Soil in the Tropics: Classification and Characteristics

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Introduction

In 1950, C. E. Kellogg predicted that as detailed maps became available more distinct soil types would be found within the tropics than in the other parts of the world. Moormann (1972) attributed the lack of appreciation for soil variability in the tropics by agricultural and other scientists to the generalized, small-scale soil maps by which they were guided. Buol and Sánchez (1978) were even more harsh in their appraisal, stating that "the reality of soil variability has been masked by small scale reconnaissance soil surveys that portray a false sense of uniformity and serve only to widen the gap between scientists, who overinterpret such maps, and farmers, who know what the soils are like."

The realities of working in the tropics, regardless of how mindful we are of soil variability, are that research sites are sparse and detailed assessment of soil characteristics equally sparse. To compensate for the lack of available characterization data, agronomic researchers have to assume greater responsibility in characterizing the sites where they work in order to enhance the validity of technology transfer. Any agronomic study that fails to quantitatively identify the soil in field studies, or the soil material in the case of a greenhouse or laboratory study, severely limits the value of the data generated. Dismissing this responsibility by giving a geographic place or name, such as a country or region of a country, or a soil map unit name or even a soil taxonomic order, connotes a false sense of quantification that frequently does more harm than good.

The objectives of this paper are to: point out some agronomically important variabilities known to exist within and between soils in tropical areas; and suggest some minimum measurements that can be conducted to improve site identification and characterization and thus the value of the research to other locations.

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No single parameter such as soil characterization totally quantifies the uncontrolled variables in an agronomic experiment, but the closer we can define these variables, the closer we are to understanding, evaluating, and extrapolating the results.

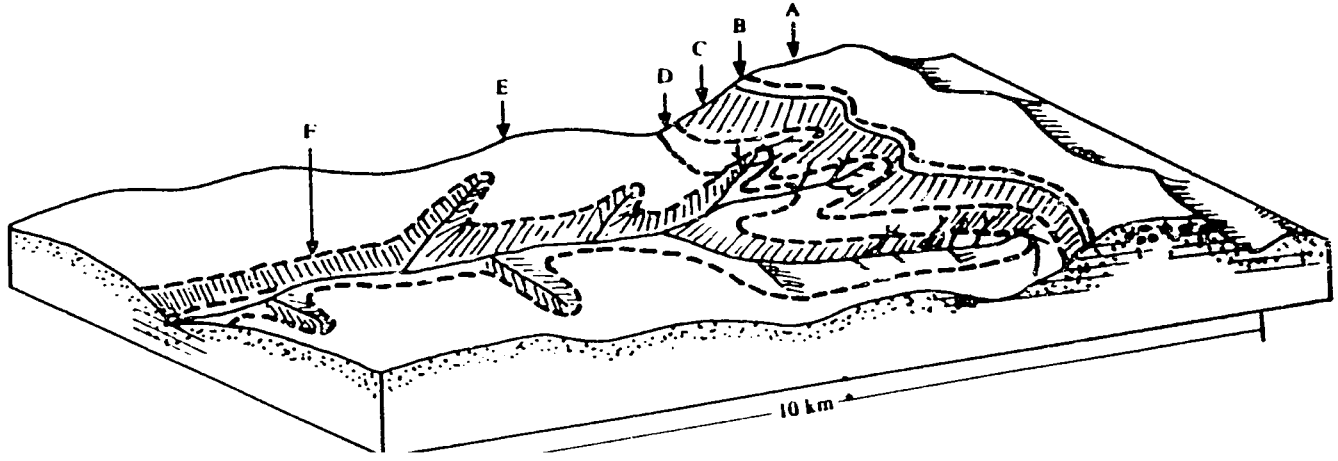
Map units

Perhaps more than other disciplines soil classification further confuses many people whose first contact with the soil classification is via a soil map. Mapping is the representation of a naturally occurring area, at a much reduced scale, and does not represent a soil classification unit. Unfortunately, in soil science, not unlike other disciplines, taxonomic names are used to name soil map units. Many people seem to lose sight of this obvious fact and attempt to name the soil they work with from the name given on a soil map that may be on some minute scale that allows for areal inclusions of several hundreds of hectares of contrasting soil. The sample site may be less than 10 cm in diameter or the experimental plot well less than 1 hectare. No map, except possibly those done under very controlled conditions at scales larger than 1:10,000, can possibly be reliable in identifying such small areas (Buol et al., 1980).

