m from the soil surface, provide a one-to-one correlation with the *Vertisols* RSG of the WRB.

Meadow soils

The genetically defined "meadow soils" are groundwater-affected soils of lowland areas with redoximorphic features (Stefanovits, P. 1963; Szabolcs, I. 1966). However, the lack of the criteria for depth and expression for the colour patterns allowed subjectivity in the classification and correlation process. With the introduction of the definition of reducing condition, the gleyic colour pattern and depth criteria, correlation with WRB is easier. Meadow soils with periodic reducing conditions within 50 cm from the soil surface, and evidences of the gleyic colour patterns in more than 50 per cent of the matrix between 50–100 cm from the soil surface likely correlate with the WRB *Gleysols*. Other groundwater influenced soils with deeper redoximorphic features may correspond with other WRB RSGs but can be specified with the *Gleyic* qualifier in the correlation process.

Carbonate soils

Carbonate soils are also new in the modernized HSCS. These soils have high amount of $CaCO_3$ (calcium carbonate equivalent ≥ 25%) within 50 cm from the soil surface. This high amount of mostly secondary carbonates have generally weathered or have been leached from the primary parent material (i.e. from limestone, loess, marl). The secondary accumulation of carbonates is often combined with erosion ("bringing" accumulations close to the surface). Significant part of Hungary is a carbonate rich basin, where carbonate soils can develop in various soil forming environments from hill sediments to eroded loess plateaus. Since the amount and the depth criteria of carbonates of the HSCS Carbonate soils are much stronger than the WRB Calcisols, the correlation is not straight forward. Most HSCS Carbonate soil fulfil the requirements of the WRB Calcisols, however, only a portion of WRB *Calcisols* correspond with the HSCS Carbonate soils.

Steppe soils

The traditional Dokuchaev Chernozem concept (Dokuchaev, V.V. 1883) influenced most genetic-based national classification systems. As result of substantial surveys, new knowledge, as well as degradation processes, changes occurred in the classification of the deep, dark steppe soils (soils developed under grassland vegetation). In the WRB four RSGs are dedicated to soils with high organic matter content in the dark mineral surface soils: The *Chernozems* and *Kastanozems* (secondary carbonate present at shallow depths), the *Phaeozems* (secondary carbonate leached to a depth ≥ 50 cm below the organic matter-rich mineral top horizon) and the low base *Umbrisols*. In the Carpathian Basin most of the Steppe soils formed on loessy parent material and have deep, dark OC reach surface horizons and subsurface horizons with secondary carbonates. The criteria of the humus-rich surface horizon corresponds with that of the WRB mollic horizon in terms of depth (20 cm), colour (Munsell chroma ≤ 3), base saturation (≥ 50%), and favourable structure, however, based on the statistical studies of national data sets (Láng, V. 2013), in the classification key of the diagnostic based HSCS stronger criteria was set for OC content (≥ 1%) for the Steppe soils, similarly to WRB chernic horizon for the Chernozems. This allows satisfactory correlation of the HSCS unit with the lighter coloured WRB *Kastanozems* and the darker *Chernozems*. The close taxonomic relationship is evident, however, not all WRB *Kastanozems* and *Chernozems* satisfy the HSCS Steppe soil criteria – as in the HSCS key the presence of > 20 per cent coarse fragments to 50 cm depth, or continuous rock or clay accumulation horizon within 1 m are also excluded from Steppe soils. As these soils represent the most fertile soils of Hungary (Várallyay, G. *et al.* 1985) further fine-tuned studies are going on for nomenclature (the Steppe soil name is not satisfactory for the authors) and the lower level specifications.

Soils with clay accumulation

In the traditional genetic approach clay accumulation soils were listed among the brown forest soils in many countries, at the same time other members of brown forest soils were often confused with clay accumulation soils (Cline, M.G. 1949; Tavernier, R. and Smiths, D.G. 1957). In most modern soil classification systems clay accumulation soils are representing individual classes and do not preserve forest related nomenclature. In the modernized diagnostic based HSCS the criteria for the presence of the clay accumulation horizon is corresponding with WRB *argic* horizon in terms of depth (within 1 m) of the clay enriched horizon and clay increase (1.4% × compared to the leached horizons) and the requirements of clay skins in case of truncated, ploughed or polygenetic soils (with lithological differences). This allows an easy correlation of the HSCS Clay accumulation soils with the *Luvisols* of the WRB. In forested areas where clay accumulation soils develop deep, high OC containing surface horizons, they may correlate with the WRB *Umbrisols.* In limited areas where the acidification processes are intensive and the effective base saturation of the clay accumulation horizon is < 50 per cent, the *Alisols* RSG may be the corresponding WRB unit.

Sandy soils

Sandy soils of Hungary are typically weakly developed soils, have low amount of organic and inorganic colloids, which resulted in unfavourable physical-, chemical properties and low fertility. These soils have a weighted average texture class of sand or loamy sand to a depth of 1 m from the soil surface, or to a depth of a cemented or indurated layer, whichever is shallower. These criteria are fully matching the WRB *Arenosols* reference group, providing an easy correlation. In cases when sand is covering other soils or layers with contrasting texture, correlation is more complicated and requires decisions based on the specific situation.

