# T H E   T R O P I C A L   E N V I R O N M E N T

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Contents





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# THE TROPICAL ENVIRONMENT

## 1 - INTRODUCTION

What does tropical mean?

For most people it is a region of the world with high annual rainfall and humidity, high temperatures and with evergreen tropical forest.

With the exception of temperature, this concept is far from true, because not more than 24% of the tropical regions present this conditions.

The geographical concept.

This concept states that tropical is that part of the world located between the Tropics of Cancer and the Tropic of Capricorn, or between 23.5$^{o}$ north and south of the Equator. This is the part of the world where the sun passes directly overhead , in some parts of the year(Figure 1).

Why is the region so important?

- Comprises 38% of the earths land surface ( 5 billion hectars) and shelters 45% of the world population (>2 billion people).

With exception of tropical Australia, China, Pakistan, Hawaii, parts of Brazil and northern Argentina, it comprises developing or underdeveloped countries (Figure 1).

-In most tropical areas, if climatic conditions are favorable , soils limit crop production, due to low fertility and/ or presence of toxic elements, high salinity, low water holding capacity,shallow soils and rock outcrops, crusting and surface sealing, craking, steep slopes.

- Since this environment has been less intensively studied than the colder regions, it is cientifically more attractive, and there are more problems to be investigated.

- For development purposes the environmental conditions, as geology, geomorphology, climate, vegetation, soil and land use and sicio-economical conditions must be analysed and understood. The aims of this course are to present and discuss some of this conditions,with emphasis os soils and land use of Brazil.

## 2 - GEOLOGY AND GEOMORPHOLOGY

The geology and geomorphology of the tropical regions is as complex as in most other regions of the world.

Most of the tropics (77%) present elevations below 900m, in 20% the altitudes range from 900 to 1800 m and only in 3% elevations exceed 1800m (Andes in south and central America,Ethiopia and Kenya in Africa and parts of Burma and Indochina (Figure 2).

### 2.1 - The tropical America

The Andean Cordillera, the Central America highlands, the Guyana and Brazilian shields, the Amazon , Orinoco, and Paraná basins and the Caribbean Islands, are the main surface features of tropical America.

The Andes and Central America highlands rose from the sea during Tertiary period, with great vulcanic activity. The Andes have flat intermountain valleys where population is high.

The Guyana and Brazilian shields are crystalline plateaus (granite and gneiss) and originated during Archean and Paleozoic periods. Most of them are covered by Tertiary and Quaternary sediments originated from erosion of rocks after the Andes uplift.

The Amazon, Orinoco, and Paranà basins are Tertiary and Quaternary in age and the sediments originated from erosion of the surrounding highlands. Recent sediments are found in the present fluvial valleys.

## 2.2 - The tropical Africa

This continent is a worn-down crystalline plateau, two thi ds of which is covered by sediments which filled in the basins, with exception of Ethiopia and Kenya highlands.

The oldest rocks (Precambrian) are found in the east and west , parallel to the coast and consist of granite, gneiss and schist. During Cambrian,Ordovician and Silurian periods, great parts of Africa were covered by sea,but little from these sedimentary rocks remain.After uplift, great parts of the interland were occupied by lakes, mainly in Carboniferous time and sediments from which remain in the Congo basin. During Jurassic period West Africa was affected by vulcanic activity, originating basaltic rocks, and, afterwards the Sahara and West coast were covered by the sea, originating marine deposits in this region.Most of the continent is today covered by sediments originated by the intense weathering ,erosional and depositional processes, which occurred mainly in Tertiary and Pleistocene.

## 2.3 - The Tropical Asia

The mainland of southeast Asia, the tropical region of this continent, is a combination of mountain ranges, as the basaltic Plateau of India and the highlands of Thailand and Laos, and large valleys, as the Ganges, Brahmaputra, Irrawaddy, Chao ,Phya, and Mekong, with recent sedimentary deposits, the rice growing flat lands of Asia. Indonesia, Philippine and many Pacific islands have benn affected by vulcanic activities.

# 3 - CLIMATE,VEGETATION,SOILS AND LAND USE

Since natural vegetation and land use in the tropics are closely related to climatic conditions, these factors will be analyses in conjuction and with the general distribution of soils.

Rainfall intensity and distribution is the main parameter used to differentiate tropical climates, for agricultural purposes. The evaluation of monthly rainfall variability in each tropical region is very important for agricultural development programs. The temperature, with the exception of the tropical highlands, is constantly high throughout the year in tropical lowlands.,which comprises 77% of this region, The lack of limitations in temperature for cultivated crops, gives high agricultural potential to the tropics.

To simplify the subject, we will consider only four main climatic regions in the tropics:humid, with more than 9.5 months of water availability;sub-humid, with 4.5 to 9.5 humid months (seasonal);semi-arid, with 2.5 to 4.5 humid months, and, arid, with less than 2.5 humid months (Table 1 and Figure 3). The tropical mountain regions, because of lower temperatures will be analysed separetely.

## 3.1 - The tropical humid region

The larger areas in which this climatic conditions occur, are found in the upper Amazon basin, the Congo basin, most of Indonesia, Malaysia and parts of Philippines. Smallerr areas are found at Cental America, West Africa and in many Pacific islands.

Rainfall exceeds potetntial evapotranspiration in all or most months of the year (Figure 4).The temperatures are constantly high (isohy erthermic).The original vegetation consisted of evergreen tropical forest,which with the exception of the Amazon basin and parts of Indonesia, has been replaced by crops as rice, cassava, cacao,bananas, rubber, coconuts and other crops, mainly in shifting cultivation system. This situation is now changing because of colonization projects in Indonesis (Transmigration) and Amazon region. Lets hope that the more intense use of this weak environment will not result in its degradation.

The soils in this region are mostly very deep, yellowish in collour, strongly weathered and acid , consisting of Xanthic Ferralsols, Ferric Acrisols, Ferralic Cambisols and Arenosols. Fluvisols and Plinthic Acrisols and Luvisols occur in the flood plains, as well as Gleysols.

3.2 - The tropical sub-humid region

In this climatic region well defined wet and dry seasons alternate yearly. Somewhat lower solar radiation and temperatures characterize the wet season while higher temperatures and solar radiation are indicative of the dry season (Figure 5).The monsonic type of climate of Asia is included in this class.

This climate is found in about 50% of the tropics, covering large areas in Central Brazil, Llanos of Colombia and Venezuela, Pacific coast of Central America, large areas between the Sahara and Kalahari deserts in Africa, most of India, Indochina and belt in northern Australia.

In Central Brasil, Llanos of Colombia and Venezuela, northern Mozambique, Zambia and Tanzania , very deep reddish yellow to red ,strongly weathered, very deep and acid Rhodic And Acric Ferralsos are found, on old and stable surfaces. In the less stable surfaces of west and east Africa, southern Thailand, less deep, less weathered and moderately acid Ferric Acrisols predominate. In the lower lands of Asia Fluvisols, Gleysols, Gleyic Acrisols occur.

The natural vegetatation in the sub-humid ,well drained soils is mainly savanna (cerrado) or semideciduos or deciduos forest. Until recently it was though that these areas (soils) were suitable only for extensive grazing. Experiences in Central Brasil have proven that agricultural development with high technological management can be succesfull in this soils and so the cerrado is been replaced by cultivated grass and agricultural crops (dry rice, maize, cotton, soybeans). The lowland soils of Asia are intensively cultivated with rice and other crops.

3.3 - The tropical semi-arid region

This region presents a rainy period of 135 days or less, mostly with torrential storms, during which one unirrigated crop, as rice, beans, maize, sorghum, cotton can be grown. The precipitation and temperature distribution of this region is illustrated in Figure 6, with data from Iguatu station, northeastern Brazil.

The largest areas affected by semi-arid climatic conditions is a belt south of the Sahara desert in Equatorial Africa, the Kalahari Desert in south west Africa, northeastern Brazil, north Australia and northern Venezuela and Mexico.

Many different soils and land uses are found in this regions. Because of intense seasonal precipitation on almost bare soil, erosion is a serious problem ,particularly in ondulating surfaces with Cambisols, Lithosols and Rankers. Many soils present surface crosting and sealing (Luvisosl), high throughout (Solonchak) or sub-surface salinity (Solonetz and Solodic Planosols) hardening and cracking (Vertisols) , low effective depth for rooting (Lithosols) or sandy texture (Arenosols), which limit crop production.

The natural vegetation of thorny shrubs, cactus and grasses has mostly been replaced by cultivated crops.

3.4 - The tropical arid region

The Sahara, Arabian, Somali and Australian deserts and narrow coastal strips in Peru, Chile and southwest Africa compose the tropical regions affected by arid climate, with less than 2.5 humid months . This region covers about 11% of the tropics. Figure 7, with data of the Reggan Station of Algeria, illustrates the climatic conditions of the arid tropical regions. Without irrigation only nomaly grazing is possible in some of these areas, but when irrigated high yields of crops as cotton, rice , sugarcane ,vegetables and other crops may be obtained withoud other great inputs.

Beside dunes,which characterize the African deserts, in these regions occur also soils with high salinity throughout (Solonchak) or at some depth (Solonets and saline phases of Cambisols),and Yermosols and Xerosols.Vegetation , if not completely absent,is very scarce and consist of shrubs,cactus and grasses.