Every soil map unit contains soil types not identified in the name given to that map unit. One example of soil variability in an area properly identified on general soil maps as Oxisols is presented in Figure 1. Detailed maps identify Oxisols, Ultisols, Inceptisols, Alfisols, and Mollisols, and mean values of selected surface soil properties from map units delineated on detailed maps clearly illustrate agronomic contrast.

Taxonomic units

While the map unit limitations are readily understood by most scientists, ranges of characteristics defined in taxonomic units of soils are, in my experience, not as easily understood or accepted. Although I will use examples from Soil Taxonomy (Soil Survey Staff, 1975), the same problems exist in other systems to an even greater degree because of less rigid definitions and fewer categories and classes. To understand the inherent problems of classifying soil, one has to realize that in no one place can an entire taxa, be it



	A	B	C	D	E	F
Bases (meq/100 soil)	0.6	1.6	5.1	1.4	0.3	0.8
Exchangeable Al (meq/100 g soil)	0.9	0.1	0.0	0.1	1.3	0.7
Clay (%)	18	11	10	6	12	10
Carbon (%)	0.6	0.6	1.0	0.6	0.6	0.5

Figure 1. *Mean values of selected soil properties for the 0-20 horizons in detailed soil map units of an Oxisol dominated landscape in São Paulo, Brazil (Adapted from I. F. Lepsch, et al., 1977.)*

soil series or soil order, be seen, sampled, or described. Individual soils defined by every category of a classification system exist *in toto* only as abstractions defined by the words and phrases of the classifications system. Examples of the various kinds of soil are observed and characterized at specific sites. Too often, persons form rather firm concepts of the characteristics of specific examples and falsely assume that all sites classified by that name have all the properties they observed in the examples they know best. The example is not unlike taking a person to a mature field of sorghum so he can observe the morphological characteristics of the crop. At another site, perhaps a nutrient-deficient, weed-infested, and insect-damaged site of another cultivar, that person remarks that this doesn't look like sorghum. Because individual examples of soils are often separated by great distances and the opportunity for examination limited by the necessity to confine complete observations of soils to pits or road banks, this problem is exacerbated.

Table 1 briefly highlights some of the properties permitted in the range of soils properly named Oxisols, one of the 10 soil orders common in tropical areas. Essentially the only soil properties identified by the order name Oxisols are low cation exchange capacity (CEC) values, the lack of weatherable minerals, and exclusion of soils with less than 15 clay or argillic horizons in the subsoil. No limits are made on soil temperature or moisture regimes, thus Oxisols are present in arid regions as well as in the most humid of tropical areas. Mean annual temperatures range from the warmest known to no defined limit, although no Oxisols have been reported in regions colder than 8°C mean annual temperature. No limits are made on the pH value or degree of base saturation, at the Oxisol order level. Perhaps most Oxisols are acid and have low base saturation, but "Eutr" great groups are from 35% to 100% base saturated (Table 2). The critical point to remember is that a classification name defines only those properties of the soil used as criteria to define that class.

Invariably, these limits are far less confining than a person's concept of that soil gained from personal experience at one, or even several sites. Also, it is highly probable that no two persons will acquire the same personal impression of a kind of soil unless their experiences are totally parallel. As an aside, this is no different than the perception of a cow a person from India may have compared to the perception of a person from the Netherlands—a Brahman versus a Holstein-Friesian.

Table 1. Synopsis of Oxisol properties.

Division	Some of the major criteria to define classes
Oxisol order:	CEC less than 16 meq/100 g clay in some 30 cm thickness within 2 m of the surface and only traces of weatherable minerals in the silt and sand.
Oxisol suborders:	Perudic, Udic, Ustic, Aquic, or Aridic soil moisture regimes (this means Oxisols are present in every rainfall regime found in the tropics).
Oxisol great groups:	"Acr": effective CEC less than 1.5 meq/100 g clay. "Eutr": more than 35% base saturated. "Hapl": less than 35% base saturated. "Umbr": more than 1% but probably less than 20% organic matter content in surface. "Plinth": continuous plinthite within 30 cm of surface.
Oxisol subgroups:	"Quartzipsammentic" 15 to 20% clay in some part above 1.25 m. "Epiaquic" yellow color over redder subsoil. "Ultic": 40% more clay (relative) in subsoil than topsoil.
Families:	"clayey": more than 35% clay. "fine-loamy" 18 to 35% clay "ferritic" more than 40% ferric oxide (Fe_2O_3). "kaolinitic" more than 50% kaolinite (kaolin clay).

Table 2. Examples of contrasting Oxisol profiles.

