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A universal soil classification system from the perspective of the General Theory of Classification: a review

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Abstract. The paper addresses issues related to the application of the General Theory of Classification in the development of a universal soil classification system. The requirements for such a system, a comparison of different approaches to its development, and obstacles on the way to it are outlined. Additionally, the problem of the definition of soils and the importance of distinguishing between differentiating and diagnostic criteria are discussed. It is shown that, from the perspective of the General Theory of Classification, a universal soil classification system should be natural, genetic, "fundamental-and-specific", and hierarchical. It is concluded that the World Reference Base for Soil Resources (WRB) does not meet these requirements and therefore cannot be considered as universal. Ways of addressing the problems of a universal soil classification system are suggested.

Key words:
soil definition,
essential character of soils,
genetic classification,
morphological classification,
WRB

Introduction

There is an aspiration to develop a universal (global, world, basic, unified, international) and generally accepted soil classification system (hereinafter referred to as "UCS"). For example, Hartemink (2015) states that this is one of the most demanding tasks in soil science on which progress should be made. The development of UCS has occupied the minds of scientists as the subject of research studies, scientific publications, and conferences. However, there is no consensus yet on many issues concerning UCS, for example, its type and the definition of its objects. The following questions are usually debated in this regard: Should UCS be genetic or morphological; natural or artificial; fundamental or specific (purposeful); hierarchical or non-hierarchical? Could the choice and ranking of differentiating criteria of UCS be objective? Should there be only one UCS? Moreover, in some cases, the very need for, and possibility of UCS are also questioned. The paper seeks to find answers to these questions basing primarily on the General Theory of Classification (classiology), which is defined as "a science studying the principles and rules of classification of the objects of any nature" (Rozhkov 2012). However, primarily, the following question should be answered: What is the difference between classification, a classification system, and classifying, which are frequently confused? In this paper, in accordance with the General Theory of Classification, these terms shall have the meanings indicated: classification is the logical process, a classification system is the resultant product of classification, and classifying is the act of using the classification system (Prusinkiewicz 1985;

Rozova 1986; Arnold 2002; Hjørland 2017). At the same time, in the World Reference Base for Soil Resources (WRB), the term "classification" refers to allocation of soils to the correct class (IUSS Working Group WRB 2015) or, in other words, means "classifying". A similar approach is adopted in the recent Russian classification system (Shishov et al. 2004). It is also common to find confusion between classification and zoning and, as a result, between classification systems and map legends, in spite of the fact that they are different things (Subbotin 2001).

It should be stated that numerical (quantitative) classifications and classification systems based on statistical methods are not the subject of discussion in the paper because they are ad hoc and like-kind map legends and therefore cannot be considered as universal.

We begin with the requirements applicable to UCS.

Requirements applicable to UCS

From the perspective of the General Theory of Classification, USC should, above all, be scientific. This means that it should include all morphological types and varieties of the objects of classification and reflect their natural connections, evolutionary stages, and mutual transitions. Then, it should be genetic, natural, and mappable (Leont'ev 1956, quote according to Rozova 1986; Rozova 1986) and should not violate the rules for logical division of concepts (Sokal 1974; Armand 1975; Arnold 2002; Hjørland 2017). These rules are as follows:

(1) A classification system should have only one criterion of division at a time.
(2) A class at a lower level must not have limits that exceed those established by higher-level classes.
(3) A classification system should have mutually exclusive, non-overlapping, and jointly exhaustive classes.
(4) The division of concepts should be without spaces between logical steps.

If these rules are not fully followed then the classification system is logically flawed (Rozova 1986). An example of a violation of the first rule is the use as differentiating criteria parent materials because the division of soils in this case has to be carried out in accordance with a set of properties of parent materials at a time (such as their solidity, stoniness, calcareousness, texture, lithology, and others).

However, what is a genetic classification system?

Genetic versus morphological UCS

One has to agree that there have been two opposite approaches in soil classification: "genetic and morphological of which the morphological approach became dominant" (Hartemink 2015). For example, one of the most influential international systems, namely the WRB (Brevik et al. 2016), is properties-oriented (Gerasimova and Khitrov 2012), in other words, morphological. According to the General Theory of Classification, the division of objects in the case of genetic classification is based on the causes (main factors) of their formation and development, while in the case of morphological one it is based on their effects (Rozova 1986). Besides that, while morphological classifications aim to provide a fair description of objects (therefore these classifications are descriptive), a genetic one aims to forecast changes in these objects and to reveal their origin, making it possible to "know them in a deeper way than just to know about sets of their attributes" (Dupré 2006, quoted according to Hjørland 2017).

