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GENERAL PEDOLOGY OF TROPICAL SAVANNAS

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1. Introduction

This symposium is dedicated to the discussion of various aspects of savanna soils of the tropics. It is,therefore, a legitimate question to ask: What are savanna soils? To answer this question, considerable elaboration is required.

Since DOKUCHAEV'S classic work it has become a unifying philosophy of pedology to regard soils as the result of the intergrated effect of five independent environmental factors. It is not surprising,therefore, that scientists in the 19th century attempted to group soils on the basis of environmental criteria, in particular climate and vegetation. In the process, terms like desert soils, forest soils, tropical soils, savanna soils, etc. emerged. Characterizations of this nature may have sufficed for the broad generalizations with which the early pedologists were concerned and reflected, moreover, the state of knowledge of the day.

However, what was good then is not necessarily of value today. Our knowledge of soils has progressed enough to realize the inadequacy of such characterizations, and the science of soils is sufficiently advanced that we can classify soils on the basis of soil properties rather than employ vague environmental criteria.

Unsatisfactory and often confusing as terms like "savanna soils" and "forest soils" necessarily are, their usage is nevertheless perpetuated by by people from disciplines other than soil science. It is the purpose of this

paper to discuss, in general terms, the diversity of soils found under savanna vegetation. It should make clear that the term "savanna soils" has at best an ecological and/or geographical meaning, but is of doubtful pedologic significance.

2. Tropical Savannas

2.1 Definition of Savanna

The term "savanna" probably had its origin in Central America as a Carib word for any area not covered with forest (1). It is now used throughout the tropics to characterize plant communities in which grasses (Graminae) and sedges (Cyperaceae) are important. It should be emphasized that savannas comprise a great range of communities from treeless grassland to woodland with continuous herbaceous undergrowth.

Savannas may be divided into three categories on the basis of the grass cover they support (1):

I. High grass - low tree savanna

II. Acacia - tall grass savanna

III. Acacia - desert grass savanna

2.2 Distribution

Figure 1 shows the world-wide occurrence and distribution of savannas in a generalized way, and table 1 lists savanna types and their typical occurrence

in tropical countries.

The fact that savanna is more widespread in Africa than in any other continent, is perhaps related to human activities over more than 10,000 years. There is even an eyewitness account of great fires covering the landscape as early as the fifth century B.C. (1).

2.3 Theories of Savanna Formation

There exists no general agreement among authorities as regards the origin of savannas. The conflicting theories are discussed here only inasmuch as they are of interest to the pedologist.

Contrary to the opinion of 19th century plant geographers there is no clear correlation between climate and the occurrence of savannas, and there is no particular "savanna climate" as postulated by SCHIMPER (3). One observation which caused some authorities to abandon the idea of "climatic savannas" is the extreme sharpness of the present boundary between savanna and forest. This and other facts lend support to the "pyrogenous theory". There can be no doubt that frequent burning off, as practiced almost universilly in Africa, must have considerable impact on the plant community. In fact, the majority of savanna trees, particularly in Africa, are fire-resistant because of the peculiar structure of their trunks.

While there is much evidence in favour of the fire theory ("plagioclimax status") there exist savannas the formation of which appears to be controlled by local soil conditions. The Llanos of the Orinoco Basin are a good example for this type (1). The sub-soil of much of the Llanos is very heavy and frequently water-logged during the pronounced rainy season. This wetness, contrasted with the extreme dryness of the soil during the dry season may prevent the germination of most species of trees. This constitutes in essence a geomorphic control of savanna formation, which has also been suggested for some savannas of central Brazil.

3. Soils of Tropical Savannas

3.1 Taxonomic Range

The soils found in areas of tropical savanna exhibit a great taxonomic diversity. A soil map of the tropics recently published by the National Academy of Sciences (2) and partially reproduced in figure 2 indicates that eight out of the ten orders recognized in Soil Taxonomy (4) are encountered in savanna areas. The suborders differentiated are listed in table 2.

3.2 Correlation of Savanna Types and Suborders

Table 3 indicates that there exists very little correlation between the

type of savanna and the soils developed under them. It is noteworthy, however, that all soils found under acacia-dessert savannas have aridic or ustic moisture regimes, i.e. they are dry for more than 90 cummulative days in most years.

