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Relationships between U. S. Soil Taxonomy, the Brazilian Soil Classification System, and FAO/UNESCO Soil Units

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Introduction

In reflection of growing government interest in natural resources, most countries in tropical America are engaged in active soil survey. An intrinsic element and important aspect of these programs is the classification of soils.

Soil surveys are expensive and no government or institution would be inclined to support such activities unless they are of practical value. Yet, while many soil surveys have been extremely useful, some have failed. The inadequacies were mostly the result either of failure to identify the purposes for making the soil survey or failure to maintain strict scientific control over the identification, description and classification of the soils. To be useful, soil surveys must be both practical in purpose and scientific in construction. The classification systems applied in soil survey must, therefore, be capable of meeting these requirements and should in particular facili-

tate comparisons of soils for both similarities and differences (Smith, 1965). Viewed in the context of this perspective, the classification of soils is not a mere academic exercise, as some would see it. It is a scientific means for a practical end.

Whereas there is, in general, international agreement on botanical, zoological, mineralogical and similar classifications, there exist several kinds of soil classification and many more are possible. This is partly a reflection of the fact that soil classification systems have been developed largely by government institutions for specific purposes and particular pedologic conditions. As a consequence, several systems of soil classification are currently in use in tropical America.

In a recent review of soil survey methods in Latin America, Van Wambeke (1973) reports that national systems of soil classification are employed in Brazil and Panama. In the French territories, soils are correlated with taxa of the classification developed by ORSTOM (Aubert, 1966). The Central American countries have usually compared their soils with the great soil groups established during the original soil survey of Hawaii (Cline, 1955). In the British Antilles soil series are recognized but are neither correlated nor placed in a taxonomic system, and the same holds true for Guatemala where the arrangement of soil series is merely alphabetic.

Costa de Lemos (1971) reports that in several Latin American countries, notably Chile, Colombia, Mexico, Perú, and Venezuela, efforts are under way to classify soils according to the U. S. Soil Taxonomy (Soil Survey Staff, 1970).

By virtue of the recently published soil map of South America(FAO, UNESCO, 1971), the soils of this sub-continent have also been correlated with units of the legend for the FAO/UNESCO Soil Map of the World (FAO, 1970).

In terms of area of application, the U. S. Soil Taxonomy, the Brazilian system and the FAO/UNESCO scheme are the most important soil classifications used in tropical America. It is the objective of this paper to discuss and compare these systems and to evaluate their role in the agricultural development process.

Approaches to Soil Classification

In most of the existing systems of soil classification there is the basic assumption that there are individual soils that can be treated as a population. While 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 change signifies a major breakthrough in pedologic thinking and provided the scientific basis for taxonomic classification systems.

Although there are as many classifications conceivable as there are objectives for grouping, there are basically only two fundamentally different approaches to soil classification. One can group soils for a great variety

of technical purposes and thus establish technical groupings, each for a limited objective and with a special bias dictated by the objective (Cline, 1949).

In natural or taxonomic classifications, on the other hand, the objective is to show relationships in the greatest number and most important properties without reference to a specific practical purpose. To quote Cline (1949), "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".

There are two main methods of elaborating natural systems: one may reason from ideas to facts, or from facts to ideas. In the first case the method is analytic and descending and such systems are of necessity essentially genetic (Manil, 1959). The second method is synthetic or ascending and requires a great amount of data about recognizable bodies of soil, especially those identified as soil series. The U. S. Soil Taxonomy essentially is an example of this type, whereas the Brazilian classification may be considered a "system built from above" (Van Wambeke, 1973). Because soil classification in tropical America is chiefly employed in soil surveys and these are expected to be of practical use, an argument

in favor of technical systems of classification could be made. However, Smith (1965) has stated that soil survey, although practical in its purpose, must also have reasonable scientific standards. 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. Yet, at least one more step beyond the taxonomic classification is needed to order the "natural" groups into "practical" groups (Smith, 1965). There are compelling reasons for flexible criteria below some level of generalization that are not subject to the restrictions of definition inherent in taxonomic classes (Cline, 1963). This can be accomplished by groupings of phases of classes on the basis of characteristics that are important to the purpose of the moment (Smith, 1965).