### 3.5 - The tropical highlands

Since the mean annual temperature decreases by more or less 0.6°C for every 100m increase in elevation, the tropical areas with more than 900m altitude present lower temperatures than the lowlands.The precipitation is variable. Mountains in eastern parts of the Andes, in Peru and Chile are desertic,because the moist air moving upslope in the western flank, discharges most of the precipitation before reaching the top. Highlands in Mexico,Guatemala,CostaRica, Colombia,Equador,Peru,Bolivia,Kenya and Ethiopia,receive regular rainfall (Figure 8) and are areas where large parts of population is located and agriculture developed in these countries.

Two main soil groups are found in the tropical highlands:a) the Andosols, developed from vulcanic material, which are moderately deep and have reasonable productivity, and b) Cambisols, Lithosols ,Rankers and other soils, in which slope, erosion ,limitations to root growth are serious problems for agricultural development.

The original vegetation in the humid highlands was forest,which has been mostly replaced by cultyvated crops.

## 4 - ADDITIONAL SUGESTED READING

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TABLE 1. Major climatic regions and predominant vegetation and areas (in million ha) in the tropics (Adapted from Sanchez, 1976).

| CLIMATIC REGIONS | HUMID MONTHS | VEGETATION | DISTRIBUTION AFRICA | AMERICA | ASIA | TOTAL | % |
|---|---|---|---|---|---|---|---|
| Humid | 9.5 | Evergreen Forest | 197 | 646 | 348 | 1190 | 24 |
| Sub-Humid | 4.5-9.5 | Savanna & Semi-deciduos forest | 1144 | 802 | 484 | 2430 | 49 |
| Semi-Arid | 2.5-4.5 | Shrubs & grass | 486 | 84 | 201 | 771 | 16 |
| Arid | 2.5 | Bare & Shrubs | 304 | 25 | 229 | 558 | 11 |

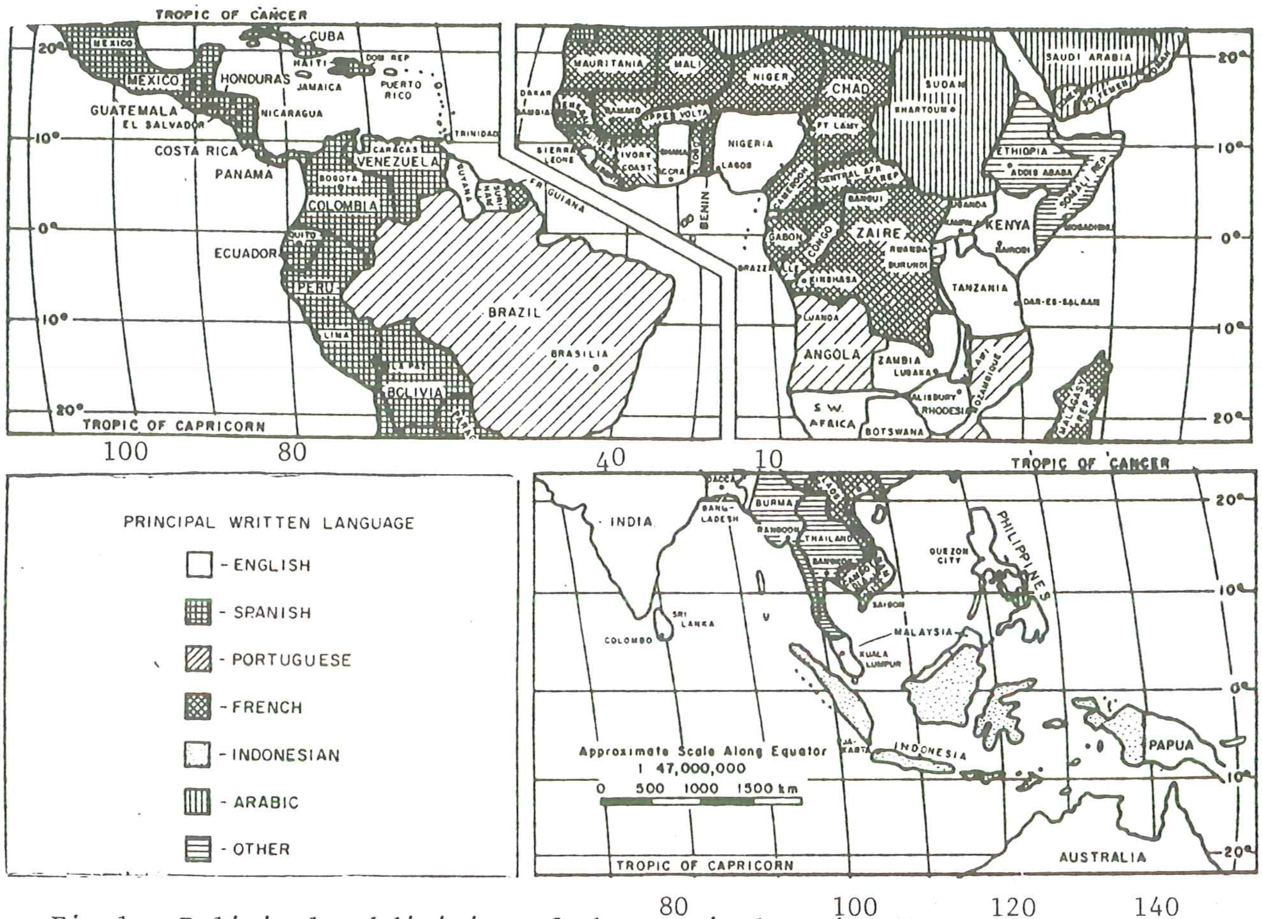


Fig.1 . Political subdivision of the tropical region.(Adapted from Sanchez. 1976).

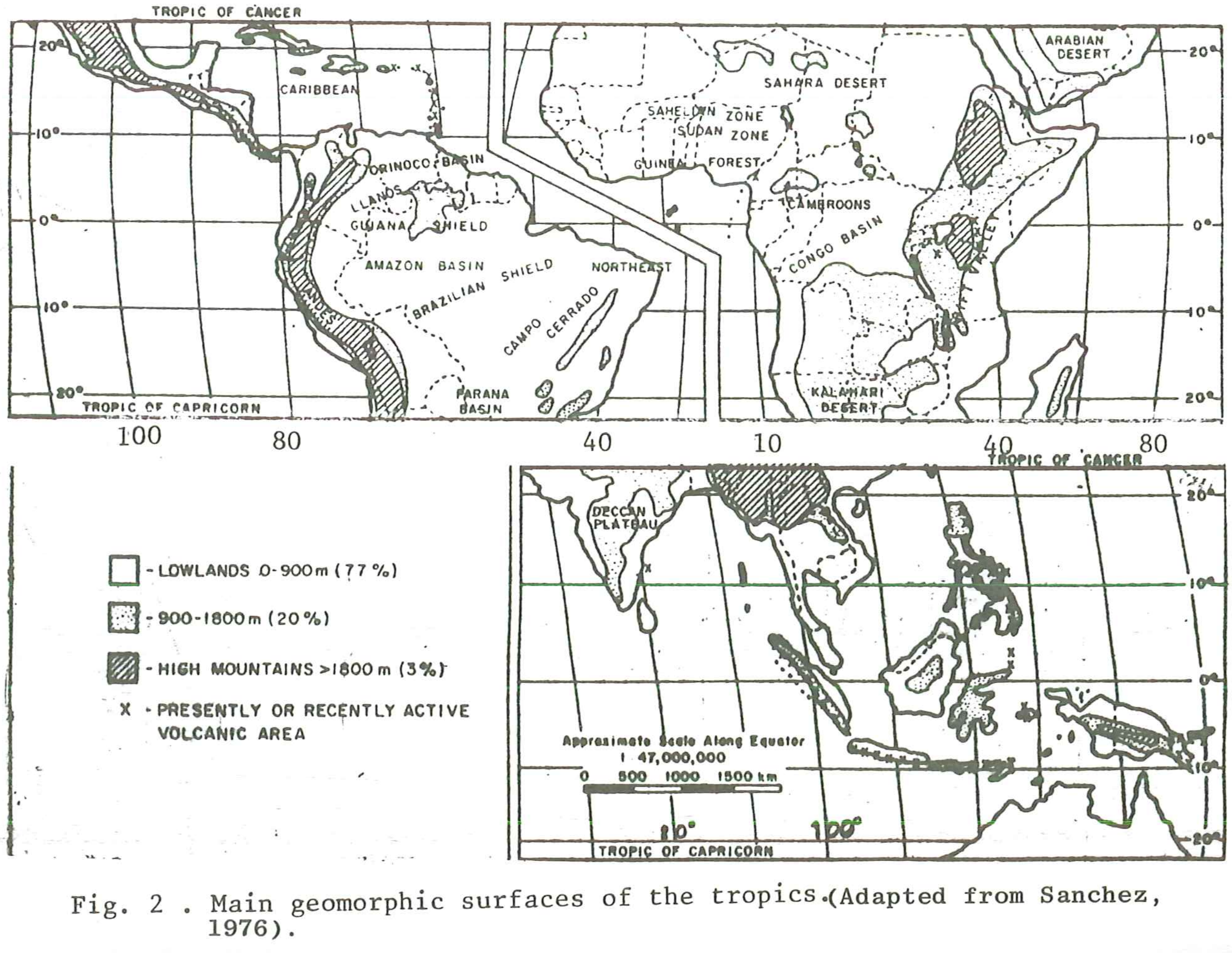


Fig. 2 . Main geomorphic surfaces of the tropics.(Adapted from Sanchez, 1976).