3.3 Pedogenetic Considerations

In view of the considerable variation of soil-forming found in savanna areas, the pedologic diversity is not surprising. Climate may be humid or arid; all types of parent material are encountered; the geomorphic surfaces where these soils occur may be Recent or Tertiary or older; and vegetation may be desert grassland or herbaceous woodland. All these factors control pedogenesis, the soils must necessarily vary accordingly.

No one environmental factor can be singled out as the dominating soil-forming condition for all savanna soils. Considering the wide taxonomic range, it is particularly doubtful if the savanna vegetation per se influences pedogenesis. The cause-effect relations appears to be such that climate, human activity and/or soil conditions the occurrence of savanna vegetation rather than savanna vegetation controlling soil formation.

Pedogenetic considerations are further complicated by the fact that the climate was subject to considerable fluctuations during the Pleistocene corresponding with glacial and interstadial periods in the higher latitudes. Thus the advanced stages of weathering exhibited in the Oxisols on old geo-

morphic surfaces which now support savanna vegetation are likely related to periods with higher rainfall than today.

4. Salient Properties of the Soils of Tropical Savannas

The following is a brief description of the salient properties of the eight orders encountered in savanna areas. Discussed are mainly those criteria which are employed in Soil Taxonomy (4) to differentiate soils at the order level, the highest category of the system.

4.1 Alfisols

The main diagnostic features of Alfisols is the presence of a horizon of clay illuviation, the argillic horizon, and a base saturation of more than 35 percent in the lower part of this horizon. In the tropics they may be considered intermediate between Inceptisols and Ultisols. Alfisols comprise soils that were formerly named Gray-Brown Podzolic and Noncalcic Brown soils. In the FAO system they are either Luvisols or Planosols.

4.2 Aridisols

Aridisols are primarily the soils of dry places. They normally have aridic moisture regimes and subsurface horizons of salt accumulation, such as natric, salic, calcic and gypsic horizons. Because many deserts once had a more

humid climate than the present, argillic horizons are also common. These desert soils are classified as Yermosols and Xerosols in the FAO system.

4.3 Entisols

Entisols tend to be of recent origin and their youthfulness is reflected in the absence of genetic horizons. The lack of horizonation may also be due to a regolith consisting of highly resistant minerals, such as quartz, or may be caused by the addition of fresh material at a faster pace than horizon development proceeds. These soils have been identified as Alluvial Soils, Regosols or Lithosols, and are classified as Fluvisols, Regosols or Arenosols in the FAO scheme.

4.4 Inceptisols

Inceptisols are intended to include those soils exhibiting initial stages of soil formation. They show no evidence of significant illuviation, eluviation or extreme weathering, but they have one or more of the diagnostic horizons that are thought to form rather quickly, such as a mollic epipedon or a cambic horizon. A suborder of importance in the tropic are the Andepts which comprise the soils derived from volcanic ash.

This order includes soils that have been called Brown Forest Soils and are Cambisols, Gleysols or Andosols in the FAO system.

4.5 Mollisols

The central concept of Mollisols is one of soils having a mollic epipedon, a usually dark and thick surface horizon with more than 1 percent organic matter and 50 percent or more base saturation. These soils were named Chernozems, Chestnut Soils and Rendizinas. The few Mollisols found in the tropics are mainly Phaeozems in the FAO system.

4.6 Oxisols

Oxisols represent advenced stages of weathering and are characterized by the presence of an oxic horizon or an aquic moisture regime and plinthite. The oxic horizon is a mixture of hydrated oxides of iron and aluminium and various 1:1 lattice clays. It is nearly completely devoid of weatherable minerals and has CEC of 16 meq/100 g clay or less. Many of the soils that were formerly called Latosols, Laterites, Ferallites or Terra Roxa are now classified as Oxisols. In the Fao system they are Ferrasols.