Structure, Differentiae and Nomenclature of the U. S. Soil Taxonomy, the Brazilian Classification and the FAO/UNESCO Legend

In contriving a taxonomic system of classification and thus to arrive at an "orderly abstract of knowledge, and concepts derived from knowledge" (Cline, 1963), three main problems are encountered. These are the selection of differentiating criteria, the definition of classes and their grouping in categories, and the nomenclature of taxa. The systems discussed below represent three different endeavors.

a) U.S. Soil Taxonomy

This system is an attempt at a comprehensive taxonomic classification of soils. For reasons explained by Kellogg (1963), it 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 substantial 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 great 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 to 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 in 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, suborders 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 accessory 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.

For more detailed analyses of various aspects of the new system reference is made to the papers by Cline (1963), Flach (1963), Heller (1963), Johnson (1963), Orvedal and Austin (1963), Riecken (1963), and Simonson (1963).

b) Brazilian System of Soil Classification

When soil survey activities were started in Brazil some 20 years ago, the soil classification system of Baldwin, Kellogg and Thorp (1938) in its revised form (Thorp and Smith, 1949) was employed. However, as the soil surveys proceeded it soon became evident that the then U. S. system did not afford satisfactory groupings for the soils of Brazil. Neither did the taxa of the "7th Approximation" (Soil Survey Staff, 1960) appear to provide suitable classes for Brazilian soils, particularly as the classification of Oxisols was not fully elaborated at that time (Bennema, 1966).

It was, therefore, decided to develop a system of classification specifically for Brazilian soils. J. Bennema of the FAO and M. Camargo of the "Divisao de Pedologia e Fertilidade do Solo" (DPFS) assumed the leadership, and the new system was first published in 1964 (Bennema and Camargo, 1964). Further development of the scheme is in full progress with particular

emphasis on the classification of the soils formerly called Red-Yellow Podzolics and Latosols.

The Brazilian system in its present form recognizes twelve "soil classes of high level" each of which is subdivided at four successively lower levels. These categories are not formally named and have not yet been developed in equal detail for all high-level classes. New taxa may be added as new knowledge materializes and the Brazilian system thus constitutes an example of a descending classification.

Considerable progress has been made in the classification of the two high-level classes that comprise the main tropical soils of Brazil (Costa de Lemos, 1968). These two classes are separated, at the highest level, on the basis of the presence of a latosolic or a textural B horizon which are roughly analogous to the oxic and argillic horizons of Soil Taxonomy. At the next lower level, mainly chemical characteristics, such as cation exchange capacity and base saturation, are employed to establish classes. The criteria used to subdivide the third level include iron content as related to soil color and type of parent rock, Al_2O_3 / Fe_2O_3 ratios, and the degree of A horizon development. Classes of the fourth level are differentiated chiefly on the basis of color, profile differentiation, and presence or absence of plinthite. At the lowest level, texture is used to distinguish among classes of soils with latosolic B horizons, whereas type of parent rock is applied in the case of soils with textural B horizons. The use of "phases of vegetation" has been proposed to characterize the ecological conditions which a

given mapping unit represents, but these have only been developed for tropical forests. (Bennema, 1966).

The nomenclature of the Brazilian classification is heterogenous. In eight of the twelve high-level soil classes descriptive terms are employed such as "Soils with solonetzic B horizons", "Red, Yellow and White Sand." or "Hydromorphic Soils." The names of great soil groups of the classification of Baldwin, Kellogg and Thorp (1938) were retained for the classes of Lithosols, Podzols and Regosols. The more recent term Grumusol is used to name the remaining high-level class. With the exception of the term Latosol, no names are given to taxa of the lower levels. These classes are briefly described in the fashion of a key and carry numerical designations.

c) FAO/UNESCO Legend

In 1961 FAO and UNESCO initiated a joint project for the preparation of the Soil Map of the World at a scale of 1: 5, 000, 000. One of the most important aspects of this project was the correlation of soil units used in various parts of the world with the aim of preparing a universal legend. Field correlation activities and research undertaken to this effect eventually led to the publication of the "Definitions of Soil Units for the Soil Map of the World" (Dudal, 1968). Subsequent to minor revisions, the final key to soil units was distributed in 1970 (FAO, 1970). The legend was first applied in the two sheets of the Soil Map of the World covering South America (FAO/UNESCO, 1971).

