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Beinroth,F.H.

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Some Considerations on Soil Classification in general, and "Soil Taxonomy" in particular

F. H. Beinroth

College of Agricultural Sciences
University of Puerto Rico
Mayaguez, Puerto Rico

Introduction

The recognition of soils as independent natural bodies possessing various kinds and degrees of internal organization expressed in the soil profile provided the first model for the scientific study of soils proper. Moreover, this theory, developed some hundred years ago in Russia under the leadership of V. V. Dokuchaev, marks the most fundamental change in the concept of soil and subsequently led to the establishment of soil science as a separate discipline. As most scientific models, the Russian concept underwent considerable changes with time in reflection of advances in soil geomorphology, soil chemistry, soil physics, soil mineralogy, and soil biology. A further significant change has occurred in the quantitative aspects of the model. As a consequence, the present concept is more nearly a quantitative representation of our knowledge since most soil properties can now be characterized in terms that have quantitative meaning at some level of precision (Cline, 1961).

This has had great impact on the development of soil science. For as Lord Kelvin has pointed out, "...when you cannot measure what you are speaking about, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind;... scarcely advanced to the stage of science...".

Since soils then are objects whose inherent properties can be quantified in terms of defined criteria, they may also be classified on the basis of these characteristics, and many systems of soil classification have been proposed in recent years. Yet, all are subject to criticism because they are circumscribed by the current understanding of soils. As this knowledge is still incomplete, most systems of soil classification contain a certain amount of speculative logic. Consequently, soils as they occur in nature may not in all instances conform to the theories and schemes propounded by pedologists. As Bertrand Rusell has put it, "nature herself cannot err, because she makes no statements. It is men who may fall into error when they formulate propositions".

The purpose of the present paper is to examine some of the underlying rationales of soil classification and to discuss some aspects of the official U. S. system, Soil Taxonomy.

Basic Rationales of Soil Classification

In most existing systems of soil classification there is the basic assumption that there are individual soils, just as there are individual

animals and plants. The aggregate of an almost infinite number of these individuals constitutes the soils of the world. Whereas former concepts would regard the pedosphere not as a universe of individuals but as a kind of continuum varying from place to place in reflection of changing soil-forming conditions, the present view considers soil as a "collection of bodies" (Soil Survey Staff, 1960). Cline (1961) pointed out that "the perspective in which we view our model has changed from one in which the whole is emphasized and its parts are loosely defined and indistinct to one in which the parts are sharply in focus and the whole is an organized collection of parts." This implies that there are small, discrete units which can be treated as a population.

Although the individual is the smallest entity one may call "a soil", it would be impractical to deal with all of these units in any system of soil classification. However, these individual pedons are the sampling units used to define the lowest category of most soil classification systems, the soil series. Thus, soil pedons are the only things existent in reality that can be measured and analyzed, whereas the categories of soil classification systems are conceptional abstractions of these particulars made at different levels of generalization.

Parenthetically it may be noted that this kind of reasoning conforms to the theories of Realism, originally postulated by Plato and later moderated by Aristotle, according to which universals exist and are implicit in particular instances. On the rationale that categories of soil classification

may not exist independently of our mental constructions, Robinson (1949) prefers to regard these categories as "constructed universals" following the philosophy of the Representationists.

It is of interest in this context to consider Kant's (1781) ideas concerning knowledge and experience as advanced in his Critique of Pure Reason. On the assumption that experience is necessary but not sufficient for knowledge, he set out to explain experience in terms of concepts rather than vice versa. Knowledge which is in principle independent of experience is termed " a priori" and whatever derives from experience is described as "a posteriori". Both of these concepts have been used in developing systems of soil classification (Manil, 1959). In a priori or descending systems, the higher categories are conceived in consideration of hypotheses and principles of generally pedogenetic nature and more detailed categories are added as observation proceeds. Many of the soil classification systems developed in Europe are examples of this kind. Although such systems are the only possible ones when no large amount of accurate data are available, they have the inherent defect of all preestablished schemes used to accommodate factual knowledge. Bridgeman (1927) has pointed out that the scientist "recognizes no a priori principles which determine or limit the possibilities of new experience". --The second method of elaboration is a posteriori or ascending and here the reasoning is from facts to concepts. This approach requires, of course, a great amount of data about recognizable bodies of soil, especially those identified as soil series. The

U. S. Soil Taxonomy is essentially of this type. It should be stressed, however, that the organization of categories and classes are direct consequences of the theory in our current model (Cline, 1961).