4.7 Ultisols

The order Ultisols include those soils that have an argillic horizon which has a base saturation of less than 35 percent in its lower part. Although weathering and soil evaluation is quite advanced there are still some weatherable

minerals present that can release bases. The high amounts of exchangable aluminum that are usually present in Ultisols is their chief chemical constraint. Most of the soils formely called Red-Yellow Podzolics and Reddish-Brown Lateritic Soils are now classified as Ultisols in Soil Taxonomy and as Acrisols in theFAO scheme.

4.8 Vertisols

Vertisols are more than 50 cm. thick soils that contain more than 30 percent clay of the 2:1 lattice type. They typically occur in climates with marked seasonality, have gilgaí relief and develop cracks in the dry season. Although normally dark-colored, they frequently have less than 2 percent organic matter. Both CEC and base saturation is generally high in these soils. They have gone by a variety of names which include Grumusols, Regur, Tirs, Black Cotton Soil and Tropical Black Clays. They are now called Vertisols in both Soil Taxonomy and the FAO scheme.

4.9 Summary

In light of the above discussion it is obvious that savanna soils differ greatly in environmental, physical, chemical, mineralogical properties. The approximate range in some key properties of these soils summarized in table 4. Probably the only property that is common to all savanna soils

is moisture stress for some unspecified time of the year.

5. Conclusions

It is obvious from the preceeding discussion that the term savanna soils carries exceedinly litter pedologic information. Variation in key soil and environmental properties is such that no single criterion exists that applies to all savanna soils. Because of this wide range in soil characteristics important to soil management, great care must be taken in extrapolating agronomic experience from one savanna soil to another.

The term "savanna soils" is a carry-over from the early days of soil science and should long since have become obsolete Soil Taxonomy provides accurately defined classes to characterize "savanna soils" in a way that is more meaninful to both agronomist and pedologists.

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Figure 1 AREAS OF TROPICAL SAVANNA

