CLASSIFICATION OF BLACK SOILS, CHERNOZEMS AND CHERNOZEM-LIKE SOILS

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Abstract. *For ages Chernozems were recognized as the most fertile soils in Eurasia; the scientific study of soils started from Chernozems. However, the concept of the genesis of Chernozems evolved since the 19th century. This evolution was somewhat circular because many researchers returned back to the theories that stressed the importance of excessive moisture in the past and specific paleoclimates in the formation of Chernozems rather than the contribution of current vegetative cover. The study of Chernozems and Chernozem-like soils throughout the world resulted in the amplification of the concept of the genesis of these soils. In places, we observe the convergence of soils of different genesis that leads to the formation of similar deep black soil horizons. Soil classifications reflect the diversity of Chernozem-like soils; some classifications are inclusive, and the others intend to divide black soils into several distinct groups. Taxonomic distance analysis shows that most Chernozems and Chernozem-like soils form a compact group, though dark-coloured Rendzinas and Vertisol-like soils show high dissimilarity with Chernozems.*

Keywords: *Dokuchaev, history of soil science, taxonomic distances, food security*

INTRODUCTION

The study of Chernozems started as early as in the 5th century DC when Herodotus mentioned exceptionally dark and deep soils in Scythia (Krupenikov et al., 2011). People working on these soils valued them for their natural fertility and used for denominating them their black colour as the most obvious feature. Black or dark soils, if present, are recognized and named after their colour in almost all the world cultures. The name “Chernozem” was widely used in Russia in the statistical books on land tenure and later appeared at the first general soil maps of European Russia. The distribution and origin of Chernozems were also studied in the 19th century by German agrogeologists in Eastern Europe and Russian Empire. A review of their views was given by Vasiliy Dokuchaev in 1883 in his seminal book “Russian Chernozem” (Dokuchaev, 1967). Before this publication black soils of South-Eastern Europe were regarded either as marine sediments (e.g. the theories of R. Murchinson and A. Petzgold) or dried peat lands (e.g. E.I. Eichwald, F.F. Wangenheim and some others). Dokuchaev argued that Chernozems were terrestrial soils formed under graminaceous vegetation; this book is considered to be the first publication that outlined the principles of contemporary soil science (Krupenikov, 1993). It should be recognized that folk understanding of the origin of Chernozems was correct from the very beginning: the farmers believed that Chernozems form due to the continuous accumulation of decayed plant roots. Also several researchers before Dokuchaev (e.g. M.V. Lomonosov and F.I. Ruprecht) believed that Chernozems are contemporary soils formed under graminaceous vegetation (see Krupenikov 1993). Dokuchaev made the most important step in the understanding of the genesis and geographical regularities in the distribution of Chernozems.

The total area of “black soils” with a dark-coloured surficial horizon is 8.23 x10^6 km^2 in the world, which is 6.49% of the Earth's land surface, home to 6.6% of the world's population (Blum 2013). The area occupied by Chernozems in their current understanding along with the WRB concept is about 230 million hectares (2.3 x10^6 km^2). With a wide strip they pass through all of Eurasia from the Hungarian Pasht to the uplands of Mongolia and the great plains of Northern China. In the Eastern Hemispere they are formed mainly in the prairies of North America, while in the pampas of Argentine and Uruguay the soils resemble Chernozems, but lack contemporary secondary carbonates in the profile (thin hard *tosca* layer is believed to be a relict feature).

The difference in the approaches to the classification of Chernozems resulted in the need for an inclusive concept that led to the establishment of the International Network of Black Soils (INBS) in the frames of Global Soil Partnership (GSP). The Harbin Communiqué adopted at the launch meeting of INBS in September 2018 define black soils as having the following core characteristics: 1) High organic carbon content as per the following: >1.2% for cold and temperate and >0.6% for tropical and subtropical regions, 2) dark to black coloured surface horizons, 3) thickness of dark to black surface horizons not less than 25 cm, 3) these horizons should have a high base saturation >50%, strong aggregate stability and high level of nutrient content (FAO, 2018). Even superficial comparison with common soil classifications shows that this definition is broad and not very accurate that seems natural because of the intention to cover all the dark-coloured fertile soils in the world. However, it is evident that the concept should not extend to the soils having dark colour but lacking high fertility typical for Chernozems and Chernozem-like soils: well-decomposed peat soils, dark coloured volcanic soils, black Vertisols and soils derived from lignite shale's and other dark parent materials. In this study we tried to limit the concept of black soils to those soils that have common features and form more or less compact conceptual group using the methods of taxonomic distance assessment.