Kinds of soil classifications and their purposes

Cline (1949) has stated the "the purpose of any classification is so to organize our knowledge that the properties of objects may be remembered and their relationships may be understood most easily for a specific objective". It is implicit in this statement that there are as many systems of soil classification conceivable as there are objectives for grouping soils. Each of these systems may be the "best" for the particular purpose for which is was designed. Yet, as the things important for one objective are seldom important for another, a single system will rarely serve two objectives equally well (Cline, 1949). For example, a system developed for classifying soils on the basis of their suitability as bauxite ore will not be very useful for determining the site-index for loblolly pine. Such systems which may be constructed for a great variety of technical purposes or soil uses have been called "technical" classifications by J. S. Mill (1925).

These kinds of systems which are limited by the special bias dictated by their purpose are opposed to "natural" or "taxonomic" classifications where the objective is to show relationships in the greatest number and most important properties without reference to a specific

practical purpose (Cline 1949). A taxonomic classification recognizes that soils have many properties, some of which are associated in an apparently causal relationship. These attributes of the population are considered and those which have the greatest number of covariant or accesory characteristics are selected to define and separate the various classes and categories (Mill, 1925). To quote Cline (1949) again, "the natural classification, therefore, performs the extremely important function of organizing, naming, and defining the classes that are the basic units used (a) to identify the sample individuals that are the objects of research, (b) to organize the data of research for discovering relationships within the population, (c) to formulate generalizations about the population from these relationships, and (d) to apply these generalizations to specific cases that have not been studied directly".

The U.S. Soil Taxonomy, discussed in more detail below, is an attemp at a comprehensive natural classification of soils. As will be shown, there is, however, a clear tendency to give more weight to properties of agricultural relevance, particularly at lower categoric levels.

Soil Taxonomy

The U. S. system of soil classification, Soil Taxonomy, represents the most advanced effort to tackle the three main problems encountered in contriving a taxonomic system. These are the selection of differentiating

criteria, the definition of classes and their grouping in categories, and the nomenclature of taxa.

In recognition of the real need for an entirely new system, Soil Taxonomy has been developed over the past 20 years in the Soil Conservation Service of the USDA under the leadership of G. D. Smith with cooperation of soil scientists of U.S. universities and certain pedologists from other countries. The system went through a series of approximations of which the "7th Approximation" was published in 1960 (Soil Survey Staff, 1960). After substancial revisions it is now in press and will be available in the near future as a book entitled "Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys".

In developing the basic rationales of the system its authors were influenced by Bridgeman's "Logic of Modern Physics" (Bridgeman, 1927). They also drew on Western European experience, particularly on the definitions of concepts basic to the French classification (Smith, 1965). More than 70 years of soil survey provided the detailed information without which the development of the system would have been impossible.

Like most taxonomic systems, Soil Taxonomy is a multi-categoric system. Each category is an aggregate of taxa, defined at about the same level of abstraction, with the smallest number of classes in the highest category and the largest number in the lowest category. In order of decreasing rank these categories are: order, suborder, great group, subgroup, family, and series.

Applying concepts of pedogenic processes, orders, suborders and great groups are differentiated on the basis of the presence or absence of a variety of combinations of diagnostic horizons and soil properties. Three levels of such sets are employed in the three highest categories, each set of properties marking pedogenic processes that operate within the sets characterizing the higher category or categories. Examples of differentiae used at the order level are diagnostic horizons, such as the oxic and spodic horizons or the mollic epipedon. Soil moisture regime and extreme chemical or mineralogical properties like the presence of large amounts of allophane are examples of criteria for differentiating suborders. Properties that appear to be superimposed on the diagnostic features of the orders and suborders, such as various kinds of pans or the presence of plinthite, are used to differentiate great groups.

Subgroups are subdivisions of great groups representing either the central concept of the category, intergrades to other groups, or extragrades which have additional aberrant properties. Families and series are distinguished on the basis of properties selected to create taxa that are successively more homogeneous for practical uses of soils. Thus, families attempt t o provide classes having relative homogeneity in properties important to the growth of plants, and series are subdivisions of families intended to give the greatest homogeneity of properties with the genetic soil or the rooting zone, consistent with the occurrence of mappable areas at scales of detailed soil surveys.