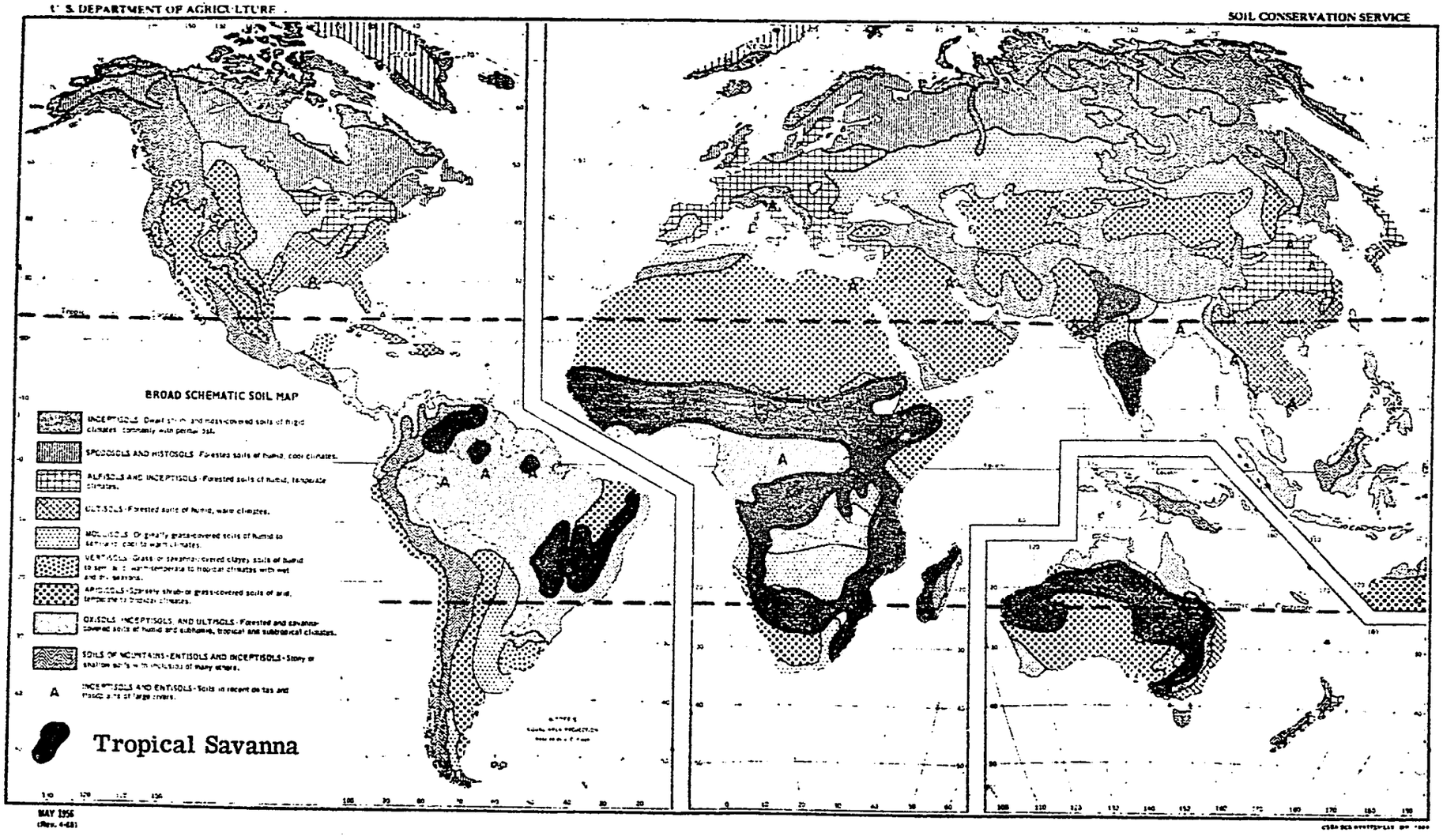
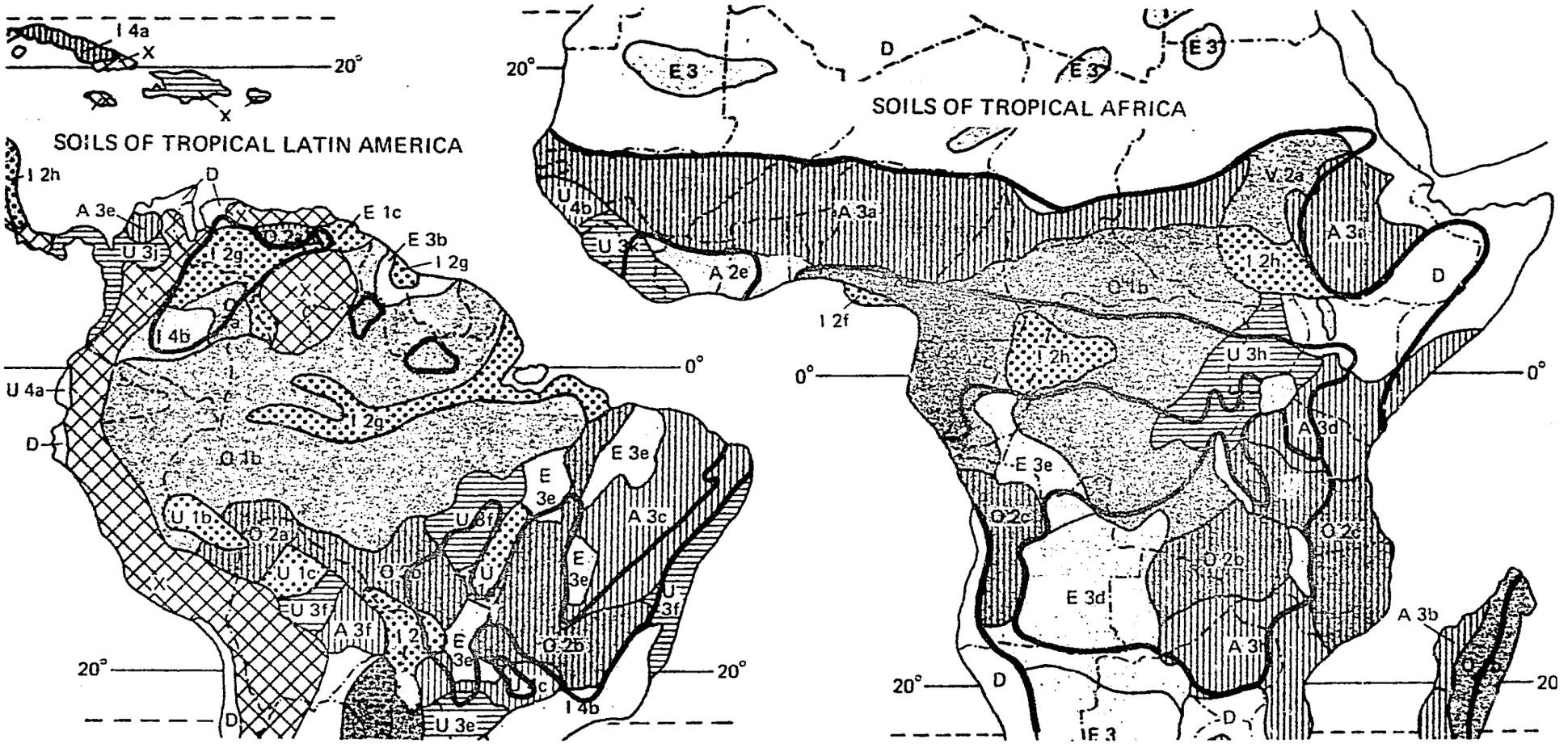