MATERIALS AND METHODS

We compared the properties of Chernozems and Chernozem-like soils obtained from three national and international soil databases. The United States Department of Agriculture, National Resources Conservation Service's National Cooperative Soil Survey Soil Characterization Data and the National Soil Information System served as a basis for grouping the Mollisols (Soil Survey Staff, 1999). The database was evaluated for the database quality to provide continuous pedon data with taxonomy-related information. The final dataset contained 6307 pedons for 32 Mollisol Great Groups (GGr). The ISRIC-WISE v3.1 dataset was used to serve the centroids of Reference Soil Groups (RSGs) of the WRB (IUSS Working Group WRB, 2015). The WISE dataset is a compilation of soil profiles data, collected from 149 countries worldwide (Batjes, 2008, 2009). There were eight related RSGs selected for this study. This resulted in a total of more than 1770 profiles included in the calculation from the WISE 3.1 database. The third dataset was obtained from available data from Russia because Russian Federation possesses the most extensive area of black soils, where only the area of Chernozems *sensustricto* equals to 122 million hectares (Krasilnikov et al., 2018). The major part of the Russian dataset was obtained from the Soil-geographic database of Russia, the project of Dokuchaev Society of Soil Scientists (www.db.soil.msu.ru). Totally we used the data for 668 soil profiles of eight selected soil types (SoTs).

For allocating profiles in the space of properties we used integral characteristics of the profile such as the depth of the upper limit of a hardened layer or of the maximum of concentration of carbonates, or the maximum or minimum values in the entire profile, or integral values for the layers 0-25 and 0-100 etc. (Table 1). This approach allows describing a soil profile with a single point in the coordinates of the two principal components. There were 31 dominant identifiers used for this study, taking the available data and the representation of every selected group into consideration. Some of the properties might seem repetitive, but in fact, reflected the properties that had different pedogenetic interpretation and importance for soil use. For example, Max-Clay (0-150) was a value reflecting maximum clay content in the profile within the 150 cm, avg-Clay (0-20) – the average clay content in the surficial horizon, and avg-Clay (0-100) – the average clay content within the upper 100 cm of the soil. The calculations were done from the first mineral horizon, counting as a top, respectively to the depth of appearance of each attribute. The parent material (C horizon) was also included in the calculations, as no *a priori* conclusions about the evidence of pedogenesis were made.

Table 1. List of major identifiers

Max-$CaCO_3$_Top	Upper limit of the horizon with maximum $CaCO_3$concentration
Min-pH_H_2O	Minimum pH (H_2O) in the layer 0-100 cm
Max-pH_H_2O	Maximum pH (H_2O) in the layer 0-100 cm
Max-Gypsum	Maximum gypsum in the layer 0-100 cm
Max-$CaCO_3$	Maximum $CaCO_3$concentrationin the layer 0-100 cm
Max-OC	Maximum organic carbon concentration in the layer 0-100 cm
Bottom_of Max-OC	Lower limit of the horizon with maximum organic carbon concentration
Max-Clay(0-150)	Maximum clay content in the layer 0-150 cm
cec@Max-Clay	Cation exchange capacity in the horizon with the maximum clay content in the layer 0-150 cm
Double Clay Depth	Upper limit of the horizon with a double increase in clay content compared to overlaying horizon
Max-exch Na	Maximum exchangeable Na content in the layer 0-100 cm
Max-SAR	Maximum sodium absorption ratio in the layer 0-100 cm
NewTop-SecCarb	Upper limit of the horizon with secondary $CaCO_3$
NewTop-Redox	Upper limit of the horizon with redox features
NewTop-Duripan	Upper limit of the horizon with duripan feature
NewTop-Lithic	Upper limit of the horizon with lithic contact
NewTop-Contrlayer	Upper limit of the cemented or compact layer
Avg-R (0-20)	Weight average of R-part of RGB colour system in the layer 0-20 cm
Avg-G (0-20)	Weight average of G-part of RGB colour system in the layer 0-20 cm
Avg-B (0-20)	Weight average of B-part of RGB colour system in the layer 0-20 cm
Avg-OC (0-25)	Weight average of organic carbon in the layer 0-25 cm
Avg-OC (0-50)	Weight average of organic carbon in the layer 0-50 cm
Avg-OC (0-100)	Weight average of organic carbon in the layer 0-100 cm
Avg-CEC (0-100)	Weight average of cation exchange capacity in the layer 0-100 cm
Avg-BS (0-25)	Weight average of base saturation in the layer 0-25 cm
Avg-BS(25-50)	Weight average of base saturation in the layer 25-50 cm
Avg-BS (0-100)	Weight average of base saturation in the layer 0-100 cm
Avg-Clay (0-20)	Weight average of clay(<0.002) content in the layer 0-20 cm
Avg-Clay (0-100)	Weight average of clay(<0.002) content in the layer 0-100 cm
Avg-Sand (0-100)	Weight average of sand(>0.05) content in the layer 0-100 cm
Avg-EC (0-50)	Weight average of electric conductivity in the layer 0-50 cm