The FAO/UNESCO legend is a bicategorical scheme which recognizes 26 higher classes subdivided into 104 soil units. For map units, three textural classes, three slope classes, and nine phases are provided. The soil units have been selected on the basis of their significance as resources for production, present knowledge of pedogenesis, and the feasibility of representing them on small scale maps. As a consequence, the soil units established may not strictly adhere to taxonomic rules and may belong to different levels of generalization (Dudal, 1968). It is further obvious that the FAO/UNESCO legend was not conceived as a taxonomic classification proper. Rather, it basically constitutes an organized compilation of definitions of map units and may be considered a compromise between a taxonomic and technical classification.

Soil units of the FAO/UNESCO legend are differentiated on the basis of quantitative criteria similar to those of U. S. Soil Taxonomy. In particular the definitions of most of the diagnostic horizons have been drawn largely from Soil Taxonomy and are, therefore, identical in both schemes as regards nomenclature and essence, though not detail, of definition. In addition to the diagnostic horizons of Soil Taxonomy, the FAO/UNESCO scheme further recognizes gleyic, plinthic and thionic horizons. At the phase level, classes of texture and slope, and phases to indicate the presence of hard rock, stones, gravel, indurated layers, and salinity and alkalinity may be employed as modifiers of the soil units.

The nomenclature of the units of the higher category of the FAO/UNESCO

legend reflects a tendency to retain traditionally established names such as Chernozems, Podzols, Solonchaks, and Rendzinas. Also adopted were names that have become popular in recent years like Vertisols, Rankers, Andosols, and Ferralsols. The need to coin new terms was nevertheless felt in cases where existing names were liable to cause confusion due to different usage in different countries. Some of these new names include Luvisols, Acrisols, Yermosols and Nitosols. Twenty-eight connotive terms such as mollic, takyric, dystric or luvic are used as adjectives to the names of units of the higher category to form the names of the lower category soil units. The etymology of this nomenclature and the justification for its selection are discussed in detail by Dudal (1968).

Comparison and Correlation of Taxa of U. S. Soil Taxonomy, the Brazilian Classification and FAO/UNESCO Soil Units

The foregoing discussion indicates that the U. S. Soil Taxonomy, the Classification of Brazilian Soils and the FAO/UNESCO Legend are systems that were contrived on divergent rationales for different purposes. As a consequence the schemes differ in structure, nomenclature and definitions. These inherent differences of the three schemes severely compounds the problem of correlating their taxa.

The number of taxa distinguished at comparable levels of abstraction varies significantly in the three systems. Considering, for example, a class which is defined almost identically in all three schemes, the order Oxisols of Soil Taxonomy has five suborders, 19 great groups and 35 subgroups; the Ferralsols of the FAO/UNESCO legend are split into six soil units; and the Soils

with latosolic B Horizons of the Brazilian scheme comprise five classes of Latosols which are subdivided at two lower categories with 6 and 10 classes, respectively. It is thus improbable that taxa of one system can be matched with exact counterparts in another system.

An analysis of the schemes suggests that six of the 26 higher category units of the FAO/UNESCO legend correspond closely to orders of Soil Taxonomy; e. g. Acrisols= Ultisols, Ferralsols= Oxisols and Podzols= Spodosols; but not all Oxisols are Ferralsols, Plinthaquox are Gleysols. The remaining 20 units are appoximately equivalent to suborders or great groups; e. g. Rendzinas= Rendolls and Nitosols= pale-great groups of Alfisols and Ultisols. The lower category soil units are roughly equivalent to great groups and, in some cases, to suborders or subgroups; e. g. some Humic Ferralsols= Humox, some Haplic Luvisols= Hapludalfs, and some Dystric Nitosols= Oxic Palehumults. It is, therefore, impossible to correlate soil units of the FAO/UNESCO legend and taxa of Soil Taxonomy at a consistent categoric level.

As regards the Brazilian classification, the high level classes of this system can, in most instances, be related to orders of Soil Taxonomy and high category units of the FAO scheme. Lower category taxa of the Brazilian classification cannot be matched unequivocally with classes below the highest categories of the two other systems.

The main difficulty encountered in correlating taxa of the three schemes is that different criteria are employed in their definitions. Thus, in Soil Taxonomy udic and ustic soil moisture regimes are used as a differentiae

at the high categoric level of suborder or great group. Neither the FAO/UNESCO scheme nor the Brazilian classification consider these criteria, although in the latter system phases of vegetation provide some indication of it.