Figure 2

SOILS OF THE TROPICS



LEGENDS—Orders and Suborders*

ALFISOLS	A 2 *Udalfs*	INCEPTISOLS	I 4 *Tropepts*	ULTISOLS	U 1 *Aquults*	VERTISOLS	V 2 *Usterts*
	A 3 *Ustalfs*	MOLLISOLS	*Albolls*		U 2 *Humults*	OTHER	X *Mountain areas*
ARIDISOLS	D		*Rendolls*		U 3 *Udults*		*Lakes*
ENTISOLS	E 1 *Aquents*		*Ustolls*		U 4 *Ustults*		
	E 3 *Psamments*	OXISOLS	*Orthox*				
INCEPTISOLS	I 2 *Aquepts*		O 2 *Ustox*				

Areas of Tropical Savanna

Table 1: Occurrence of Savannas in the Tropics

Savanna Type	Occurrence
High grass - low tree savanna (Elephant grass savanna)	Guinea, Sierra Leone, northern Ghana, central Nigeria, northern Congo, southern Sudan, Uganda
	South-western Congo, northern Angola
Acacia - tall grass savanna	Gambia, Senegal, northern Nigeria, central Sudan, southern Kenya, eastern Tanzania, Mozambique, Rhodesia, Botswana, Madagascar
	Brazil (Mato Grosso), Llanos of the Orinoco Basin Australia (Queensland) India (NE of Deccan)
Acacia - desert grass savanna	Senegal, Eritrea, SE Ethiopia, northern Kenya, Botswana Australia (Queensland, Northern Territory) India (Wand SE Deccan)

Table 2 : Orders and Suborders of Soils Found under Tropical Savanna

Order	Suborder
Alfisols	Udalfs, Ustalfs
Aridisols	
Entisols	Aquents, Psamments
Inceptisols	Andepts, Aquepts, Tropepts
Mollisols	Ustolls
Oxisols	Orthox, Ustox
Ultisols	Udults, Ustults
Vertisols	Usterts

Table 3: Relationships between Savanna Types and Suborders

Savanna Type	Suborders
High grass - low tree savanna	Udalfs, Ustalfs Psamments Aquepts Orthox, Ustox Usterts
Acacia - tall grass savanna	Udalfs, Ustalfs Andepts, Aquents, Psamments Tropepts Ustolls Orthox, Ustox Aquults, Udults, Ustults
Acacia - desert grass savanna	Ustalfs Aridisols Psamments Ustults Usterts

Table 4: General Range in some Key Properties of Soils of Tropical Savannas

Property	Approximate Range
Texture	Sand to clay
Solum Thickness	Shallow to deep
Infiltration Rate	Low to high
pH	acid to alkaline
CEC	~5 to 50 meq/100 g soil
Base Saturation	10 to 100 %
Organic Matter	~1 to 10 %
Mineralogy	theoretically all classes
Moisture regime	aridic, ustic, udic, aquic
Temperature regime	isohyperthermic, isothermic
Climate	humid to arid
Geomorphology	Recent to Tertiary surfaces
Parent Rock	All types of rocks