However, currently, by "genetic classifications" different scientists can mean different things (Rozova 1986; Krasilnikov et al. 2009). For example, it is widely thought that soil genesis can be reflected in classification systems either directly – through soil-forming factors (the causes of soil formation and development) – or indirectly – through diagnostic properties (the effects of soil formation and development). Smith (1983) justifies "the indirect reflection", saying that diagnostic horizons bring genesis into the definition of soil units since they result from soil genesis. An example of such an approach is a new system of Russian soils, which considers the soil-forming factors to be taken into account in a "hidden" form (through the diagnostic horizons and features) (Lebedeva and Gerasimova 2012). It should be noted that, in comparison with the "direct reflection" of soil genesis, the indirect one is generally regarded as more correct. It is con-

sidered that, as self-sufficient natural-historic bodies, soils should be classified as such (irrespectively of soil-forming factors), otherwise, instead of soils, the more general concepts (such as landscapes, geobiocoenosis, and ecosystems) would factually be the objects of classification (Sokolov 1978). As a result, soil classification systems based on grouping soil profiles as combinations of horizons are considered genetic (Krasilnikov et al. 2009). An example of such a classification system is the WRB.

The situation is complicated by the fact that, since soils also reflect the soil-forming conditions of the past, the dependence of soil properties on soil-forming factors is not linear (Phillips et al. 1996, quoted according to Krasilnikov et al. 2009). Additionally, ideas on soil genesis are thought not to be objective and therefore shaky as a basis for soil classifications (Nachtergaele et al. 2002). Nevertheless, some scientists speak out in favour of incorporation of soil genesis into soil classification (either through the soil-forming factors or through landscape features) (Smith 1983; Basher 1997). Cline (1962) explains this as follows, "if the classes are to have counterparts in mappable soil bodies consistently" then "it is necessary to incorporate the geographic relationships among pedons into the definitions of classes deliberately". Other scientists indicate deficiencies in both strictly morphological and strictly genetic approaches, which "have no chance to success" (Sokolov 1991).

In the General Theory of Classification, genetic classification systems are usually regarded as the most mature types of natural systems (Rozova 1986). However, what is a natural classification system?

Natural versus artificial UCS

Natural classification systems are usually contraposed to artificial ones. The following features distinguish these two types from each other:

- In natural systems, the objects are in an order according to their essential character (Robinson 1950, quote according to Muir 1962); artificial systems generally can be constructed based on any attribute (Abushenko 1998).
- Natural systems are designed to find an explanation for the reasons behind the similarities and differences between the objects that means to identify natural regularity (Subbotin 2001); artificial systems merely document the similarities and differences between the objects.
- Natural systems are based on a substantial theory; artificial ones have no clear statement of principles or theory. Therefore, natural systems are fundamental while artificial ones are empirical (Rozova 1986; Subbotin 2001; Hjørland 2017).
- Generally, natural systems are complex and multilevel while artificial ones are simple registers (Bar 1959, quote according to Rozova 1986).

It follows that the WRB is not a natural classification system since it does not have these characteristics.

The other debated questions on UCS are as follows: Could it be purely fundamental? Should it be aimed at practical purposes? What are the scientific and practical purposes of UCS? How many UCSs could be? These questions are connected with each other and are discussed in the following section.

Fundamental versus specific (purposeful) UCS

There are two main points of view regarding the purposes of UCS. One is that it should be specific (aimed at practical purposes) (Jones et al. 2005). Another is that, being a basis for specific systems (Rozova 1986), it should be fundamental, meaning created independently of potential use in practice (Fridland 1979). In accordance with the General Theory of Classification, in future, a joint "fundamental-and-specific" UCS could be created.