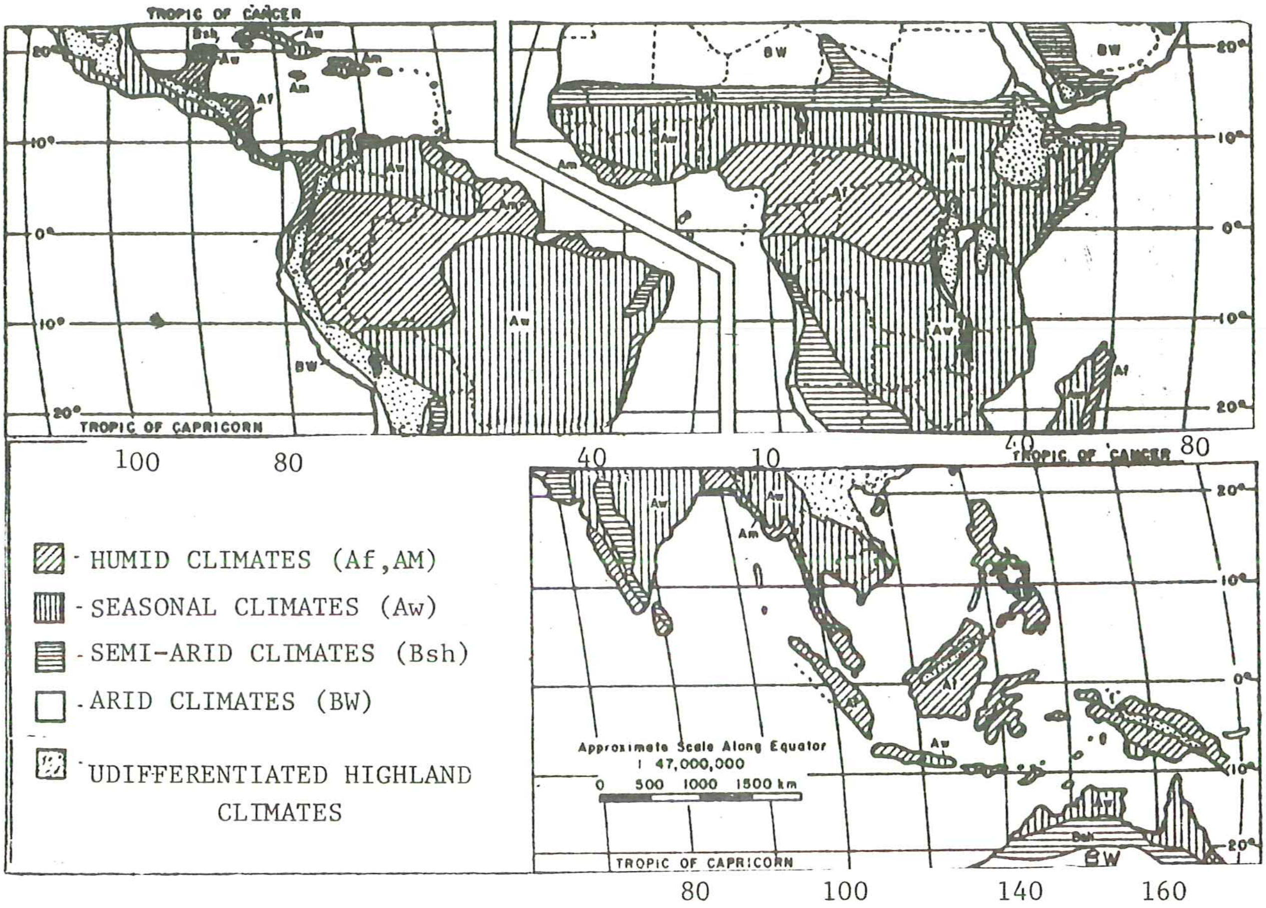


Fig. 3 .Climatic regions of the tropics, adapted from Sanchez (1976).

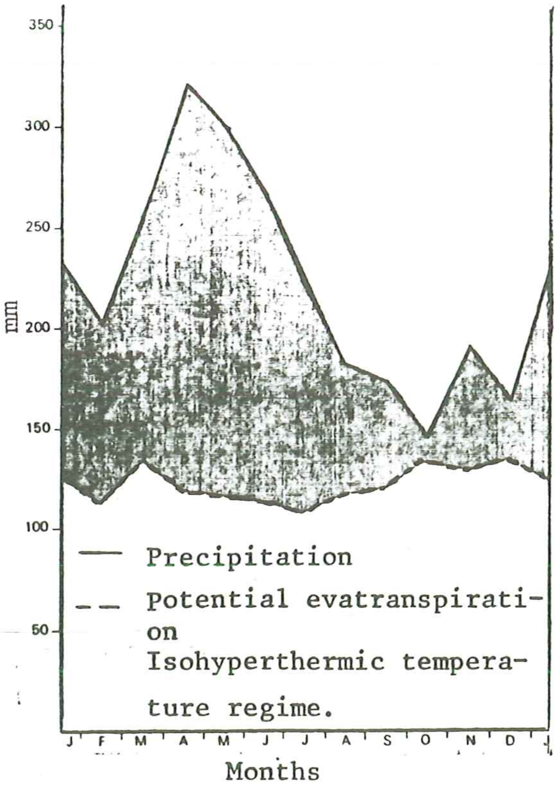


Fig. 4 . Precipitation x potential evapotranspiration (Thornthwaite & Mather, 1955) balance at Santa Isabel do Rio Negro Station, Amazon Basin, Brasil, with a humid tropical climate.

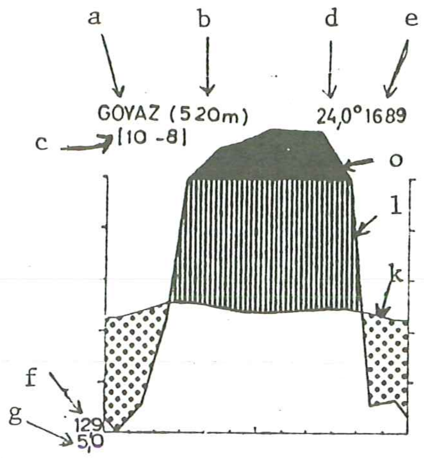


Fig.5.Climatic data of Goyas Station, Central Brazil, tropical sub-humid region.

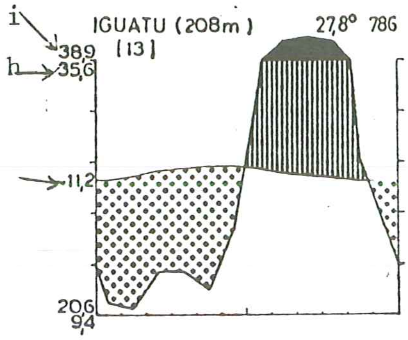


Fig. 6. Climatic data of Iguatu Station, northeastern Brazil.tropical semi-arid region.

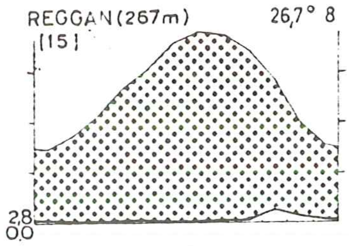


Fig.7.Climatic data of Reggan Station, Algeria, tropical arid region.

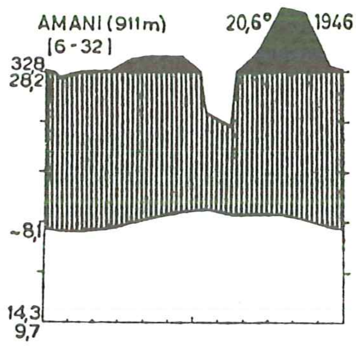


Fig.8.Climatic data of Amani station, Tanzamia,tropical higl-land,

Legend:

a)Name of station.

b)Altitude

c)Number of days of observation

d)Mean annual temperature (°C)

e)Mean annual precipitation

f)Mean temperature of coldest month

g)Absolute minimum temperature

h)Mean of hottest month

i)Absolute máximum temperatur

k)Mean temperatur

l)Mean precipitation

O)Precipitation above 100 mm.

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# AMAZON SOILS

## 1. The geology.

Brazilian Amazonia consists of a low, sedimentary area, the Amazon valley proper, and parts of the cristalline shields of central Brazil and the Guianas (fig.1). The cristalline shields are of pre-Cambrian age and mainly consist of granites, gneisses and mica schists. The sedimentary part of Amazonia consists of several basins, namely the basin of Acre, of the Amazon proper, of Marajó and that of Maranhão. The sedimantary part has at its surface only narrow bands of Paleozoic-Mesozoic deposits, of varying character; the greater part consists of Tertiary unconsolidated sediments, which are kaolinitic clays and quartz sands. The Pleistocene sediments, which are similar in character to the Tertiary ones, are thin, and their extend has been reported to be limited. Holocene deposits comprise a small area, much less than was estimated by early explorers of Amazonia.

## 2. The geomorphology.

In the watershed regions to the north and south of the Amazon river system the following geomorphological units can be distinguished:

1. Undulating terrains with outcropping, pre-Cambrian, cristalline basement.
2. Undulating terrains with outcropping Paleozoic, Mesozoic or early Tertiary deposits.
3. Two peneplanation surfaces inside the area designated as cristalline on the geological maps.