The FAO/UNESCO units and taxa of Soil Taxonomy are often thought to have a high degree of correlation because both schemes use similar or identical differentiae and definitions. However, additional criteria are applied in Soil Taxonomy, some of the same criteria , e. g. the natric horizon, are used at different levels of generalization and the key to soil unit of the FAO/UNESCO legend is structured differently than that of Soil Taxonomy. Also, definitions are less precise in the FAO system. For example, Acrisols are defined as soils with argillic horizons having a base saturation of less than 50 percent (by NH_4 OAc) in at least some part of the B horizon and Luvisols are other soils with argillic horizons. As Alfisols are only required to have a base saturation of more than 35 percent (by sum of cations) at 125 cm depth, some Alfisols, such as Ultic Tropudalfs, may actually be Acrisols, although customarily Alfisols are correlated with Luvisols.

In the Brazilian classification, color figures prominently as a differentia in addition to criteria like iron content and parent rock which are not used in the two other systems. Cation exchange capacity is an important differentiating criterion in all system but is employed with different numerical values in the Brazilian Classification. Bennema (1966) has pointed out

that the latosolic B horizon is, in many aspects, "similar to the oxic horizon of Soil Taxonomy, ... the most important difference being that a latosolic B horizon can never include a textural B horizon, while an oxic horizon may include an argillic horizon". This statement cannot go unchallenged. First, an oxic horizon is, of course, exclusive of an argillic horizon. Second, the vertical increase in clay in latosolic B horizons may be such that it meets the requirement for an argillic horizon if some clay skins are present. Thus, some soils classified as Latosols may be and in fact often are really Ultisols rather than Oxisols (S. W. Buol, 1973; personal communication).

With respect to the correlation of taxa, it is well to remember that the name of a taxon only conveys specific quantitative information about those properties which are differentiating criteria in its definition. The more specific the definition of a taxon, the more specific statements can be made about its properties. Vice versa, a greater number of criteria have to be known to allow positive placement in specifically defined taxa. The correlation of taxa has to be made on the basis of the information contained in its name plus consideration of the position of the taxon in the key. Three examples follow to substantiate these points.

1. Haplorthox, as defined in Soil Taxonomy, are soils with oxic horizons, a CEC of between 1.5 and 16 meq/100g. of clay, and a base saturation of less than 35 percent. In the Brazilian Classification, Haplorthox therefore can be either one kind of taxon defined as "Latosols with a CEC of less than 6.5

meq/100 of clay and a base saturation of less than 50 percent" or another kind defined as "Latosols with a CEC of less than 6.5 meq/100 g. of clay".

- In the FAO/UNESCO scheme, Haploxthox may be Rhodic, Xanthic or Orthic Ferralsols. In neither the Brazilian nor the FAO/UNESCO system can Haplorthox be accurately placed on the basis of the information contained in its definition because color, iron content and type of parent rock are not diagnostic criteria.

2. The Terra Roxa Legitima of Brazil is classified as a soil with a latosolic B horizon with a CEC of less than 6.5 meq/100 g of clay, a moderate or weakly developed A horizon, more than 18 percent Fe_2O_3, and colors of 2.5 YR or redder. These soils may occur as savanna phase, semi-evergreen forest phase, and semi-deciduos forest phase (Bennema, 1966). Assuming that the semi-evergreen phase indicates a udic moisture regime, this class of soils corresponds with the Orthox of Soil Taxonomy and may be either Gibbsiorthox, Acrorthox or Haplorthox. If their moisture regime is ustic, these soils are Acrustox or Haplustox. -In the FAO scheme, the Terra Roxa Legitima may qualify for Acric, Rhodic or Orthic Ferralsols. Again, more specific placements are not possible because the criteria of the Brazilian classification are not the same as those of Soil Taxonomy and the FAO system.

3. The FAO/UNESCO soil unit of Ochric Andosols comprises soils that, by definition, are derived from volcanic ash, have no mollic or umbric A horizons but have a smeary consistence. These soils belong with the suborder

of Andepts of Soil Taxonomy. However, the information contained in the definition of Ochric Andosols does not allow a positiv placement at the great group level. While they could be Cryandepts, Durandepts, Hydrandepts, Placandepts or Dystrandepts, they probably correlate with Hydrandepts because of their smeary consistence. -The Brazilian classification in its present form does not provide taxa for soils developed from volcanic ash, as these are not important in Brazil.