As distinct from specific classification systems, a fundamental one has scientific (theoretical) purposes, which are as follows:

- to harmonise the existing data on soils (Cline 1949; Arnold 2002; Hartemink 2015; Baruck et al. 2016) by developing a system of soil knowledge in order to compare and extrapolate these data (Harris 1960; Kiryushin 2011);

- to increase the understanding of origin and genesis of soils, their genetic relationships in space and time (Muir 1962; De Bakker 1970; Sokal 1974; Arnold 2002; Hartemink 2015; Baruck et al. 2016) and to thereby widen and deepen the knowledge of soils (Zonneveld 1959, quoted according to De Bakker 1970) and discover the laws of nature (Basinski 1959).
- to determine and reflect the main stages in the origin and development of soils (Kovda et al. 1967) and, on this basis, to develop the ability to predict their behaviour and responses to management and manipulation (Kellogg 1963; Arnold 2002).
- to express the paradigm of soil science and indicate the path towards its future development and progress (Rozova 1986; Ibáñez and Boixadera 2002; Kiryushin 2011);
- to facilitate the communication of soil information between scientists from different countries by providing a common scientific language (Avery 1965; De Bakker 1970; Hempel et al. 2013; Hartemink 2015; IUSS Working Group WRB 2015; Brevik et al. 2016).

It can be seen that the WRB cannot be termed "fundamental" since it does not have most of the purposes listed above.

With reference to the possible number of UCSs, it is thought that it could be large because of the large number of practical purposes aimed at application in agricultural or other technological uses of soils (De Bakker 1970). For example, Cline (1962) considers that "it is folly to think of one and only one multicategoric system as the classification to serve all ends; many are needed". This is also the opinion of Ibáñez and Boixadera (2002) who say, "the search of a comprehensive system of soil classification suitable to solve all current demands of soil information is a fantasy". On the other hand, it is argued that there should be only one UCS because it should provide a common language and, as a consequence, the integrity of soil science (Fridland 1986). The General Theory of Classification justifies the opinion that there should be one UCS and justifies this with the fact that our world is one as well (Rozova 1986; Pokrovsky 2014).

The following question also need to be answered is: How should UCS be structured?

Hierarchical versus non-hierarchical UCS

There are two main methods for developing classification systems:

(1) analytic or descending (hierarchical and usually genetic) starting from general facts and principles and going down to increasingly detailed categories;

(2) synthetic or ascending (bottom-up) and relying on morphological characteristics chosen with or without pedogenetic considerations or various other characteristics chosen without genetic considerations (Manil 1959; Arnold 2002).

One often raised question concerns the need for UCS to have a hierarchical structure (Rozova 1986). For example, hierarchical systems are questioned for complicating rather than assisting the task of soil correlators (Nachtergaele et al. 2002) as well as for being "subjective, expert-dependent structures, which facilitate the search and recall of objects within the system rather than being a reflection of any real organization of entities into natural groups" (see Krasilnikov et al. 2009). On the other hand, various points are raised in favour of a hierarchical structure for UCS. For example, it is considered that "hierarchical structures optimize the flow of information" (Ibáñez and Boixadera 2002) and may help "to more holistically combine soil formation factors with soil geography and pattern" (Miller and Schaetzl 2016) while systems without hierarchy lead to pedological anarchy (Eswaran, personal communication 2001, quoted according to Nachtergaele et al. 2002).

The WRB is being developed as a non-hierarchical system.

As has been noted above (in the section "Genetic versus morphological UCS"), in accordance with the General Theory of Classification, UCS should be genetic and reflect cause-and-effect relationships. However, from our point of view, this cannot be done without distinguishing between differentiating and diagnostic criteria.

Differentiating and diagnostics criteria of UCS

Differentiating criteria are the most important elements of classification systems in determining the systems' other elements and features, as well as how successfully they will be developed and function (Rozova 1986; Subbotin 2001; Hjørland 2017). Differentiating criteria are essential (internal) properties of the objects of classification (Muir 1962; Rozova 1986) used for the subdividing of these objects, while diagnostic ones are the most vivid (external), often the most superficial and, on a large scale, morphological properties of the objects used for their identification (Rozova 1986; Bezuglova 2009).

Substitution of differentiating criteria for diagnostic ones when functions of diagnostics are attributed to differentiating criteria (Rozova 1986) occurs frequently (see Avery 1973; IUSS Working Group WRB 2015; Baruck et al. 2016). In the event of substitution, characteristics of division are represented by morphological but not genetic properties of the objects because there is a perception that "we should classify soils by the measurable attributes and not on the basis of our doubtful ideas on soil genesis" (see Krasilnikov et al. 2010). In the WRB there is also a substitution of differentiating criteria for diagnostic ones. This is evidenced by the fact that one of its main principles sounds as follows: "For the classification, only the diagnostic criteria are relevant" (IUSS Working Group WRB 2015). However, in accordance with the General Theory of Classification, the substitution of differentiating criteria for diagnostic ones in genetic classification systems should not be allowed (Rozova 1986).