The broad axial part of Amazonia consists of:

4. Flat plateau land, known as Amazon-Planalto, and of Plio-Pleistocene age.
5. Upland terrains at a lower level, fashioned to terraces at various levels, and of Pleistocene age. (The units 4 and 5 are designated together as Planicie ).
6. Lowlands of Holocene age.

## 3. The areal distribution of soils.

The areal distribution of soils in the Amazon is shown in table 1 at the order, suborder and great group level. This table is considered tentative and subjected to change as more detailed surveys become available. FAO-equivalents,named in part 4, have been added.

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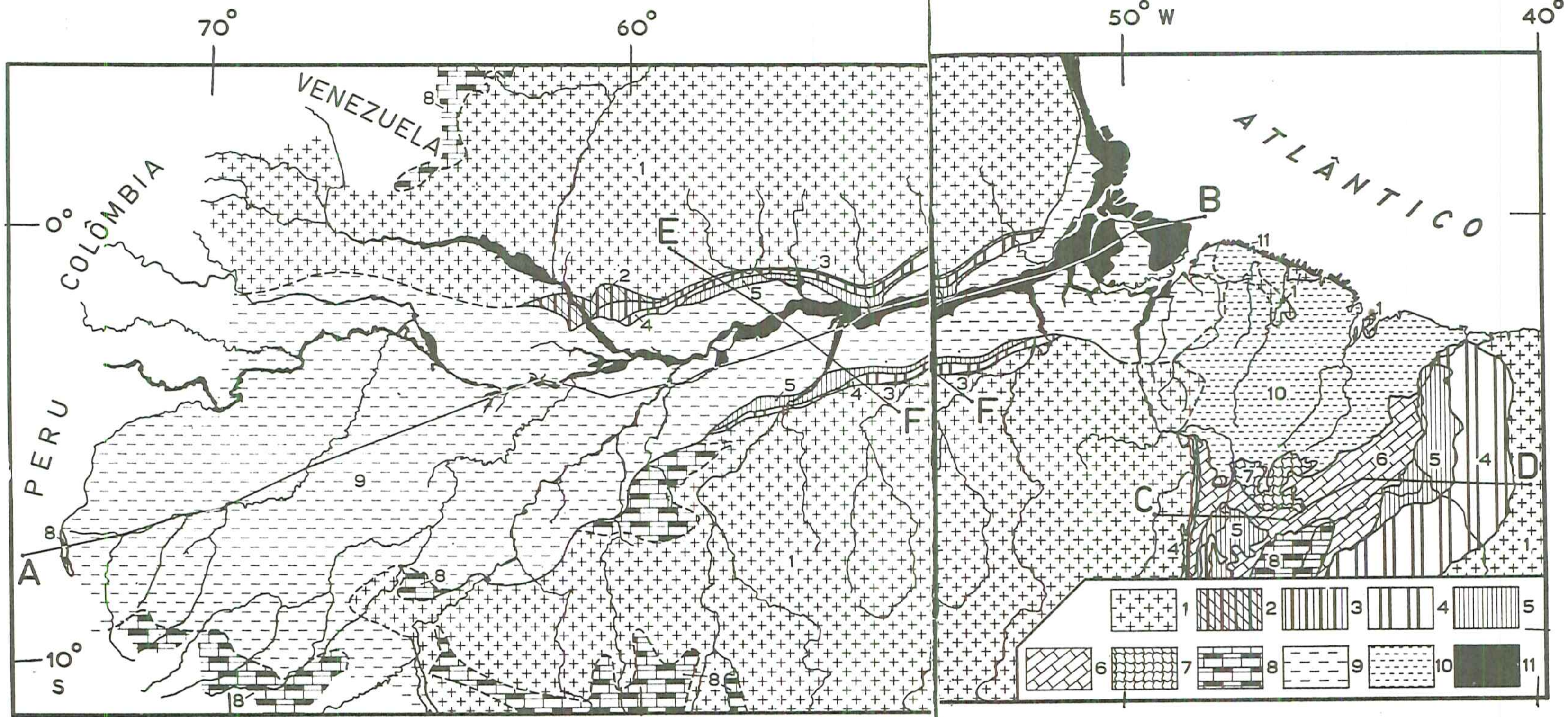



1. Pre-Cambrian/*Pré-cambriano*

2. Pre-Silurian/*Pré-siluriano*

3. Silurian/*Siluriano*

4. Devonian/*Devoniano*

5. Carboniferous/*Carbonífero*

6. Jura-Triassic/*Jura-Triásico*

7. Jurassic (diabase)/*Jurásico (diabase)*

8. Mesozoic undifferentiated, probably largely Cretaceous/ *Mesozóico não diferenciado, provàvelmente mormente Cretáceo*

9. Tertiary and Pleistocene/ *Terciário e Pleistoceno*

10. Cretaceous, Tertiary and Pleistocene/*Cretáceo, Terciário e Pleistoceno*

11. Holocene and inland water/ *Holoceno e água no interior*

*ig. 5 Mapa geológico esquemático da Amazônia brasileira. Do mapa preliminar da* PETROBRÁS (1961) *o último mapa geológico do Brasil* (LAMEGO, 1960). *O Holoceno foi esboçado de mapas básicos preli- inares da* AAF (1942), *mapas de Inventário Florestal e observações pessoais*

*Fig. 5 Schematic geological map of Brazilian Amazonia. From preliminary map of* PETROBRÁS *(1961), and the latest geological map of Brazil* (LAMEGO, 1960). *The Holocene sketched from AAF preliminary base maps (1942), Forest Inventory maps, and personal observations*

fig.1

The majority of soils are classified as Oxisols (Ferralsols) and Ultisols (Acrisols), which together account for 75% of the region. Following in extensiveness are the Entisols (Fluvisols), with about 15%, most of which are of alluvial origin found along the river network. The remaining orders cover relatively small areas; Alfisols (Luvisols) 4%, Inceptisols (Cambisols, Gleysols) 3%, Spodosols (Podsols) 2%, and Mollisols and Vertisols with less than 1 procent.

Table 1 shows that 75% of the Amazon soils are included in five great groups: Haplortox (29%), Tropudults (17%), Acrortox (14%), Fluvaquents (9%), and Paleudults (6%).

Fig. 2 shows the distribution of soils in the Amazon region. The legend (table 2) gives a further comparison between brazilian, FAO, and Soil Taxonomy system.

Table 1. Soil distribution of the Amazon region at the great group level. Tentative classification.

| FAO: | Order | Suborder | Great Group | Million hectares | % of Amazon |
|---|---|---|---|---|---|
| Ferralsols | OXISOLS | Orthox | Haplorthox | 137.8 | 28.5 |
| | | | Acrorthox | 67.5 | 14.0 |
| | | | Eutrorthox | 0.3 | 0.1 |
| | | Ustox | Acrustox | 6.6 | 1.4 |
| | | | Haplustox | 4.8 | 1.0 |
| | | | Eutrustox | 2.0 | 0.4 |
| | | Aquox | Plinthaquox | 0.9 | 0.2 |
| | | Total Oxisols: | | 219.9 | 45.5 |
| Acrisols | ULTISOLS | Udults | Tropudults | 83.6 | 17.3 |
| | | | Paleudults | 29.9 | 6.2 |
| | | | Plinthudults | 7.6 | 1.6 |
| | | Aquults | Plinthaquults | 12.2 | 2.5 |
| | | | Tropaquults | 7.1 | 1.5 |
| | | | Paleaquults | 0.7 | 0.1 |
| | | | Albaquults | 0.1 | 0.1 |
| | | Ustults | Rhodustults | 0.5 | 0.1 |
| | | Total Ultisols: | | 141.7 | 29.4 |
| Fluvisols | ENTISOLS | Aquents | Fluvaquents | 44.8 | 9.3 |
| | | | Tropaquents | 6.7 | 1.4 |
| | | | Psammaquents | 2.8 | 0.6 |
| | | | Hydraquents | 0.6 | 0.1 |
| | | Orthents | Troporthents | 6.9 | 1.4 |
| | | Psamments | Quartzipsamments | 5.5 | 1.1 |
| | | Fluvents | Tropofluvents | 4.7 | 1.0 |
| | | Total Entisols: | | 72.0 | 14.9 |
| Luvisols | ALFISOLS | Udalfs | Tropudalfs | 16.5 | 3.4 |
| | | Aqualfs | Tropaqualfs | 3.3 | 0.7 |
| | | Total Alfisols: | | 19.8 | 4.1 |
| Cambisols Gleysols | INCEPTISOLS | Aquepts | Tropaquepts | 10.6 | 2.2 |
| | | | Humaquepts | 0.5 | 0.1 |
| | | Tropepts | Eutropepts | 4.3 | 0.9 |
| | | | Dystropepts | 0.6 | 0.1 |
| | | Total Inceptisols: | | 16.0 | 3.3 |
| Podzols | SPODOSOLS | Aquods | Tropaquods | 10.5 | 2.2 |
| | MOLLISOLS | Udolls | Argiudolls | 2.8 | 0.6 |
| | | Aquolls | Haplaquolls | 0.9 | 0.2 |
| | | Total Mollisols: | | 3.5 | 0.8 |
| Vertisols | VERTISOLS | Uderts | Chromuderts | 0.5 | 0.1 |
| | Total Orders | | | 484.0 | 100.0 |