On the rationale that the same processes operate in most soils, though at widely different rates and intensities, the classification of tropical soils in Soil Taxonomy is consistent with that of other orders. Soils of tropical areas are differentiated by their soil temperature regime, and importance is given to the degree of continuity of biologic activity: Soils of the humid tropics are distinguished at high categoric levels, order, suborder or great groups. With few exceptions, e.g. Torrox and Torrerts, soils of arid and semi-arid tropical regions are differentiated at the family level because seasonal lack of soil moisture is not unique to the tropics (Smith, 1965).

Evidently, the classes of Soil Taxonomy have been formed in consideration of concepts of pedogenic processes. However, as these causes are not fit as diagnostic criteria, some of their more prominent effects were selected as differentiae. Insofar as possible properties that are the result of soil genesis were chosen as differentiae because such properties carry the maximum number of accesory properties and have geographic implications of susceptibility to mapping. As a basic principle, these differentiae are soil properties and there are defined operations to identify them (Smith, 1965). The Soil Survey Manual and the Soil Survey Laboratory Methods (Soil Survey Staff, 1951 and 1967) provide the definitions and procedures essential for these operations.

The nomenclature of Soil Taxonomy marks a complete departure from past practice. It was not conceived to mystify the outsider as

some might think, but because the old names were ambiguous, of diverse linguistic provenance, difficult to re-define and generally unsuited for use in systematic taxonomy. Therefore, new names were coined, largely from Greek and Latin roots, that fit any modern European language without translation. The name of each taxon clearly indicates the place of the taxon in the system and connotes some of its most important properties.

Soil Taxonomy is the official system of the National Cooperative Soil Survey of the U.S., but it is also used in some other countries, particularly in South America (Costa de Lemos, 1971). Of the numerous classifications used in tropical areas, Soil Taxonomy is among the most important ones (Aubert and Tavernier, 1972). Although it has not met with unanimous acceptance outside the U.S., Soil Taxonomy is likely to be adopted as a system of reference for international communication, especially in technical papers.

Special Considerations Regarding Soil Taxonomy

a) Dependence on the state of knowledge

Soil Taxonomy is not a "zero-defect-system". It is an organized abstract of current knowledge of soils and of concepts derived from this knowledge and can, therefore, be no better than the state of that knowledge. Yet, our knowledge of soils is still sketchy and this is especially true for many soils of the tropics, particularly Oxisols. As a result, the classification of Oxisols has been based on a limited amount of factual

data, hence has lagged behind that of other orders of mineral soils, and is certain to have many shortcomings (Soil Conservation Staff, 1973). However, the Soil Conservation Service is now beginning to direct efforts toward more meaningful methods of assessing organic soil materials and toward characterization of relevant properties of tropical soils (Flach, 1973). In all probability this will lead to additional differentiae for classifying Oxisols and will entail future changes in the present system.

b) Genetic bias and its implications

The definition of criteria, classes and categories of Soil Taxonomy are factual and leave no scope for subjective speculation. However, the guiding rationales underlying the development of the framework of Soil Taxonomy are provided by concepts of soil genesis. This is reflected in the choice of differentiae and class limits. As many pedogenetically significant processes take place in the subsoil, criteria relating to subsoil properties tend to be used more frequently as differentiae than those relating to surface soil properties. Even a casual analysis of the Key to Soil Taxonomy reveals that diagnostic subsoil properties commonly take precedence over surface soil criteria. This controls the kind and amount of information which a taxon contains by virtue of its definition. With few exceptions, a greater amount of quantitative statements can be made about the subsoil than the surface soil. However, because the criteria of Soil Taxonomy have many

covariant properties and accessory characteristics, qualitative inferences of reasonable accuracy can be made about the surface soil.

There are, of course, compelling reasons to place comparatively more weight on subsoil properties in a taxonomic system: In cultivated soils, the surface is also the main management zone and as such affected by frequent changes as regards physical and chemical properties. If these properties were selected as differentiae, the classification of cultivated soils would also be subject to change with equal frequency.

c) Aspects related to crop production

In view of the fact that a considerable portion of the root zone of annual crops coincides with the surface soil, the greater importance assigned to subsoil properties signals certain limitations of Soil Taxonomy regarding its validity for agricultural interpretations. Although the system provides, at the family level, for criteria explicitly selected to reflect conditions important to plant growth--texture, mineralogy and temperature--these differentiae are also applied to the subsoil. The control section for the determination of both the particle-size and mineralogy classes starts below the A-horizon, and soil temperature regimes are usually measured at 50 cm depth.