Tropeptic Eutrorthox (Puerto Rico)				Typic Acrorthox (Puerto Rico)			
Depth (cm)	Clay (%)	Base saturation[a] (%)	pH (1:1 H_2O)	Depth (cm)	Clay (%)	Base saturation[a] (%)	pH (1:1 H_2O)
0-20	73.1	72	5.6	0-28	54.5	11	5.1
21-46	81.2	68	5.4	29-46	57.7	1	5.0
47-69	85.5	83	5.9	47-71	59.6	.	5.0
70-99	89.5	83	5.6	72-96	55.7	.	5.2
100-130	90.6	89	5.7	97-120	59.7	2	5.5

a. Base saturated by pH 7 method.
SOURCE: Soil Survey Staff. 1975

Soil dynamics

Soil is an entity, unique in its position at the interface between the organic and inorganic worlds, and composed of solid, liquid, and gas. The characteristics of a soil are very dynamic, easily manipulated by the whims of weather and vegetation. In addition, one also has to include the whims of man who cuts, burns, plants, and harvests vegetation; and who fertilizes, drains, irrigates, and physically manipulates the soil.

A few of the dynamic aspects of soil that are frequently of concern in characterizing soils in the tropics are best illustrated by the following changes that take place in the soil after clearing natural rain forests. Data compiled by Sánchez and Salinas (1981) consistently showed increases in pH value, available calcium (Ca), magnesium (Mg), phosphorus (P), and potassium (K) contents in the topsoil after burnings, thereby decreasing exchangeable aluminum (Al) contents. For a year or more after the start of cultivation organic matter contents decrease actively releasing organically bound nutrients. Organic matter content then stabilizes at a level reflecting the new environment and, since organic matter is not rapidly decomposing, few nutrients are released for plant growth. Although sites differ rather markedly, the pattern is clear. The interpretation of the available data that I believe is of greatest significance is that no fertility requirement or soil suitability conclusions should be made on the basis of field data during the first two years after clearing. Similar errors are introduced by taking soil into the greenhouse. Certainly the chemical and probably the physical and microbiological composition of the soil as it undergoes the "shock" of changing from a forest to cultivated site, is considerably different than it was before clearing or the character of the soil after continuous or rotational cultivation has been established. Management techniques found suitable during the first two years after clearing will undoubtedly not identify the soil nutrient problems, nor will weed and disease problems likely be encountered until after the soil system has stabilized to its new environment.

Of equal concern in evaluating crop technology on kinds of soils are the changes imparted to the soil by past management practices. This is frequently of greatest concern with trials on experiment stations. The residual effects of lime in the topsoil of Oxisols are clearly illustrated in Table 3. Not all of the residual effects are confined to the topsoil, and marked subsoil improve-

Table 3. Effects of lime application rates on the topsoil of annually-cropped Oxisol, 6 and 66 months after application.

Lime applied (t/ha)	pH (1:1 H_2O)		Al saturation (%)		Exchangeable Ca + Mg (meq/100g)	
	6	66	6	66	6	66
	(months)		(months)		(months)	
0	4.7	3.9	63	80	0.6	0.3
1	5.0	4.2	45	61	1.1	0.6
2	5.1	4.3	25	46	1.5	1.0
4	5.6	4.8	6	15	3.1	2.1
8	6.3	5.2	2	2	4.4	4.0

SOURCE: Sánchez, P. A. and Salinas, J. G. 1981.

ment has been recorded following several years of continued cultivation, liming, and fertilization (Sánchez et al., 1983).

The evidence is clear. Soil properties, especially topsoil properties that have direct relevance to crop plant growth, are significantly altered by the manipulation of vegetative cover, fertilizers, and lime.

Classifying soil

Faced with the dynamics of soil properties, not unlike the dynamics of plants and animals, how do soil scientists classify the object of their attention? Quite simply, they use measurable criteria that have been found to be least changed by expected soil management techniques. Soil classification has to avoid features of the soil changed by plowing or the result is mapping units reflecting corn soils and forest soils. While such a soil boundary would be easy to see and measure, it does absolutely nothing to help predict what kind of response can be expected when the forest is cleared and the area planted to corn. Likewise, it would not help predict what site quality could be expected if the corn fields were planted to trees. Thus, a soil classification system based solely on properties of agronomic significance, i.e., exchangeable and/or available quantities of nutrients in the topsoil, would have no value in evaluating the potential of virgin soil but merely reflect the accumulated past management. This apparent "no win" scenario can be resolved most satisfactorily by a combination of

classification to efficiently identify the soil properties that are not easily changed by expected management and a "check plot" characterization of available nutrient and pH status at the beginning of any field experiment. This available nutrient status must also be reported in the publication of the results of the experiment.