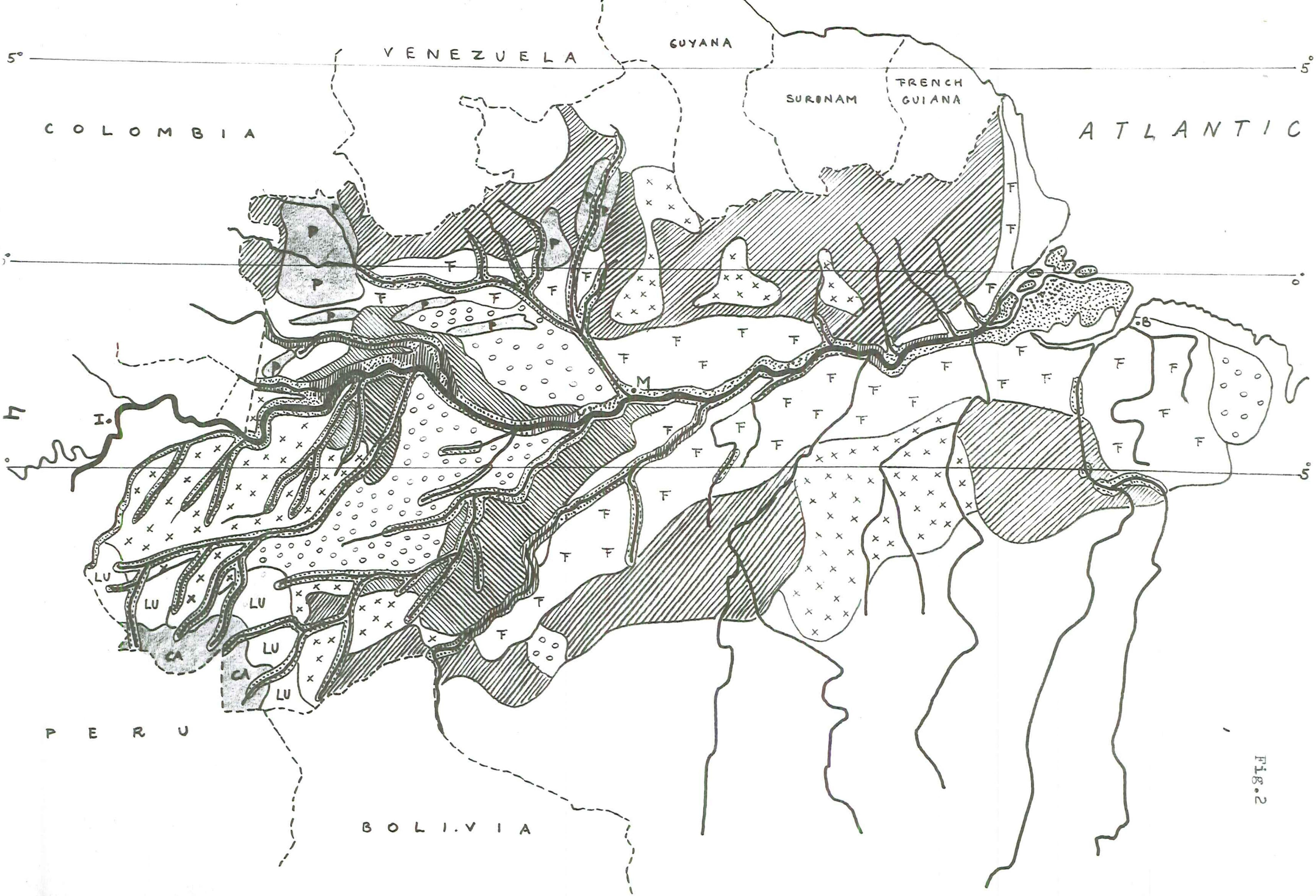

VENEZUELA
GUYANA
SURONAM
FRENCH GUIANA
COLOMBIA
ATLANTIC
PERU
BOLIVIA
5°
0°
5°
M
I.
B
LU
CA
P
F

Fig.2

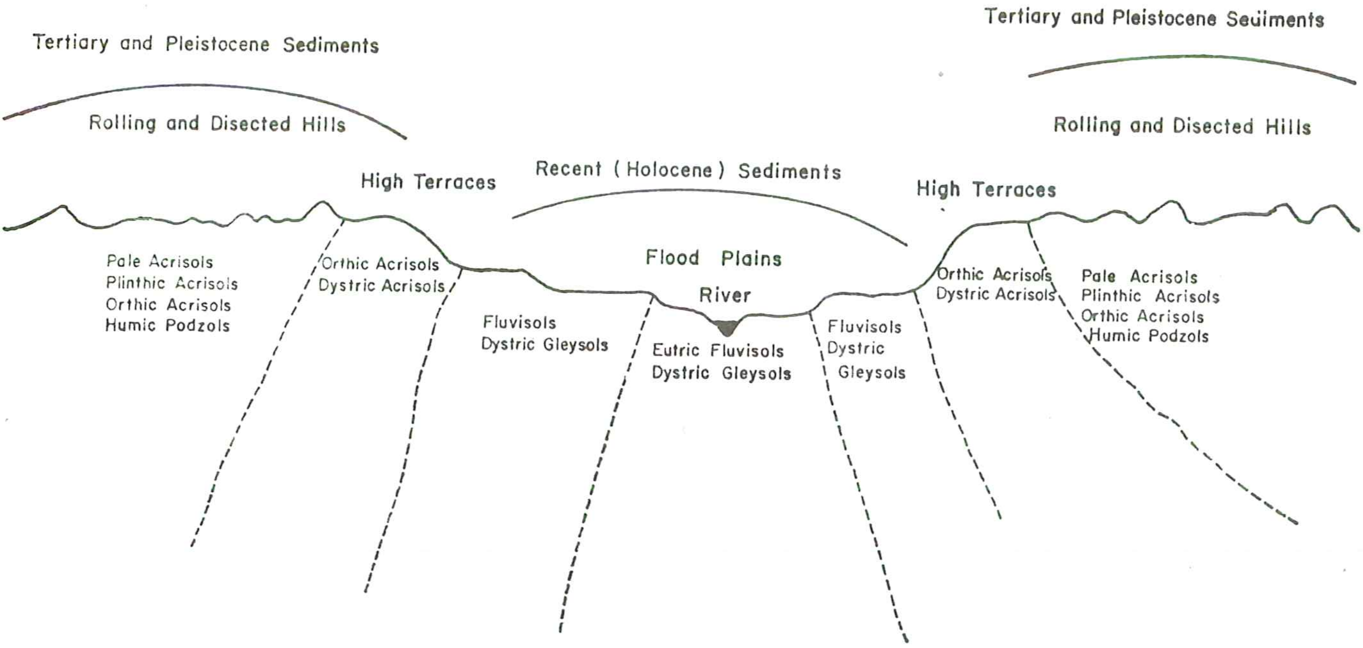
Tabel 2, legend of the soil map (fig.2).

| | | Brazilian Soil Map | FAO. | Soil Tax. |
|---|---|---|---|---|
| | Ppd | Podzólico Plintico distrofico | Plinthic Acrisol | Pinthudult |
| | Fd | Laterita Distrofica Hydromorfica | " " | " |
| | Fd | " " " | " " | " |
| | Pd | Podzolico Vermelho - Amarelo Distrofico | Ferric Acrisol | Paleudult |
| | Lld | Latosollo " " " | Orthic Ferralsol | Hapl-Acrorthox |
| T | La | Latosollo Amarelo Distrofico | Xanthic Ferralsol | Hapl-Acrorthox |
| P | Z | Podzol | Podzol | Tropohumod |
| CA | Ce | Cambisollo Eutrofico | Eutric Cambisol | Eutropept |
| LU | Pe | Podzolico Vermelho - Amarelo Eutrofico | Ferric Luvisol | Alfisol |
| ×x×x× | Pd | Podzolico Vermelho - Amarelo Distrofico | Ferric Acrisol | Paleudult |
| | Gd | Solos Gley | Gleysols | Tropaquept. |
| | A | Solos Aluvias | Fluvisols | Fluvent |

4. The soils in relation to the various geomorphological units.

a) West of Manaus.

The geomorphic configuration of the western Amazon can be divided into two physiographic units: low terraces subjected to flooding of recent alluvial origin, and the second, of an extended undulated surface with various degrees of dissection due to continuous erosion processes, which make up the deep sediments of the Tertiary and Pleistocene.
In the following sections the Morphological characteristics of low land soils in the Amazon plain are described. Fig.3 shows the distribution of such soils in the various landscapes.




igure 3. Soils distribution in the lowlands of the Peruvian Amazon Basin.

Fluvisols : Tropofluvent Great Group (soil taxonomy, 1973), Solos aluvias (Brazilian system). This group combines soils derived from recent alluvial sediments deposited by the large rivers such as the Amazon, Maranón, Ucayali and others. They are distributed along the banks, islands and low terrasses that are periodically flooded.
Predominent Fluvisols are eutric, without major subsurface diagnostic horizons. They have fine sandy loam and silty clay loam texture and stratified morphology.
Due to definite hydromorphic influence, many of these soils have been transformed into Gleysoils which complete the group of soils whitin the floodplains.
Fluvisoils are slightly acid to neutral (pH 6.5-7.0) and contain moderate amounts of organic matter in the A horizon.

