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Soil-forming factors and *Soil Taxonomy*

J.G. Bockheim [a,*], A.N. Gennadiyev [b], A.E. Hartemink [a], E.C. Brevik [c]

[a] University of Wisconsin, Department of Soil Science, 1525 Observatory Drive, Madison, WI 53706, USA
[b] Faculty of Geography, Moscow State University, Moscow, Russia
[c] Department of Natural Sciences, Dickinson State University, Dickinson, ND 58601, USA

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ABSTRACT

Here we analyze the past and present roles of the five soil-forming factors in USDA *Soil Taxonomy*. As opposed to the 7th Approximation of 1960, the factorial and genetic approach is clearly present in *Soil Taxonomy*. Soil climate is the most important factor in *Soil Taxonomy*. It is used at the highest level to define two of the 12 soil orders: Aridisols, the soils of the dry regions, and Gelisols, the permafrost-affected soils. Climate is also used to differentiate suborders in eight of the remaining orders. Parent material is used to fully define two orders: Histosols and Andisols, and partially to define the suborders in the Entisol order (Fluvents, Psamments). Only one group of organisms, the worms (Verm-), is used at the great-group and subgroup levels in several orders. Relief and time are not used in defining taxa in *Soil Taxonomy*. Three of the eight epipedons are defined on the basis of parent material (folistic, histic, melanic), two from human activities (anthropic and plaggen), and two from the interaction of climate and vegetation (mollic and umbric). Of the 19 subsurface horizons, 11 originate from the interaction of climate and parent material. There is an imbalance in the utilization of the soil-forming factors in *Soil Taxonomy*.

1. Introduction

Dokuchaev postulated in 1886 that the soil is always and everywhere a function of parent rock, the climate, the vegetation, the age of the terrain, and the terrain topography Dokuchaev, 1883. This was widely discussed between 1927 and 1935 at the first and third International Congresses of Soil Science (e.g., Crowther, 1930; Joel, 1927; Mitchell and Muir, 1935; Nikiforoff, 1935; Rice, 1927). These relationships seemed to get particular attention at the second International Congress of Soil Science held in Leningrad, Russia in 1930, with a section consisting of 22 papers focusing on soil genesis and the influence of the various soil forming factors (Prassolov and Vfleruky, 1930; Shaw, 1930). The factors were recognized as interacting and changing over time.

Jenny (1941) formalized the factors and did not see the factors as formers, creators or forces, but as state factors that define the state of the soil system (Hoosbeek and Bryant, 1994). It became clear that the soil-forming formula was not easily solved from a mathematical perspective (Kline, 1973; Phillips, 1998; Stephens, 1947), but the soil-forming factors have provided a strong framework for our thinking and approaches and have dominated soil genesis research since they were postulated. Overall, the soil-forming factor equation has become a popular concept in pedology (Bockheim et al., 2005).

The soil-forming factors have also influenced the development of soil classification systems, although differently in various countries. Krasilnikov et al. (2009) provided an excellent overview of over 25 national soil classification systems. Some of the systems rely on processes, but most systems use soil properties, morphology and features to group different soils. The diagnostics are mostly quantitative and based on a combination of horizons, soil properties and materials. Most soil classification systems group according to genesis of the soil.

Early soil classification systems in the USA by Marbut (1935) and Baldwin et al. (1938) took into account the factors of soil formation. However, there was widespread concern about their usefulness, and in 1949 the initial work on the development of *Soil Taxonomy* started. There were seven approximations before the first edition of *Soil Taxonomy* was launched in 1975 (Soil Survey Staff, 1975); the second edition was published in 1999 (Soil Survey Staff, 1999). *Soil Taxonomy* is a detailed categorical system that has defined quantitative boundary values for each unit at each level. The system was designed to be of assistance to the preparation of soil surveys which includes both the mapping and the interpretation of map units. The rationale for the system has been well explained (Forbes, 1986) but also criticized (e.g. Sombroek, 1985; Webster, 1960). *Soil Taxonomy* is a mature system that is widely used in the USA and dozens of other countries (Krasilnikov and Arnold, 2009). The soil-forming factors are largely hidden in *Soil Taxonomy*.