Volcanic ash (Andept) heterogeneity

Soils developed on volcanic ash are common in some tropical areas and are generally associated with high phosphate fixation. There are outstanding examples of high P fixation in volcanic ash soils, but by no means do all such soils cause fixation problems. The distribution of those soils with high P fixation properties may be identified in local patterns, but because the factors that lead to the formation of this problem are strongly related to age and nature of volcanic ejecta, their spacial distribution is usually very heterogeneous. Figure 2 is a plot of data from volcanic ash soil samples from Chile, Ecuador, Guatemala, and Costa Rica showing the relationship of ammonium oxalate, extractable Al content, and P retention percentages. Clearly not all Andepts are alike, but P retention can be predicted by oxalate extractable Al. Alvarado (1982) has shown that a 10-minute field test using NaF and thymolphalein indicator will predict the high P-retaining soils. Care must be taken to adjust the 1*M* NaF pH to 8.2. The thymolphalein color changes above pH 10.7 indicate soil with P retention above about 90%. Many of the sites in Chile and Ecuador were field checked by this method by Alvarado and myself while on the tour with very satisfactory results. Either the oxalate Al, NaF, or P retention method of characterizing the field sites is strongly suggested as future research attempts to evaluate methods of phosphate fertilization in volcanic ash soils.

It should also be remembered that P retention is not usually well correlated with oxalate Al or NaF pH value in most other soils. Juo and Fox (1977) showed some variation related to parent material but overall agreement with BET-N_2[1] surface area of the sample. Since surface area is well related to the amount of clay, a reasonable prediction of P retention can be made from particle size analysis data (Pope, 1976; Figure 3). Attempts to use BET-N_2

1. Based on the Brunauer-Emmett-Teller (BET) method devised for the Manhattan project but which uses N_2 to scan and analyze the soil surface.

8

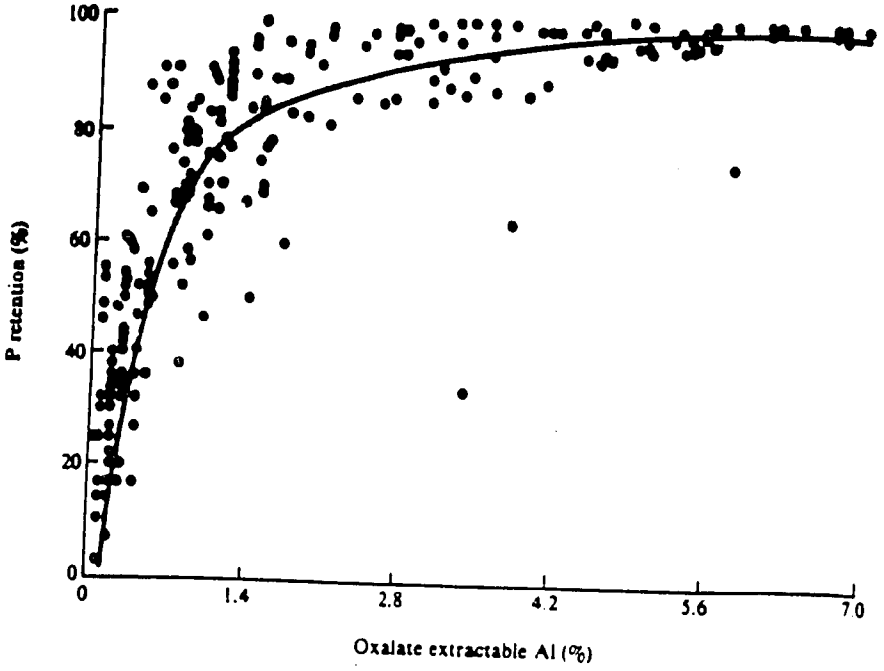


Figure 2. *Percent P retention versus percent oxalate extractable Al in Andepts from Ecuador, Chile, Costa Rica, and Guatemala. (Adapted from the United States Department of Agriculture (USDA)-Soil Conservation Services (SCS), and Alvarado, A., 1982.)*