This would constitute a serious defect of Soil Taxonomy if it were to be a technical system for crop production. Since it is a natural classification, this merely points to the inherent limitations of any taxonomic system when used for a specific purpose.

Recently a technical system of soil classification has been developed by Buol et al. (1974) which has been designed for the expressed purpose of grouping soils on the basis of similar fertility properties. This system recognizes the need to place greater emphasis on the nature of the plow layer. The criteria used in this scheme are to a considerable degree identical to differentiae employed in Soil Taxonomy, but some are new. Buol's system may therefore with some justification be considered a derivative of Soil Taxonomy, interpreted and restructured for the specific purpose of fertility evaluation. The system, although incomplete at this time, represents a promising approach and the testing it is now undergoing may well demonstrate its value.

d) Applicability in the process of transfer of agrotechnology in the tropics

In reflection of growing government interest in natural resources, many tropical countries are engaged in active soil surveys. Soil classification has an important function in these programs because it provides the framework for a systematic land resources appraisal based on soil surveys. An equally important function of soil classification should be to facilitate the transfer of experience gained with a given kind of soil in one place to a similar kind of soil in another place.

This transfer of experience is clearly a technical purpose and thus an argument could be made in favor of using some kind of technical system for this process. However, while this may be a reasonable

statement of principle it appears that this transfer has to be made on the basis of the existing soil maps and the classification systems employed in their construction. The systems most widely used in tropical areas are the FAO/UNESCO Legend (Dudal, 1968; FAO, 1970), the French Soil Classification (Aubert, 1965; Commission de Pédologie, 1967), the Classification of Brazilian Soils (Bennema, 1966), and the U.S. Soil Taxonomy (Soil Survey Staff, 1973). Taxa of these systems can be correlated at various categoric levels and, in most cases, with some degree of accuracy (Beinroth, 1974; Beinroth et al., 1974).

All of the mentioned systems are, in principle, taxonomic classifications. Their application in soil surveys alludes to the rationale that soil surveys, although practical in purpose, must also have reasonable scientific standards to be useful. In particular, a soil survey should not become obsolete with changing agricultural technology and it should further facilitate the interpretation for a variety of uses some of which might not have been anticipated at the time when it was made. It is evident that these requirements can only be met if a taxonomic system is used (Smith, 1965).

With respect to transfer of agrotechnology, Smith (1965) has further contended that in order to be useful, a classification "should be a multicategoric system with a large number of taxa in the lower categories... (These) must be as specific as possible about a great many soil properties... Higher categories are essential for comparisons of the soils

of large areas, but are of limited value for the transfer of experience."

Because classes of Soil Taxonomy are defined in terms of soil properties and because soil behavior correlates with soil properties, taxa of the system should reflect behavioral patt erns. As soil families are, within a given subgroup, differentiated primarily on the basis of soil properties important to plant growth and indicative of soil-water-root relationships, taxa of this category should have the greatest prediction value. Soils classified into the same soil families should, therefore, have nearly the same management requirements and similar potentials for crop production. This assumption was recently substantiated in a study of soils of the southern United States (De Ment et al., 1971). The study further showed that only general kinds of soil behavior can be predicted within classes of the broader defined higher categories.

The bulk of the world's research on soil management has been carried out in temperate regions, but the transfer of this experience into the tropics has met with varying success. Therefore the transfer process should be primarily within tropical regions. However, to date the methodology for transfering existing experience among tropical countries has not been developed. The Universities of Hawaii and Puerto Rico will, therefore, jointly initiate research along these lines. It is hoped that this research will either demonstrate the validity of Soil Taxonomy for purposes of agrotechnology transfer or establish the modifications necessary to make it viable.

Summary

The objective of taxonomic soil classification is to provide a conceptional framework to accommodate the current knowledge of soils and concepts derived from this knowledge is an organized manner. Soil classification systems allow for comparisons of soils for both similarities and differences and should also facilitate the transfer of agricultural technology. If the U. S., the Soviet and all other experiences are a guide, taxonomic systems of soil classification with a large number of precisely defined taxa in the lower categories are required for this purpose. Technical systems derived from taxonomic soil classifications may also provide a useful methodology for expediting management experience of relevance crop production.

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