Gleysols : Tropaquept Great Group, Subgroup Typic Tropaquept (ST), Solos gley distróficos/eutroficos (Br). Gleysols comprise a group of soils formed from moderately fine material on relatively recent alluvial deposits and are closely associated with eutric fluvisols. Physiographically they are found on low terraces subjected to flooding, with flat or concave topography.
Morphologically they present a thin ochric horizon with partially decomposed organic matter or an umbric, acid, fairly prominent horizon to a depth of 30 cm. This prominence is followed by a cambic horizon with stratified layers or zones with noticeble mottling. Fluctuating water levels vary near the surface.
Chemically they are very acid soils (pH 4.0-5.0), which groups them as Dystric Gleysols with base saturation below 50%. However, on the Brazilian soil map they are divived in dystric (light blue) and dystric/eutric (dark blue).

Ferric Acrisols : Paleudult Great Group (ST), Solos Podzólicos (Br.). This group together with the Plinthic Acrisols perhaps comprises the most extensive soils in the Amazon plain west of Manaus. They rest on lacustrine and marine alluvial material made up of friable kaolinitic clays. They are found in an undulated terrain consisting of old terraces, low hills in various degrees of dissection and slopes ranging from 3 to 50%. Generally they present good drainage, in comparison with plinthic Acrisols.

Morphologically, they have deep intensely weathered profiles. Their main characteristic is the presence of a deep argillic B horizon with a dept of over 1.50 m with a clay content no less than 20% throughout the profile. Generally the A2 is difuse or absent, so the A horizon rests on the argillic. The color of these soils varies from dark brown, to yellow brown, and dark yellowish red. Chemically they are extremely acid (pH under 5.0) with medium to low contents of organic matter. In the argillic B the b.s. is below 35%.

Plinthic Acrisols : Plinthudult Great Group or Plinthic Paleudult Subgroup (ST), Solos Podzólicos/Lateritas (Br.).
As in the case of Ferric Acrisols, they have developed from ancient alluvial sediments based on friable kaolinitic clays located on undulated terraces, low hills (marked hill side formation) with slopes varying from 2 to 30%. Natural drainage of these soils is usually inadequate.

Morphologically they present a strongly weathered and developed profile with extensive mottling, based on iron oxide (pseudo plinthite) over a grayish clay substructure. These soils may be precursors of the true Plinthic Acrisols which present in their profile typical plinthite layers that usually harden irreverible upon exposure, which is the case in the Brazilian Amazon region west of Manaus. In the upper Amazon (Peru) this is not yet the case.

They are extremely acid (pH below 4.0) with medium to low organic matter content and b.s. below 35% in the argillic B.

Podzols : Tropohumod Great Group (ST), Solos Podzol (Br.).
Podzols are generally found in high ancient terraces with an undalated to flat surface and have developed from highly silicic and strongly leached material. Their drainage is free, sometimes excessive (today).

Morphologically they present a thin horizon darkened by large amounts of organic matter which rests on an extensive and deep A2, highly elluviated with silicic or quartz materials, loose structure and white yellowish or whitish color. In groups where the A2 elluvial horizon is shallower, ahumic (Bh) horizon with secondary organic matter coating can be found.

Chemically, they are nutritionally poor and very acid (pH below 4.0).

The Brazilian government is planning a national park in the podzolic area to protect the vegetation.

Ferric Luvisols : Alfisol Order (ST), Solos Podzólicos (Br.).
Found in the south eastern part, near the Peruvian border. Soils having an argillic horizon which has a b.s. of 50% or more. They show fertic properties, but no albic E, calcic horizon or lime and plinthite within 125 cm.

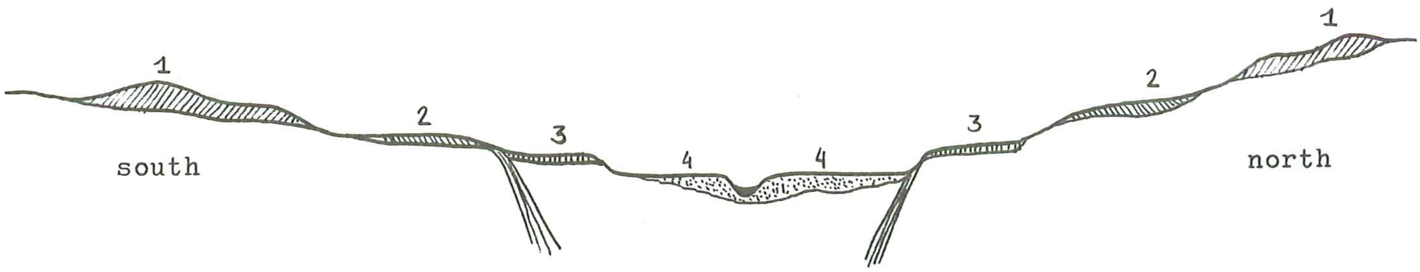
Eutric Cambisols : Eutropept Great Group (ST), Cambisollo Eutrofico (Br.). Also found in south eastern part. Soils having an ochric A and a b.s. of 50% or more at least between 20 and 50 cm; also having a cambic B lacking ferralic or hydromorphic properties.

b) East of Manaus.

Fig.4 shows the distribution of the various soils in this area.

1. Cretaceous peneplanation surface; on this shields Ferric Acrisols, lower: Orthic Ferralsc
2. Early Tertiary peneplanation surface; Xanthic Ferralsols.
3. Plio-Pleistocene Amazon planalto; Xanthic Ferralsols.
4. Pleistocene terraces; Fluvisols and Gleysols.

(3+4: Planicie).



Fluvisols : see a).

Gleysols : see a).

Ferric Acrisols : Found on the higher shields of the Cretaceous peneplanation surface, see a).

Orthic Ferralsols : Haplortox/Acrortox Great Group (ST), Latosollo (Br.). Found along the higher shields, at a lower and more flat terrain. The oxic B is neither red to dusky red nor yellow to pale yellow. For further description see Xanthic Ferralsols.

Xanthic Ferralsols : Haplortox/Acrortox Great Group (ST), Latosollo (Br.). Ferralsols are generally found in the higher terraces where the soil is submitted to deep weathering processes without a major influence of erosion (stable surfaces).

Xanthic Ferralsols have a yellow to pale yellow oxic B horizon, which distinguish them from Orthic Ferralsols.

Both present an ochric epipedon and have a b.s. of less than 50% in some subhorizons of the oxic B within 125 cm. They have a cation exchange capacity of more than 1,5 meq per 100 g clay, which distinguish Haplortox from Acrortox, which have a CEC of 1,5 meq or less per 100 g clay. Plinthite is lacking, but laterite occurs deeper in the profile. Chemically they are extremely acid. Texture: heavy clay (up to 90%).

85-2066/12 EK/tvh

# SOME ASPECTS RELATED TO MORPHOLOGICAL AND PHYSICAL PROPERTIES OF TROPICA SOILS

by Prof. E. Klamt*

## INTRODUCTION

Standard procedures have been established to described the main soil morphological properties: colour, texture, structure, clay skins, consistence, nodules and concretions, pores, types of horizons, boundary characteristics and horizon continuity, thickness and depth of horizon, and other properties to make easy communication between users of soil information.

Objective and clear descriptión of the morphological properties in the field are basic for soil characterization, classification, interpretation and correlation of analytical data and for any kind of use of the informations. Nothing can substitute for them. Detailed analytical examination on samples collected without carefull description of the environmental conditions in which the soil occurs and of their morphological properties, are of little use.

The distinction between soil morphological and analytical properties, particularly physical, is not clear, thus both will be considered, together in, this manuscript.

Emphasis will be given to properties of the very deep, yellow to red, strongly weathered and acid soils of the tropical humid and sub-humid regions.

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## SOIL COLOUR

Colour is the most prominent and observable morphological property of tropical soils, being iron the main soil painter, followed by organic matter. The normal variability of the hue of these soils is from 1YR to 10YR.

In most soil classification systems colour has been and is used as a parameter to differentiate soil classes at different catagorical levels, although "color as such has no known effect on plant growth" (Young, 1976) and "per se seems to have no accessory characteristics" (USA, 1975).

Recent studies by Kämpf and Schwertmann (1983), Torrent et alii (1984), Schwertmann (1985) and other authors, have shown that red and yellow hues are related to the proportion of hematite (redder than 2.5 YR = hematitic) and goethite (yellower than 7.5 YR = goethitic) in the soil material. Orange colours are related to the presence of lepidocrocite, yellowish brown gel like deposits are of ferrihydrite and dark colours to organic matter and/or maghemite and magnetite. Mottled colours are common in tropical soils with impeded drainage or presence of a oscillating water table. In some soils (Plinthic Acri-, Luvi-, Ferrasols) these mottles zones may developed into concretions or petroferric layers by alternate wetting and drying (Plinthite) or by draining those soils. In other soils they are related to weathering conditions and material (saprolite). These differences must be understood and considered in rural development programs.

Since the different types of iron oxides-hydroxides form in different environmental conditions, it is possible to learn about the genetical conditions in which a soil formed from its colour. Certain P soption characteristics and soil structural development, like the strong small aggregates described as "coffee powder" structure, can be related to iron minerals. Finally colour is a useful feature to relate to, when discussing soils with non technical people, and thus a useful property to differentiate soils. When relation between soil colour and other properties will be better understood, we may be able to explain why farmers in Brasil and other countries prefer red instead of yellow soils.

SOIL TEXTURE

Texture refers to the relative proportion of the various size groups of individual particles in the soil mass. It is a very stable soil property, unless soil material is removed from the profile by erosion. Most of the soil properties (morphological and physical) are more or less related to texture. Texture varies from sandy classes (Arenosols) to heavy clay class.