Another problem concerning characteristics of division is their choice and ranking. The question which is rather frequently asked in this regard is whether this choice and ranking could be objective (Nachtergaele et al. 2002).

However, what are the obstacles to a single UCS?

Obstacles to UCS

In accordance with Rozova (1986), the number-one obstacle to UCS is a lack of understanding of what classification is and how it differs from classifying and zoning. It is stressed that classification cannot be defined just as a subdividing of the objects into subgroups; the latter must be logical while subgroups must be subordinated (Rozova 1986). Within this framework, the following definition of classification is suggested: "Classification divides a universe of entities into an arbitrary system of mutually exclusive and nonoverlapping classes that are arranged within the conceptual context established by a set of established principles" (Hjørland 2017). In soil science the conceptual context (or theoretical basis) of UCS is currently absent and this represents another significant obstacle (Rozova 1986).

It is considered that the problem of UCS is particularly difficult in soil science because, being the results of the interaction of many soil-forming factors, soils are extremely complex, not strongly visible and tangible natural formations, highly structured and polyfunctional entities. Additionally, they have a continuum and dynamic nature (Basinski 1959; Ibáñez and Boixadera 2002; Kiryushin 2011), which also makes solutions to the problem difficult to achieve (Hjørland 2017). However, in accordance with the General Theory of Classification, all this does not deny the possibility of the creation of UCS (Rozova 1986; Subbotin 2001).

Among other obstacles, the clog of traditions and habits and certain ambitions of national schools of pedology are sometimes mentioned (Krasilnikov et al. 2010).

Now, there is one final matter to discuss, namely, what are the ways of addressing the problem of UCS and what do we have to offer?

The problem of a soil definition as a basis for UCS

It is recognised that any UCS is unthinkable without a precise definition of its objects that reflects their essential character (Robinson 1950, quote according to Muir 1962; Schelling 1970; Ibáñez and Boixadera 2002; Bezuglova 2009). Therefore, before everything else, it is necessary to give such a definition of soils because it is still lacking. On this subject, Ibáñez and Boixadera (2002) note that "since

1883, when Dokuchaev put forward that the soil is a natural body, there has hardly been any enrichment to its definition, only to its form" and "this is probably one of the reasons for the stagnation of our discipline". Nevertheless, new attempts to define soils continue and that proves the importance and complexity of the problem.

In his recent study, Hartemink (2015) analyses 81 definitions of soils and, by way of conclusion, suggests his own. This definition should be presented fully in order to understand its shortcomings as the basis of UCS as well as the shortcomings of the other similar definitions. It is as follows:

The soil is a living, four-dimensional natural entity containing solids, water (or ice) and air. Most soils are outside and are open systems, but soils also occur in shallow lakes and underneath pavement. A soil can have any color, any age, be very shallow or deep, and consists mostly of a structured mixture of sand, silt and clay (inorganics), rocks and organic material (dead and alive). The soil has one or more genetic horizons, is an intrinsic part of the landscape, and changes over time. Soil are distributed across the earth mostly in a systematic manner. Soils store and transform energy and matter. The soil often supports vegetation, carries all terrestrial life, and produces most of our food. It is an integral part of the natural world interacting with the climate, lithosphere and hydrosphere. Soils are often studied in combination with land-use, climate, geomorphology or the hydrology of an area.

In this definition soil is recognised as a dynamic open system which consists of elements (solids, water, air, and organic material), and is simultaneously an element of a system (soil is "an intrinsic part of the landscape"). This is in line with the General Systems Theory (open system) approach (Von Bertalanffy 1968) (hereinafter referred to as "the systems approach"), which involves studying objects as systems and as elements of systems; and this is its great advantage. However, in this definition the essential character of soils as being systems and simultaneously elements of landscape systems are mixed with the diagnostic properties of soils, which should be left outside and used for classifying (identification) of soils. Additionally, it is hard to admit some mentioned soil properties as being diagnostic ("any color, any age, be very shallow or deep") because they could also be properties of the other natural bodies. Then, from the perspective of the systems approach, one can also not accept that soils occurring under pavement can be considered as landscape elements because they practically do not interact with the other elements of landscapes (such as air and water).