The objectives of this paper are to: (i) analyze how the soil-forming factors were used in USA soil classification systems and (ii) to unravel the presence and importance of soil-forming factors in *Soil Taxonomy*, and (iii) to suggest some implications for future classification systems. There is renewed interest in soil classification systems (Hempel et al.,

* Corresponding author.
E-mail address: bockheim@wisc.edu (J.G. Bockheim).

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2013) and this paper aims to contribute to advance ideas and concepts for existing and new soil classification systems.

2. History of soil-forming factors in the USA soil classification systems (1900–1975)

The first attempts at soil classification in the USA were made in the late 19th and early 20th centuries. Detailed study of glacial and periglacial deposits and the progress in agronomy and technology played an essential role in the development of the first USA soil-classification systems. Buol et al. (2011) identified this first period as the "technical" period, which was a time of collecting data on physiography, geomorphology, and composition of sedimentary deposits.

The main goal of the first USA soil classification was to support soil surveys. These were started at the national level in 1899 and were based on Whitney's (1909) three-tiered system. The upper tier was geomorphological provinces (major soil provinces); soil series represented the second level, and soil types were the lower level. Weathering as part of soil formation was taken into account to distinguish different soils. Soil types were divided on the basis of particle-size distribution and were "characterized by unity from standpoint of agricultural production, adaptation to the same crops and requiring the same treatment" (Whitney, 1909). The criteria for distinguishing soil series were chiefly their textural properties and lithological features. One of the first soil series, the Miami, which appeared on USA maps in 1900, described soils as "representing sandy, or gravelly, or clay loams, having a surface horizon from light yellowish-cinnamon brown to black in color, well, moderately, or poorly drained and forming on morainal or alluvial deposits." Whitney (1909) recognized 260 soil series. In the course of new soil surveys, these broad combinations of different soils (similar to the Miami series) were converted into many independent series. At present there are approximately 23,000 soil series in the USA.

The necessity of systematizing the growing number of soil series was one of the reasons why Marbut (1928) and Baldwin et al. (1938) decided to use the Russian approach to soil classification. This approach was founded by V.V. Dokuchaev and further developed by Glinka (1927), Prassolov (1931), Ivanova (1956), and Gerasimov and Glazovskaya (1960). The Russian concepts of soil classification were transferred to the USA in the 1920–30s (Paton and Humphreys, 2007; Simonson, 1989). The USA soil classification systems of the 1930s and 1940s were derived from factor-genetic principles and concepts of zonality (zonal, intrazonal, and azonal soils were distinguished at higher levels). The Russian approach was used including landscape features, color, and folk names in naming soils at the second and third levels (Podzols, Chernozems, etc.) and introducing taxonomic units, such as great soil groups (comparable Russian genetic soil types).

The development of zonal or factorial ideology of soil classification reached its maximum in Russia in the 1940s to 1950s. Zonal genetic soil types were central to the system. World groups of classes of soil formation were distinguished according to the geographic belts, and soils were divided into automorphic, hydromorphic and semihydromorphic groups (Ivanova, 1956). The Russian soil-factorial concept was used in USA pedology through the 1950s. However, it was found that the USA soil series were incompatible with the system of great soil groups introduced from Russia. For example, Marbut (1928) found that it was not possible to distribute all of the soil series among the great-soil groups which had a definite conceptual factorial framework. There were no clear quantitative criteria for the great-soil groups. Therefore, as Cline (1963) and Smith (Forbes, 1986) acknowledged, there were two conceptually independent soil-classification systems in the USA during the 1920s to 1950s. One was based on the quantitative soil properties of soil series, while other relied on conceptual descriptions at higher taxonomic groups distinguished on the basis of genesis and factors of soil formation (Gennadiyev et al., 1995).