Brown earths

Brown earth was the other typical member of brown forest soils in the genetic based system (Stefanovits, P. 1963; Szabolcs, I. 1966). However, the insignificant subsurface horizonation may develop in different soil forming environment (Jenny, H. 1941; Cline, M.G. 1949; Tavernier, R. and Smiths, D.G. 1957). Hence in the WRB and most other systems soils showing slight alteration in colour and soil structure compared to the parent material are listed as separate units on the highest level of classification. Although the definition of Brown earths is corresponding with the *Cambisols* reference group of WRB, correlation might be a problem. The cause of the problem is the definition of the *Calcisols* and their position in the key, before the *Cambisols*. If a Brown earth of the HSCS has a calcic horizon (carbonates ≥ 15%) within 1 m (which is often the case, especially in eroded landscapes), they key out as a *Calcisols* RSG. The problem with the *Calcisol* definition and position in the key have been reported problematic in other countries as well and need to be reviewed by the WRB Working Group of IUSS.

Sediment soils

Sediment soils include soils with the presence of stratification within 50 cm from the soil surface as a result of accumulation of transported materials of various origin. Thus, the soil material of sediment soils was not developed in-situ, but transported and redeposited by erosion, or by fluvial or lacustrine processes. The stratification is required to be evidenced by the variation in texture/coarse fragment content, different colours or by not regular depth distribution of organic matter, or by the presence of a layer with 0.2 per cent higher OC content than the overlying layer within 1 m. These criteria are providing a satisfactory correlation of Sediment soils of the diagnostic based HSCS with corresponding *Fluvisols* or *Colluvic Regosols* of WRB. Problematic situations may occur when the sediment have a calcic horizon (as described at the Brown earth discussion). In such cases the Sediment soils key out as Calcisols, which is not a satisfactory correlation in terms of taxonomic relationships (or similarities).

Barren earths

Other soils, that do not satisfy the requirements of any other soil type of the HSCS, thus, key out at the end of the classification key as Barren earth. Barren earths are generally shallow, weakly developed soils on unconsolidated parent material or on fragmented hard rock, usually on highly eroded or on very young surfaces. Barren earths correspond with the WRB *Regosols*.

WRB reference groups that do not occur in Hungary

Out of the 32 RSGs 20 are relevant in the Carpathian Basin. The WRB reference groups that do not occur in Hungary are mostly related to climatic or parent material differences. The below statement may be reviewed, if new surveys or investigations provide evidences of presence of the listed RSGs.

Cryosols are soils of the permafrost environment, hence only paleo (mostly buried) soils have fossil cryogenic features (Berényi Üveges, J. *et al.* 2003).

Andosols are soils developed from fresh glass-rich volcanic ejecta. Soils developed from volcanic parent material in Hungary are substantially weathered and developed, consequently, no Andosols have been documented in Hungary (Madarász, B. 2005).

Podzols are very acidic soils developing mostly under boreal forests. The criteria for the subsurface accumulation of iron and aluminium with or without organic matter are very strong in the WRB. National inventories do not include pedons that correspond with the WRB Podzols criteria (Láng, V. 2013). Local formations with limited extent, however, might be possible.

Plinthosols, Nitisols and Ferralsols are highly weathered soils of the tropics, and do not develop under the current climate of Hungary. Although paleo features of such soils have been documented by Fekete, J. *et al.* (2006).

Planosols and Stagnosols are related to long term water logging and textural differentiation. Stagnic features are common mostly in the HSCS Clay accumulation soils and the Swelling clay soils, but pedons developing the required expression of the features are likely to occur, but were not documented.

Durisols are silica cemented soils of old arid and semi-arid areas and up till now, even paleo Durisols have not been documented in Hungary.

Gypsisols are gypsum accumulation soils. Although gypsum is common in Solonetz and Solonchak soils and the *Gypsic* qualifier is an option to indicate the feature.

Retisols are typical for ice-age influenced soils with coarse bleached interfingering material into a clay rich subsurface in a net-like pattern. So far, no pedon with the feature has been documented.

Acrisols and Lixisol are clay accumulation soils of old surfaces, with low (≤ 24 cmol/kg) cation exchange capacity (CEC) of the clay. In Hungary the mineralogy of clay accumulation soils is characterized with much higher CEC (Stefanovits, P. 1963) and so far, no *Acrisols* or *Lixisols* were documented.

Preserving legacy semantic and spatial soil information

With the application of a computer assisted algorithm the earlier genetic classification units can be converted to the new ones, preserving the value of the legacy soil information (Láng, V. 2013; Michéli, E. *et al.* 2014). The geographical distribution of the soil types of the modernized diagnostic-based HSCS is a greater challenge, as often no analytical data is supporting the spatial patterns. However, with the application of pedometric and digital soil mapping tools promising methodologies were documented by Dobos, E. *et al.* (2014) and Pásztor, L. *et al.* (2018) which can be adopted for the development of new national maps and correlated internationally understood maps.

The next and perhaps the most crucial test of the system is to map the new soil types (central units) and diagnostic categories and analyse their spatial patterns and their relationships with the physical geographic conditions of Hungary. An automated classification algorithm was developed to derive the classification units from legacy databases. With the application of the legacy data and new georeferenced field observations the spatial definition of new units is possible. This work is going on and will be subject of a follow up paper.

Conclusions

The 15 soil types defined in the diagnostic based, a modernized Hungarian Soil Classification System (HSCS) were developed based on the accumulated data and the genetic system. The introduced diagnostic approach with stronger morphogenetic and numerical criteria are not identical but correspond with the criteria of the classification units of the World reference base for soil resources. Although there are only few cases when one to one matching is possible, the adopted numerical criteria provide successful correlation results. Updating the national database and maps and the relevant correlated products is a challenge that needs substantial effort, however, promising methodologies have been documented.

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