The calculated mean feature values were weighted on the thickness of the horizon for each soil units. When the identifier was referred to a depth of occurrence of a certain property, and the defined criteria were not fulfilled, the maximum value of 200 cm was assigned. The depth of 200 cm was chosen based on the maximum depth criteria occurring in the WRB key (Lang et al., 2013). The final features were derived as simple arithmetic means and the distance matrix was calculated to study the correlation between the Russian classification and the WRB, and Russian Classification and Soil Taxonomy.

RESULTS AND DISCUSSION

The analysis of the consistency of the Mollisol Order in Soil Taxonomy showed that most of the GGs are similar to each other and thus Mollisols constitute a natural group of soils (Figure 1). However, there are two important exceptions: Haplrendolls and Durustolls. These two GGs are quite different from the others, most probably due to the presence of solid rock or cemented layer in the profile. It might seem mysterious that Durustolls differ also from Duraquolls and

Durixerolls, but the possible explanation is that generally Durustolls have cemented horizons closer to the surface. We believe that for shaping the big centroids of the new Universal Soil Classification System the soils with shallow profile should be separated, as it has been done in most world soil classifications, including WRB.

The taxonomic distance between the majority GGs is relatively small comparing to that between RSGs and WRB RGs (Figure 1, Table 2). It indicates that the Soil Taxonomy GGs have lower absolute taxonomic level than the RSGs and especially World Reference Base RSGs. The analysis shows that in some cases the GGs differing only in moisture regimes had low taxonomic distances, like in the case of Peleudolls, Paleustolls and Palexerolls. In other cases soils with ustic and xeric moisture regimes were similar, while soils with the udic regime were different, e.g. in the case of Calciustolls and Calcixerolls versus. Calciudolls. For some GGs the moisture regime resulted in big distances between all the GGs. Aquic moisture regime and cryic temperature regime almost in all the cases resulted in different properties. In summary, there is no general rule, and pedogenetic analysis is needed in each particular case. The practical outcome of the analysis is the conclusion that the GGs with the same great group prefix (“Natr-“, “Pale-”, “Calci-“ etc.) but different moisture and temperature regimes cannot be automatically joined in one centroid.