It is obvious that the three systems are not compatible in many aspects, and correlation of their taxa can, in most cases, not be achieved unequivocally. This writer disagrees with statements to the effect that the three systems "have a high degree of correlation ... and are fairly easily translated" (Buol, 1972). It appears that only the taxa of the highest categories of each scheme can be correlated with some accuracy (see Table 1). This is substantiated by a correlation of FAO/UNESCO soil units with Soil Taxonomy taxa prepared by Dudal and reproduced in Buol (1972). Although generally satisfactory and providing approximate equivalents, the table should not be used where exact correlations are needed. This became evident, for example, in a recent effort to place all of the soil series of the State of Hawaii in the FAO/UNESCO scheme (Beinroth and Ikawa, 1973). While it is not possible to develop precise correlation tables that are valid in all instances, an individual soil can, of course, be classified into any of the three systems if those properties are known which are used as differentiae in the respective schemes.

Critical Considerations

Soil classification in tropical America is made primarily as part of soil survey programs that are carried out for purposes of agricultural development. This objective imposes certain specific requirements on the soil classification employed. Quoting from Smith (1965), such a classification should have the following attributes:

1. "Definitions of taxa should be operational so that they carry the same meaning to each user."
2. "Differentiae should be soil properties that may be observed in the field or that may be inferred from properties observable in the field."
3. "The classification should be a multi-categoric system and should have a large number of lower categories. These should be as specific as possible about a great many soil properties to allow transfer of experience. Higher categories are essential for comparisons of soils of large areas."
4. "Taxa must be concepts of real bodies of soil."
5. "The classification must be capable of providing taxa for all soils in a landscape and not just selected pedons."
6. "The classification should be capable of modification to fit new knowledge."

The three systems discussed meet these requirements to varying degrees. Soil Taxonomy is by far the most elaborate and most quantitative of the three schemes and is particularly precise in the definition of taxa in terms

of soil properties subject to measurement by defined methods. Although, therefore, criteria and definitions are operational, considerable effort may be involved in their determination in some cases. For example, oxic horizons with a certain clay distribution become argillic horizons if clay skins occupy more than 1 percent of the volume (Soil Survey Staff, 1970). Considering the tedious and costly process of preparing thin-sections and the number of counts necessary to get confidence at the 1 percent level, this differentia appears to be unoperational from a practical point of view. Yet, a decision at the highest categoric level-Oxisols vs. Ultisols or Alfisols-may have to be based on this criterion.

In general, a considerable amount of quantitative morphological, analytical, and climatological data are needed to allow a positive placement in the lowest category of the system. Many of these criteria, such as soil moisture regime and mineralogy class, are not directly observable or cannot be inferred conclusively in the field. This detail of information is, however, indispensable if taxa are to be established which are sufficiently specific to be useful for transfer of experience. In the precison of definitions lies both the strength of Soil Taxonomy and its limitations as regards applicability in places where laboratory facilities and financial resources are scarce. (The latter is, of course, not a fault of the system per se.)

With respect to item 5 above, it is important to realize that not all soils of the world can be classified satisfactorily in Soil Taxonomy. This reflects the fact that Soil Taxonomy is essentially a national system developed

mainly on the basis of detailed information on the roughly 10, 000 soil series found in the United States and Puerto Rico. Cline (1963) has pointed out "that the system is incomplete in terms of classes, criteria of classes and precicion of definitions... crudely related to the amount, validity, and genetic correlations of data available". This is especially true for the class of Oxisols which is based largely on the 28 series of Oxisols occurring in the State of Hawaii and Puerto Rico (Soil Survey Staff, 1972). For these soils the system provides satisfactory groupings, but Oxisols from other regions may not fit well into the scheme. A similar situation exists for those tropical soils derived from volcanic ash. This would constitute a serious defect if Soil Taxonomy were to be a universal system, which it is not. It should be noted that while the "7th Approximation" was called "A Comprehensive System", the system is presently named "Soil Taxonomy of the National Cooperative Soil Survey."

The new U. S. system has been subject to much criticism, more often than not merely a reflection of improper understanding. More substantial criticism, particularly from outside the Soil Conservation Service, was voiced concerning the fact that the system underwent constant changes. Thus, the definition of Mollisols, e. g., was changed to exclude those having isohyperthermic temperature regimes and COLE-values of more than 0. 09, necessitating a shift of some Puerto Rican Mollisols to Inceptisols. Although in most cases the changes did not affect high-level criteria and were thus less disruptive, the continuous modifications discouraged pedologists outside the U. S. to use the scheme. With the forthcoming publication of Soil Taxonomy this drawback will be eliminated. It will be used

in this form for some time, but periodic revisions are intended to accomodate new knowledge, particularly about soils from outside the United States.