In the mid-1940s, C. Kellogg, director of the USDA Soil Conservation Service, set about to improve the definition of the great-soil groups and develop a set of quantitative criteria. Several working committees on great-soil groups were established. However, this was not successful because they did not find formal substantive parameters for distinguishing zonal soils from azonal and intrazonal soils. Gradually, these activities resulted in a fundamental revision of the basic principles for distinguishing taxa at higher taxonomic levels. An entirely new approach to soil classification began.

The "7th Approximation," which appeared in 1960 (Soil Survey Staff, 1960), was essentially a conceptual change to the factorial-genetic concepts that dominated USA soil classification during the 1920s to 1950s. The primary goal of the system was to quantify the requirements for orders, suborders, great soil groups, and subgroups and to allocate the many thousands of soil series and families among the higher taxa. The differentiae used among the orders were developed by generalizing soil properties that seemed to differ little in the type and effect of processes that tend to develop soil horizons (Soil Survey Staff, 1960). However, it was also recognized that the criteria for the orders tended to give a broad climatic grouping of soils.

The 7th Approximation was modified and published in 1975 as *Soil Taxonomy: a Basic System of Soil Classification for Making and Interpreting Soil Surveys*. There are distinct differences between *Soil Taxonomy* and the 7th Approximation in terms of the use of the factorial and genetic characteristics of soils (Gennadiyev and Gerasimova, 1980). There was a subtle return to the factorial-genetic approach of soil classification. In both the 7th Approximation and *Soil Taxonomy*, soil orders are distinguished mainly on the presence or absence of one or more diagnostic horizons in the soil profile. Whereas soil properties are emphasized in the systematic description of soil orders, their genetic nature is revealed only indirectly via the diagnostic horizons. Differences between the 7th Approximation and *Soil Taxonomy* are reflected in the sections that precede chapters with a detailed description of each soil order. Table 1 compares the views on soil orders in the 7th Approximation and *Soil Taxonomy* at the beginning of each of the ten soil orders. It suggests a return of *Soil Taxonomy* to the genetic approach, which contrasts with the approach in the 7th Approximation. The use of concepts associated with soil processes and factors was limited in the 7th Approximation, and soil genesis was on a "thoroughly hidden basis of order in the system" (Cline, 1963).

This trend becomes more obvious when we compare the suborders of soils in the two versions of the classification (Table 2). The number of soil-climatic (factorial) formative elements in the names of *Soil Taxonomy* suborders is greater than in the 7th Approximation. The proportion of "factorial" suborders also increases. All the suborders within the Alfisols are distinguished exclusively according to the soil climate. They include Alfisols with signs of gleying (Aqualfs), Alfisols with a low-temperature regime (Cryalfs), and Alfisols with moist (Udalfs), intermittently dry (Ustalfs), and dry summer/moist winter (Xeralfs) soil climates. This trend is even more distinct at the great soil group level. Whereas only 11 out of 105 great-soil groups (10%) had a soil-climatic formative element in their names in the 7th Approximation (cry-, therm-, ust-), 61 out of 230 great-soil groups (27%) had this feature in *Soil Taxonomy* (cry-, med-, torr-, trop-, ud-, ust-, xer-).

Soil temperature and moisture regimes in the 7th Approximation were only partially discussed and occupied less space in the chapter on "Horizons and properties of diagnostics significance" than the description of any of the diagnostic horizons. It can be concluded that a third-level role was ascribed to factorial criteria in the 7th Approximation.

In *Soil Taxonomy* more emphasis is given to soil temperature and moisture regimes and their role in soil-forming processes than in the 7th Approximation. In the 1975 section of *Soil Taxonomy* dealing with temperature and moisture regimes, it is mentioned that, owing to the absence of direct and reliable data on the regimes, use was made of some general climatic information over a 30-year period of standard observations, such as mean air temperature, annual precipitation, and evapotranspiration. The relation between the curves and subtending areas of graphic representations of the soil-moisture regimes made it