Some tropical soils, as Ferralsols (OXIC B), Cambisols and Andodols (CAMBIC B) have little textural differentiation within the profile (Figure 1), while other soils (Acrisols, Luvisols, Nitosols) show a distinct textural gradient from the topsoil to the subsurface diagnostic horizon (ARGILLIC B). In many soils it is difficult to define the subsurface diagnostic horizon, due to the presence of a weakly defined textural gradient and/or a gradient which satisfies the requirement of Argillic B horizon, but with absence of clay skins and well developed structure.

As a rule tropical soils have low silt content because primary minerals in this fraction are unstable and seccondary minerals are found mainly in the clay fraction. The silt/clay ratio is also low and used as weathering index and classification parameter. Soils with a ratio of <0.15 are regarded as highly weathered and a silt/clay ratio of <0.7 is used in the Brazilian system of soil classification to define the Latosolic B horizon.

Finger texturing many tropical soils becomes a matter of determining the relative proportion of sand and clay. Due to strong aggregation of some clayey soils they feel like sand or loams, when estimating field texture. Only after the wet sample is worked for some time, the clayey feeling increases, as aggregates are progressively destroyed. This materials are very difficult to disperse for particle size analyses and water dispersable clay is mostly very low or absent in some soils (Ferralsol). The only way to attain good dispersion of these soils is by removing the free iron oxi-hydroxides. The presence of stable aggregates explains the low translocation of clay and development of Oxic and Cambic B horizons in tropical conditions.



SOIL STRUCTURE AND AGGREGATION

Soil structure is the arrangement of the primary (individual) particles in aggregates of different grade or strength, size (class of structure) and type (form of aggregates). Soils without aggregates with naturally preserved boundaries (peds) are considered to be structureless (apedal) or massive "in situ".

Most tropical soil (Acrisols, Luvisols, Kaolimitic Ferrasols in humid climatics) present weak to moderate subangular blocky structure. Nitosols show moderately to strongly developed very fine to medium angular blocky structure and shiny ped faces, originated probably by friction betweed peds. Arenosols mostly are structureless or single grained. The strong granular or crumb like structure of some clayey soils, mainly Ferrasols in sub-humid regions, is probably related to aggregation of primary particles by amorphous and/or crystallize forms of iron and/or aluminium oxi-hydroxides, although some authors (Verheye and Stoops, 1975) have related them to biological activity (thermites). This last explanation seems untenable as this morphology is retained to depths of 6 m. or more.

As stated by Sanchez (1976), the highly aggregated clayey Ferralsols, Andosols and Ferric groups of other soils present advantages and disadvantages. The advantages are related to the fact that gravitational water is drained rapiddy, like in sandy soils and thus they can be tilled a few hours after rain and compaction and soil erosional problems are low in these soils. The disadvantages lies in the low range of available moisture of these soils, although they hold considerable amounts of water at high tensions, inside the aggregates (Figure 2). These soils present drought problemsa a few days after rain and leaching of added elements by fertilizers is considerable. Eventhough in most literature it is stated that these soils do not have problems of surface sealing, compaction and erosion, the author has seen these features in areas under intensive management with heavy equipment, resulting in decrease in water infiltration rates, plant root penetration, resistance of crops to drought, absorption of plant nutrients and increased soil erosion (Klamt et alii, 1983). The destruction of the macro aggregates related to the higher organic matter content of top horizons is probably the best explanation of this behaviour. This subject will be treated in more details in the section about degradation of tropical soils by management.

CLAY SKINS OR CUTANS

Cutans or clay skins, develop by elluviation of clay particles of the surface horizon and illuviation in the subsurface, is a diagnostic feature used to define Argillic B horizons. This feature is very difficult to observe in examining tropical soils in the field and even in thin sections, although textural gradients are present. Probably the most severe classification problem for soils with low activity clays is the placement in soil Taxonomy (USA, 1975) and even in FAO/UNESCO (1974) Soil Map of the World Legend, of pedons with a subsurface horizon that fulfills the tectural reguirements for an argillic horizon, but the clay skins are so weakly expressed that consistent quantification is doughtfull (Moormann and Buol, 1981).

CONSISTENCE

Consistence can be defined as physical strenght of adhesion (attraction of particles or molecules to solid surfaces) and cohesion (attraction of particles or molecules to each other) acting on soil particles at different humidity content.

Most tropical soils are very friable to friable when moist and slightly sticky to sticky and slightly plastic to plastic when wet, depending mainly on texture. But even the clayey soils don't get as sticky, plastic and hard as the soils of temperate or colder climates, in which mainly 2:1 type of clay minerals are found. The composition of the clay fraction of tropical soils, being entirely of Kaolinite and iron and aluminium oxi-hydroxides, confers this property to them. Many Arenosols present almost no adhesion and can not be molded by the hands, thus have loose consistence. Table 1 illustrates the differences in consistence of a clayey Ferralsol, Kaolinitic/oxidic and a clayey Vertisol, montmorillonitic. These differentes are the main reasons of the problematic management of a Vertisol if compared to a Ferralsol.

Consistence is affected by soil management, since organic matter content decreases after bringing a tropical soil into cultivation, and mostly soil particles are brought closer together (desagregation of particles, compaction) by management, particularly when heavy machinery is used in soils with high humidity, resulting in harder soils when dry, less frible when moist and more plastic and sticky when wet.



Table 1. Consistence of a cleyey Ferralsol and Vertisol of a subtropical region (Brasil, 1973).

| Soil | Horizons | Depth (cm) | C % | Clay % | Consistence: Dry | Moist | Wet | |
|---|---|---|---|---|---|---|---|---|
| Humic | Ah | 0- 15 | 1.80 | 74 | Slightly hard | Friable | Slightly plastic | Slightly sticky |
| Ferralsol | Bw2 | 90-150 | 0.67 | 82 | Hard | Friable | Plastic | Slightly sticky |
| Pellic | Ah | 0- 20 | 1.79 | 60 | Very hard | Very firm | Very plastic | Very sticky |
| Vertisol | A/C | 43- 50 | 0.76 | 64 | Extremely hard | Very firm | Very plastic | Very sticky |

NODULES AND CONCRETIONS

Nodules, concretions of iron and petric phase (layer of 40 cm or more of oxidic concretions or of hardened plinthite not continuously cemented) and petroferric phase (indurated layer in which iron is a important cement, as defined in FAO/UNESCO, 1974) are frequent features in tropical soils, particularly in Africa.

This features may be found in lowland soils (Plinthic Acri-, Luvi-, Ferralsols) in which due to the presence of a oscillating water table, iron is reduced and concentrated in mottled zones and concretions, or in upland soils, exposed by inversion of the landscape.

In the early literature about tropical soils, these features were erroneously emphasized, resulting in a misconception that tropical soils, when brought into cultivation will harden irreversibly and become worthless brick paverment (Sanchez, 1976), by a process defined as laterization. Laterites (petric or petroferrc phase) are found in less than 7 percent of the tropical soils, more often in the subsoil. When present, they constitute a serious management problem, restricting the use of equipment and machines and plant root penetration. In the Amagon region, flat rooted trees are thrown down by wind, when forests are cleared in areas with shallow petric or petroferric layers, cultivated plants as banana, cacao, pepper, eucalyptus will stop growing when the roots reach these layers.

PORES

Pore space is a important feature in soils, because the size, shape and continuity of the pores determines the movement of air and water in the soil. Most soils in humid and sub-humid tropical regions are very porous, been most pores of microscopic diameter (< 0.075 mm). This microscopic pores, which are important in relation to the physical properties of soils, are difficult to determine in the field. Indirect measurement, as the velocinity and amount of water intake by a soil ped, is a why to estimate their abundance.



Surface horizons of soils, due to the effect of organic matter, mostly have more macropores. The amount of macropores decreases sharply with intensive cropping as show the data of Table 2 (Klant et al., 1983), resulting in a increase of soil density and decrease in water infiltration rates and increase in soil erosion.

Xanthic Ferralsols developed from Tertiary sediments and which occur in the Amazon humid forest and in the sub-humid to humid Atlantic coast of Brasil, present a natural dense horizon in the top of the B horizon. The origin of this horizon is unknown and is presently under investigation.

SOIL HORIZONS

The types, boundary, continuity and thickness of horizons of most tropical soils (ACRISOLS, LUVISOLS, NITOSOLS and PLINTHIC FERRALSOLS) are easily defined in field descriptions. But in some soils (Ferralsols, Arenosols and some Cambisols) due to diffuse transition between horizons, it is very difficult to establish the limits between horizons others than the darker in colour Ah horizons.