As regards the application of Soil Taxonomy in tropical America, its general use is not advocated because it likely is not the best adapted system for the kinds of ongoing soil survey programs and their purposes. Proper classification in Soil Taxonomy depends heavily on quantitative data which it may not be possible to obtain in soil survey activities carried out under time pressure and with limited funds. Where Soil Taxonomy is used in lieu of a national system, it should be adapted to provide for any of the soils that are not properly identified in the scheme. It is, however, recommended that Soil Taxonomy be used as a system of reference for international communication, especially in technical papers.

The Brazilian classification is still too far from completion to be thoroughly and objectively evaluated. In its present form, some criteria are not operational, e.g. definitions do not say exactly what a "weakly developed A horizon" is. Also, the use of type of parent rock as a differentiae is not beyond criticism because on old geomorphic surfaces pedogenesis is frequently multi-cyclic and the parent material may or may not be derived from the underlying bedrock. Further, there is no key provided to ensure mutually exclusive classes. In addition there is a tendency to

concentrate on selected pedons considered representative of certain sets of genetic factors for the abstraction of differentiae (Van Wambeke, 1973). The structure of the system, however, permits the addition of new taxa. Although this classification has been designed for use in national soil survey programs, it appears that it is not always completely applied. Thus in the recently published "Soils of the Transamazon Highway" (Falesi, 1972), Yellow Latosols are distinguished while such a class is not recognized in the published scheme (Costa de Lemos, 1968).

The usefulness of the lowest taxa of the Brazilian classification for purposes of transfer of agrotechnology cannot be assessed properly at this time. Although detailed information is collected for the pedon typifying a soil unit, the units on the maps at scales of 1: 500, 000 or 1:1, 000, 000 are not necessarily taxonomic units and individual soils included in the map unit may diverge considerably from the typifying pedon. Whereas these maps are very useful for broad regional planning, maps where mapping units more closely correspond to the lowest taxonomic units are needed to test if the lowest taxa carry sufficient information for recommending management practices at the farm level.

The FAO/UNESCO legend has not been designed as a taxonomic classification sensu stricto and should, therefore, not be judeged on the criteria mentioned above. The main merit of the FAO scheme is that it will

provide a vehicle for the comparison of well -defined, mutually exclusive, but by necessity rather broad groups of soils on a world-wide scale once all the sheets of the Soil Map of the World have been published. Altogether 104 units delineated on maps at a scale of 1:5, 000, 000 however, cannot provide an effective basis for determining soil management requirements or to transfer experience. If the American, the Soviet and all other experiences are a guide, a classification system with a number of categories and more precisely defined lowest taxa are required for this purpose (Smith, 1965).

Applicability of Soil Classification in the Agricultural Development Process

It is an important function of soil classification to provide a 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.

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. While this may be a reasonable statement of principle, its application is difficult. First, although

an appreciable body of information about soil management in the tropics has been accumulated, experience is still lacking, particularly for "problem soils". Yet, in view of demographic pressures and limited financial resources, many countries neither have the time nor the funds required to build up through experimentation the body of agrotechnological knowledge that modern agriculture needs. Second, the mechanisms of transferring existing experience within the tropics have not been studied in detail. It appears that principles can be transferred among regions but their applications commonly cannot.

There are indications, however, that soil classification and in particular the U. S. Soil Taxonomy can play a significant role in this transfer process. 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 patterns. 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 (DeMent 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. This

would indicate that taxa of the FAO/UNESCO and Brazilian schemes are less well suited for specific management predictions and recommendations, whereas the family level of Soil Taxonomy should afford a better basis for transfer of technology.

However, the validity of family criteria with regard to management predictions at the farm level has not been widely tested for tropical soils. Therefore, the Universities of Hawaii and Puerto Rico plan to initiate parallel projects focused on research along these lines. It is hoped that these studies will either demonstrate the usefulness of the present criteria and/or indicate new or additional parameters which better characterize some of the management problems peculiar to tropical soils, such as distribution of electrical charge, Al-toxicity, moisture stress in the growing seasons, etc.