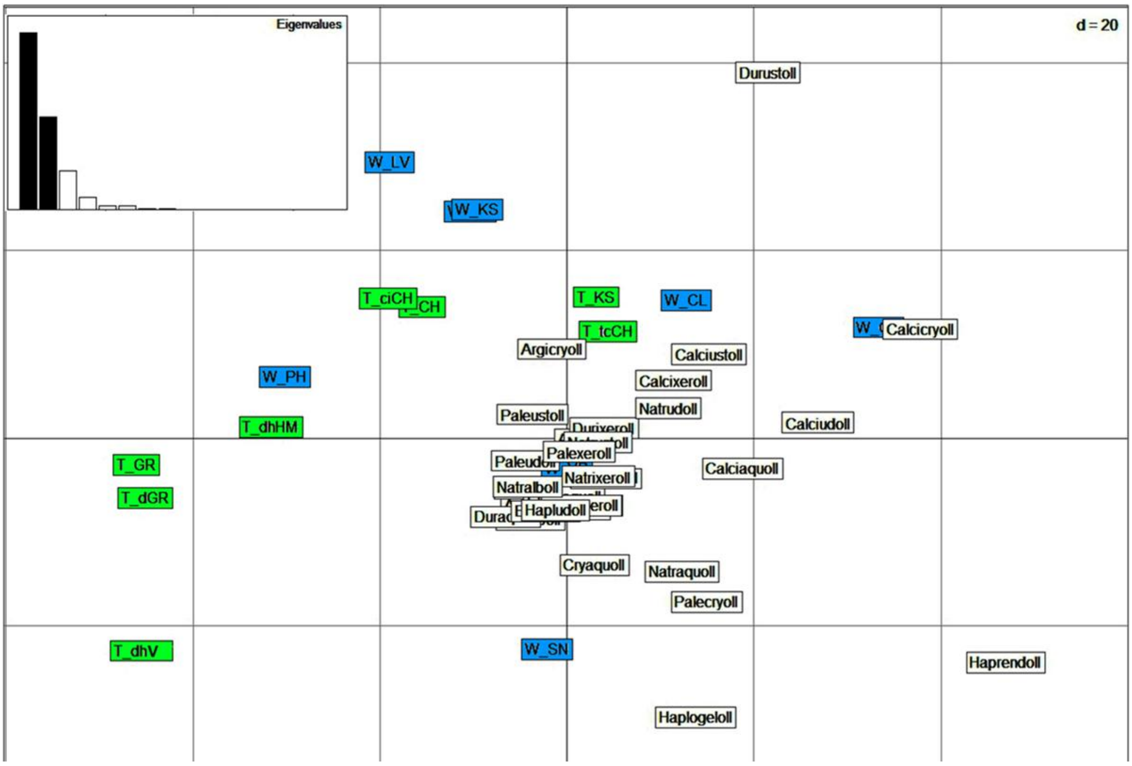

Figure 1. Principal coordinate analyze for RSC Types, WRB RSGs and ST GGs; white boxes – ST GGs, green boxes – RSC Types, blue boxes – WRB RSGs

Table 2. Explanations for the abbreviations for Figure 1

WRB RSGs	Abbreviations	RSC Types	Abbreviations
Chernozems	W_CH	Chernozems	T_CH
Kastanozems	W_KS	Clay-illuvial chernozems	T_ciCH
Phaeozems	W_PH	Textural-carbonate chernozems	T_tcCH
Calcisols	W_CL	Dark-humus compact (vertic) soils	T_dhV
Gypsisols	W_GY	Dark-grey soils	T_dGR
Solonetz	W_SN	Grey soils	T_GR
Vertisols	W_VR	Hydro-metamorphic dark-humus soils	T_dhHM
Luvisols	W_LV	Kashtanozems	T_KS

In general, the taxonomic distances between the Russian types are bigger than between the Soil Taxonomy GGs (Figure 1). Bigger distance between the groups indicates the difference between soil classes on a higher hierarchical level. Most probably, the level of the Russian soil types is somewhat higher than that of the Soil Taxonomy GGs. It is confirmed by the comparison of the number of taxa at the above-mentioned levels in two classifications: there are 344 GGs in Soil Taxonomy, and 227 types in Russia. It should be also noted that almost half of the soil types in Russian classification are “agrotypes” that cultivated analogues of natural soils.

The distance between the majority of RSGs and the main cloud of the GGs is also large. The best correlation to Soil Taxonomy GGs was shown by Russian steppe and dry-steppe soil types: clay-illuvial chernozems, chernozems, textural-carbonate chernozems and kashtanozems. This result can be explained by the fact that the USA (excluding Alaska) is a more southern country than Russia, so their classification system likely better describes the soils and soil properties found in their landscapes. The close correlation of textural-carbonate chernozems to Argiustolls may be a result of erroneous pedogenetic interpretation of the textural-carbonate chernozems in the Russian soil classification (Shishov et al., 2004): the cutans on the peds’ surfaces in the B horizon are referred in the text as clay coatings, while most probably they are stress-cutans.