If we look at the definition of soils given in the WRB from the perspective of the General Theory of Classification and the systems approach, we will reveal even more shortcomings. Therefore, this definition can also not be used for the development of UCS. It is as follows:

The object classified in the WRB is: any material within 2 m of the Earth's surface that is in contact with the atmosphere, excluding living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m. If explicitly stated, the object classified in the WRB includes layers deeper than 2 m (IUSS Working Group WRB 2015).

In view of the foregoing, the following questions arose: Why is the definition given by Dokuchaev not working and therefore not suiting the scientific community? Moreover, is there anything incorrect in it? To answer these questions, consider two versions of this definition. A well-known version in everyday use is the following: soils are natural historical bodies and surface mineral-organic composite formations that developed because of joint activities of the following factors: living and dead organisms, parent rocks, climate, and terrain topography (Dokuchaev 1879). Much more rarely another version is used, which sounds as follows: being natural historical bodies, soils are "those daily or outward horizons of rocks […] which are more or less changed naturally by the common effect of water, air and various kinds of living and dead organisms" (Dokuchaev 1886). From a comparison of these versions, it can be seen that in both of them soils are recognised as natural, historical bodies. Then, it is also noteworthy that in both versions there are no diagnostic properties of soils. On the other hand, in the first version soils are also recognised as the results of the interaction of the soil-forming factors (namely, organisms, parent rocks, climate, and terrain topography) but as results of the interaction of landscape elements (namely, organisms, parent rocks, water, and air) in the second. One can conclude that, as distinct from the first version, the sec-

ond is in line with the systems approach. In this regard, Karpachevsky (1981) expresses the following view:

An analysis of the soil definition given by V.V. Dokuchaev shows that although the soil is an especial natural body … it always should be considered as a subsystem of the other natural systems. There is no soil out of these systems. This provision, explicitly or implicitly, normally provides the foundation of all scientific researches of soils.

However, currently the essential character of natural soils as derived elements of natural landscape systems is either not taken into account or applied inconsistently and incorrectly.

Our experience shows that if we want to develop UCS then we must use the second version of the definition given by Dokuchaev, but after revision in accordance with the terminology of the systems approach. In other words, we suggest getting back to basics. The revised definition might sound as follows: soils are open geographical self-sufficient material systems and, at the same time, elements of the higher order systems that are natural landscapes (Nikiforova et al. 2014). In addition, soils are unique (derived) landscape elements (Mamay 2005) because they are the only elements that originate from the interaction of the other (basic) landscape elements – parent materials (including peats and buried soils), air, water, and organisms. We have used this definition as the basis for the development of the scheme of the hierarchical natural soil-landscape classification system that represents a combination of soil and landscape classification systems at a time and, from our point of view, meets the requirements for UCS. In some detail, this classification system will be described in the forthcoming publication.

Conclusions

The main result of this research is the formation of an idea about UCS from the perspective of the General Theory of Classification. As can be seen, UCS should be genetic, natural, fundamental, and hierarchical. It should also have both differentiating and diagnostics criteria and be based on a "system" soil definition (in other words, on a definition given from the perspective of the systems approach). As for WRB, a cursory review has shown that it cannot be termed as a universal because it does not meet the requirements for UCS being morphological, artificial, not fundamental, non-hierarchical, and having diagnostics criteria instead of differentiating ones. In addition, it is based on the definition of soils that does not reflect their essential character.

To summarise, the main ways of addressing the problem of UCS in soil science are as follows:

- Development of UCS should be based on the integration of soil and landscape sciences and philosophy.
- UCS should have a strong theoretical basis developed using the General Theory of Classification and the systems approach.
- UCS should be based on the system definition of soils reflecting their essential character.
- Differentiating and diagnostics criteria should be distinguished in UCS.
- The rules of the objective choice and ranking of the differentiating criteria should be specified.

The implementation of these tasks could address a weakness of the current soil classification systems, in which soils are considered primarily as self-sufficient systems but not as elements of systems, and in which the effects but not the causes of soil development are focused on.

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