Independently of, but related to, this research an effort should be made to classify the soils of the mayor agricultural experiment stations of tropical America according to the family category of Soil Taxonomy. This would make possible specific comparisons of soils and experimental results at an international level. It would also generate compatible and standardized data on some benchmark soils of tropical America. Although a clear distinction has to be made between such soil identification analyses and analyses for agricultural purposes, these data would be extremely valuable for use in the soil data storage and retrieval system being developed by FAO (1971).

Soil classification thus constitutes an important element in the agricultural development process because it a) provides the frame-work according to which land resources are inventoried in soil surveys, b) affords a basis for international communication of pedologists and agronomists (if a generally known system is used), and c) should prove useful in the exchange and transfer of knwledge and experience among tropical countries.

Conclusions

1. Soil classification is of central importance to the agricultural development process in tropical America because it is used in soil surveys made for systematic appraisals of land resources.
2. The classification of Brazilian Soils, U. S. Soil Taxonomy and the FAO/UNESCO Legend are the systems most extensively used in tropical America. These three schemes are unlike as regards structural organization, precision of definition and number of taxa, choice of differentiating criteria, and nomenclature.
3. Unequivocal correlation of taxa of the three schemes cannot be achieved with accuracy in many cases; only approximate equivalents of higher category classes can be established.
4. A multi-categoric system of soil classification with specifically defined lowest category taxa is a prerequisite for meaningful transfer of agricultural experience.

5. The soil classification systems should be evaluated with respect to their suitability for purposes of agricultural planning and technology transfer. In particular, the validity of family criteria of Soil Taxonomy should be tested for tropical soils with the objective to test the feasibility of employing soil classification in the process of transfer of agro-technology.

6. The U. S. Soil Taxonomy should be used as a system of reference for international communication. It is recommended that the soils of the main agricultural experiment stations of tropical America be classified according to this system to allow comparisons of soils and agronomic experience at an international level.

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Table I: Approximate Correlation of Taxa of the Highest Category of U. S. Soil Taxonomy, the Brazilian Classification and the FAO/UNESCO Legend

U. S. Soil Taxonomy (Soil Survey Staff, 1970)	FAO/UNESCO Soil Units (FAO, 1970)	Brazilian Classification (Bennema, 1966)
Alfisols	Luvisols, Planosols, Nitosols, Podzoluvisols, Solonetz	Non Hydromorphic Soils with Textural B Horizons, CEC > 24 meq/100g, base saturation > 35% (Class III) Soils with a Hardpan (Class VI) Hydromorphic Soils (Class XII)
Aridisols	Yermosols, Xerosols, Solonetz, Solonchaks	Soils with Solonetzic B Horizons (Class IV) Soils with a Hardpan (Class VI)
Entisols	Fluvisols, Lithosols, Regosols, Gleysols, Arenosols	Lithosols (Class VIII) Regosols (Class IX) Red, Yellow and White Sands (Class X) Hydromorphic Soils (Class XII)
Histosols	Histosols	Hydromorphic Soils including Organic Soils (Class XII)
Inceptisols	Cambisols, Gleysols, Andosols, Solonchaks, Rankers	Non Hydromorphic Soils with Incipient B Horizons (Class V) Hydromorphic Soils (Class XII)
Mollisols	Chernozems, Phaeozems, Kastanozems, Greyzems, Rendzinas, Gleysols, Planosols, Solonchaks, Solonetz	Non Hydromorphic Soils with Textural B Horizons, CEC > 24 meq/100g, base saturation > 35% (Class III) Hydromorphic Soils (Class XII)

Table I (Continued:)

U. S. Soil Taxonomy	FAO/UNESCO Soil Units	Brazilian Classification
Oxisols	Ferralsols, Gleysols	Soils with Latosolic B Horizons (Class I) Hydromorphic Soils (Class XII)
Spodosols	Podzols	Podzols (Class XI) Hydromorphic Soils (Class XII)
Ultisols	Acrisols, Nitosols	Non Hydromorphic Soils with Textural B Horizons, CEC $<$ 24 meq/100g, base saturation $<$ 35% (Class II) Hydromorphic Soils (Class XII)
Vertisols	Vertisols	Grumosols (Class VII) Hydromorphic Soils (Class XII)

Note: 1) The table should be read from left to right

2) Underlinings indicate the predominant FAO/UNESCO correlatives of the respective orders of Soil Taxonomy