Large distance between the northern Russian soils (grey soils, dark-grey soils and hydro-metamorphic dark-humus soils) and the main cloud of soils with mollic horizon reflects the fact that such objects are not covered by the US databases, though most probably these soils with dark topsoil would formally fall into the definition of a Mollisol. We believe that most contradictions between the two systems may be harmonized by extending the databases. Including data from the Canadian databases could change radically the correlation matrix.

The difference between a compact (vertic) soil and soils with a mollic horizon is due to a striking difference in their properties. It is recommended to keep Vertisols and even soils with vertic properties in another cluster.

In general, the WRB RSGs have smaller taxonomic distances to the Russian types and the relation between the two systems is easier to interpret in pedogenetic terms. To some extent the similarity of the results may be explained by the geographical proximity of the datasets because WISE database includes numerous soil profiles from Europe.

CONCLUSIONS

We successfully applied a centroid-based approach for taxonomic distance calculation among the black soils extracted from the databases in the Russian Classification System to two international classification systems Soil Taxonomy and World Reference Base. This method may be a helpful tool for understanding the genetic relations between soils and for detecting natural groups of soil taxa.

Most Chernozems and Chernozem-like soils had small taxonomic distances thus forming a distinct cluster. However, shallow soils (rendzinas) and soils with a hardpan stayed far from the main cluster. Also, most soils with clay illuviation features differed from the central concept of Chernozems. In the Russian classification, chernozem-like compact soils with the properties close to Vertisols strongly differed from the rest of the black soils cluster.

There is a distinct geographical bias in the taxonomic distances between the soils extracted from different databases. Russian database is in better agreement with the WISE database, which includes many profiles from Europe. The US database reflects the specific features of the environments and soils of the North American continent.

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REFERENCES

Batjes N.H. (2008). ISRIC-WISE Harmonized Global Soil Profile Dataset (Ver. 3.1). Report 2008/2. ISRIC - World Soil Information, Wageningen, The Netherlands.

Batjes N.H. (2009). Harmonized soil profile data for applications at global and continental scales: updates to the WISE database. In: Soil Use and Management. V. 25, 124–127.

Blum W.E.H. (2013). Soil and land resources for agricultural production: General trends and future scenarios-a worldwide perspective. In: International Soil and Water Conservation Research V. 1, Nr. 3, 1-14.

Dokuchaev V.V. (1967). Selected works of V.V. Dokuchaev, V. I – Russian Chernozem (Russkii chernozem). – Israel Program for Scientific Translations Ltd., Translated by N. Kaner, S. Monson, Jerusalem, 419 pp.

FAO (2015). Status of the World's Soil Resources (SWSR)–Main Report. – Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy, 650 pp.

FAO (2018). International network of Black Soils. URL: http://www.fao.org/global-soil-partnership/intergovernmental-technical-panel-soils/gsoc17-implementation/internationalnetworkblacksoils/it/ (consulted 08.11.2018)

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

Krasilnikov P., Sorokin A., Golozubov O., Bezuglova O. (2018). Managing chernozems for advancing SDGs. In: R.Lal, R. Horn & T. Kosaki (Eds.), Soil and Sustainable Development Goals. GeoEcology Essays, pp. 175–188. Catena-Schweizerbart Stuttgart.

Krupenikov I. A. (1993). History of soil science: from its inception to the present. – AA Balkema: Rotterdam. 350 pp.

Krupenikov I.A., Boincean B.P., Dent D. (2011). The black earth: ecological principles for sustainable agriculture on chernozem soils. Springer Science & Business Media. 146 p.

Lang V., Fuchs M., Waltner I., Micheli E. (2013). Soil taxonomic distance, a tool for correlation: As exemplified by the Hungarian Brown Forest soils and related WRB Reference Soil Groups. In: Geoderma. V. 192, 269-276.

Michéli, E., Láng, V., Owens, P. R., McBratney, A., Hempel, J. (2016). Testing the pedometric evaluation of taxonomic units on soil taxonomy—A step in advancing towards a universal soil classification system. In: Geoderma. V. 264, 340-349.

Shishov L.L., Tonkonogov V.D, Lebedeva I.I., Gerasimova M.I. (2004). Classification and diagnostic of Russian soils. Oykumena, Smolensk, Russian Federation (in Russian).

Soil Survey Staff (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition. Natural Resources Conservation Service.U.S. Department of Agriculture Handbook 436.