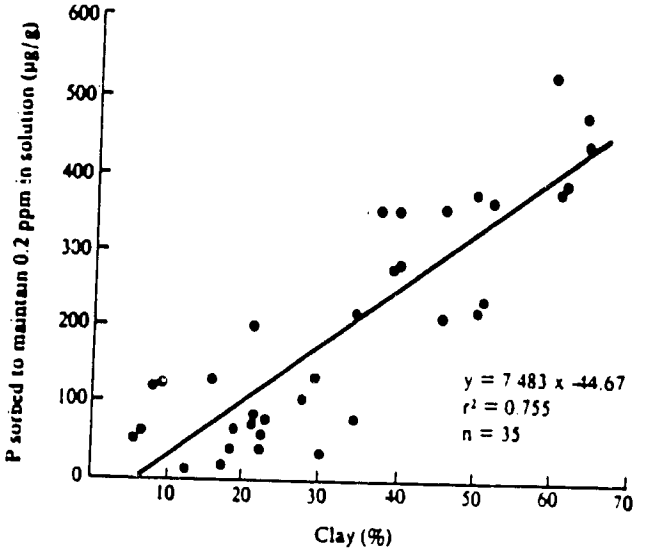


Figure 3. *Relationship between P sorption at 0.2 mg/kg P in solution and percent clay in kaolinite dominated systems. (Adapted from R. A. Pope, 1976.)*

4

surface area data or particle size in volcanic ash (Andepts) soils have been unsuccessful (Alvarado, 1982). It is clear that in Oxisols, Ultisols, and Alfisols, P fixation can be overcome by initial applications with reasonable residual effects. Where amorphous Al is present, as in some if not most of the volcanic ash (Andept) soils, each addition of phosphate initiates a reaction exposing more Al thus residual effects are much less (Veith and Sposito, 1977). Thus, there is no residual effect of P fertilization when the fixation is an amorphous Al component in the soil.

Acid soil conditions in the tropics

Evaluations of existing data and small-scale maps estimate that 43% of the tropical areas are dominated by Ultisols and Oxisols which, in the main, are acid soils. In tropical America the relative area of acid soil is placed at 70% (Sánchez and Salinas, 1981). One should quickly add that regardless of soil type, with a few exceptions, all soils can develop acid plow layers and, in a like fashion, all types of soil can have a neutral plow layer following the burning of fallow or lime application. Therefore, for soil management, soil acidity is more a soil property resulting from management practice and timing than a natural soil property. Subsoil acidity, with subsoil being defined as those layers of soil immediately below the layer disturbed by cultivation, is really what is being addressed in estimates of the extent of acid soil. This subsoil acidity is important because it limits the depth of rooting of aluminum-sensitive cultivars, thereby reducing both the amount of available water during rainless periods and the subsoil nutrient uptake (Bandy, 1980). Also, it is a slow process by which even heavily fertilized and limed soils can translocate bases into the subsoil. However, this does happen more rapidly in low CEC soils than in high CEC soils.

Fluctuations in surface soil acidity occur in response to several factors. Most significant in tropical areas are decreased acidity from ash after either the burning of fallow or from additions of lime where used. Acidification occurs in response to additions of acid-forming fertilizer, or more commonly from the organic acids released during decomposition reactions involved in organic matter decomposition which is especially active after the initiation of cultivation (Stevenson, 1982). Duration and intensity of the surface soil pH and exchangeable Al flux after any of the above cultural events depend upon a multitude of parameters and are

10

more easily measured than predicted. Some examples of nearly 3 unit increases in pH have been reported due to the influence of burning (Sánchez, 1975). As a generalization, sandy textured surface soils respond more dramatically because of their low CEC and low organic matter contents than do finer textured soils.

Summary

The characteristics of soils in the tropics are probably even more diverse than those of soils in temperate areas. Certain subsoil properties are mapable and defined by the taxonomic classification of the soil. Classification and mapping of soils can be used to transfer the results of agronomic research only when several surface soil properties are known at both the site of the research and the site of the extrapolation. Foremost among the surface soil properties that have to be known in addition to classification are: pH value and/or exchange Al percent; and P fixation capacity and ambient available P level. Both characterization of soil by classical soil classification parameters and documentation of transient surface soil properties are necessary to the successful delivery of quality agronomic research.

Soil properties in the tropics are discussed from the point of view of both semipermanent properties used to classify the soil, and dynamic, management-related properties that have to be characterized on site. Most soil classification criteria are subsoil properties because they permit uniform classification regardless of vegetative cover or management practice. This permits better evaluation of potential uses of land. For the extrapolation of management-related research results, documentation of the management induced characteristics, usually in the surface horizons, has to be provided by measurements prior to plot establishment and reported as one of the conditions of the experiment.

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12