Table 2. Effect of cultivation on the organic matter content, porosity, density and water infiltration of a Humic Ferralsol (Klant et al., 1983).

| Type of land use | Horizon | Depth (cm) | Organic Matter (%) | Porosity (%) | | | Density g.cm$^{-3}$. | Water infiltration (cm/2hr) |
|---|---|---|---|---|---|---|---|---|
| | | | | Macro | Micro | Total | | |
| Forest | Ah | 0-15 | 4.0 | 35.9 | 28.8 | 64.7 | 1.01 | 270 |
| | AB | 15-35 | 2.0 | 18.3 | 38.3 | 56.6 | 1.28 | |
| Cultivated | Ap | 0-10 | 2.9 | 17.5 | 42.8 | 60.3 | 1.17 | 5 |
| (± 20 years) | AB | 10-18 | 1.9 | 13.2 | 38.4 | 51.4 | 1.33 | |



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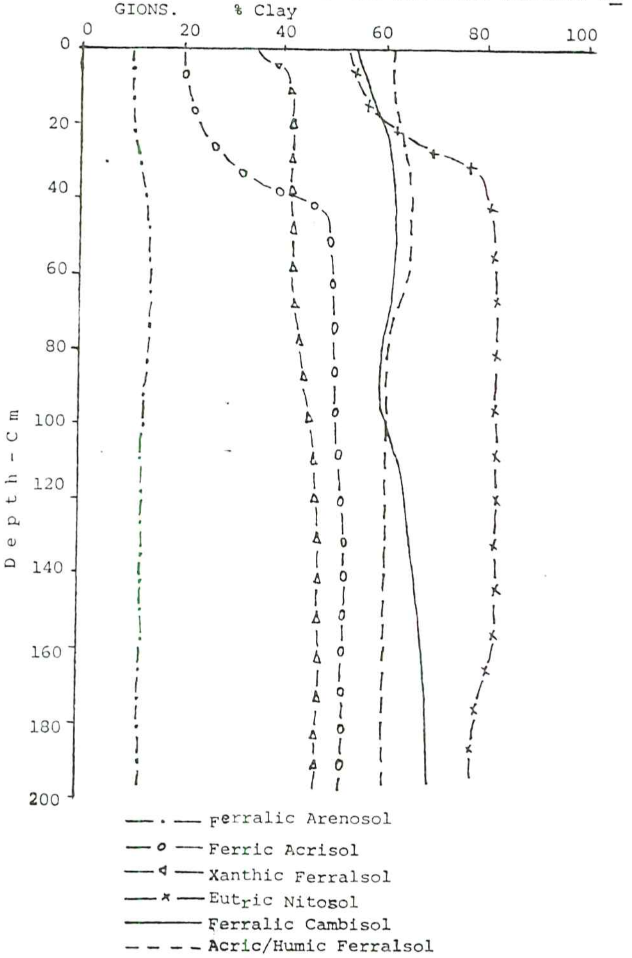
FIGURE 1. CLAY DISTRIBUTION IN PROFILES OF REPRESENTATIVE UPLAND SOILS OF HUMID AND SUB-HUMID TROPICAL REGIONS.



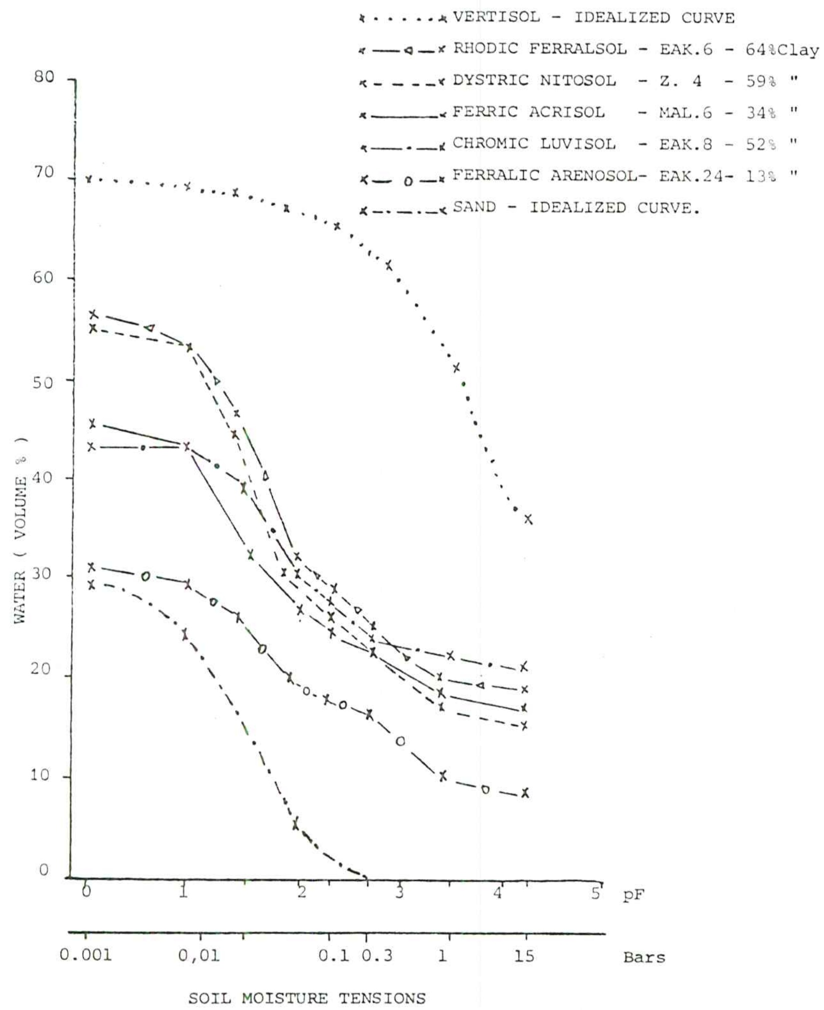




FIGURE 2. Moisture retension curves of representative soils of the humid and sub-humid tropical regions.

85-2106/7 EK/mh

# CHEMICAL PROPERTIES AND FERTILITY OF TROPICAL SOILS

by E. Klamt*

## 1. INTRODUCTION

The chemical properties and fertility are very closely related to the mineralogical composition of soils. In tropical soils these properties are more complex, varied and less well studied than in soils of temperate and colder regions, because: a) research has been concentrated on soils of temperate regions and b) in order to identify and examine mineral species by x-ray diffractometry and other methods, organic matter, amorphous materials and iron and aluminum oxihydroxides were removed from the soil clay fraction. So, the most important mineralogical components of tropical soils were ignored and descarted.

In the last decade or more, the knowledge about the mineralogical and chemical properties of tropical soils has improved considerable and this findings led to fundamental changes in management of these soils, such that tropical regions are considered today as a great frontier to increase world food production.

The purpose of this manuscript is summarize the main chemical properties of soils in the tropics and analyse some management practices to improve their fertility and crop production.

## 2. CHARGE CHARACTERISTICS AND ION EXCHANGE REACTIONS

Ion exchange in soils are reversible reactions by which cations and anions are changed between the solid-liquid and even solid-solid phases of the soils.

Based on surface charge characteristics two types of minerals are found in the clay fractions of the soils: a) those with mainly constant or permanent

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charge and b) those with variable or pH dependent charge (Van Raij and Peech, 1972; Mekaru and Uehara, 1972; Keng and Uehara, 1974; Sanches, 1976; Uehara, 1979; Gillman and Uehara, 1980; Uehara and Gillman, 1980; Bowden et alii, 1980).

## 2.1 The Permanent Charge Minerals

The surface charge of 2:1 layer silicates (montmorillonite, illite, vermiculite), 2:2 layer silicates (chlorites) and to a lesser extent in the 1:1 layer silicates (kaolinite, halloysite) arises from isomorphous substitution of ions of lower valence in a position occupied by ions of higher valence, as $Al^{3+}$ substituting for $Si^{4+}$ in tetrahedral layer (⏢) and $Fe^{++}$ and $Mg^{++}$ for $Al^{3+}$ in octahedral layer (▭), in the clay mineral structure (Figure 1a). Since the ion substitution occurs in the interior of the crystal, when the mineral is formed, the negative charge originated is permanent and constant (Berner, 1971; Zelazny and Calhoun, 1971).

As illustrated in Figure 1b, there is limited substitution of $Al^{3+}$ for $Si^{4+}$ in the tetrahedral (⏢) layer of montmorillonite, but extensive substitution of $Mg^{++}$ for $Al^{3+}$ in the octahedral layer (▭). In illite and vermiculite the substitution is extensive in the tetrahedral layer and in chlorite in both tetrahedral and octahedral layers (Berner, 1971).

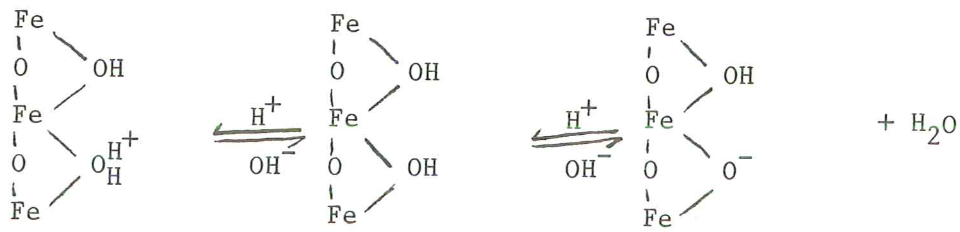
To balance the originated negative charges exchangeable (Ex) cations accumulate in the interlayer position and on the surface of the crystal (Berner, 1971). Because of extensive substitution the cation exchange capacity (CEC) of these clay minerals and soils in which they occur is high (Table 1).

Minerals with permanent charge are common in soils of semi-arid tropical regions, as Vertisols, Luvisols, Phaeozems, Solonetz, Vertic Cambisols, Eutric Planosols and others; but in the highly weathered soils of the humid and sub-humid tropics these clay minerals have been weathered out and their surface charge arives from adsorption of potential determining ions (Uehara, 1979; Bouden et alii, 1980).

## 2.2 The Variable Charge Minerals

The charge of minerals as iron and aluminum oxides and hydroxides, both crystalline (goethite, hematite, lepidocrocite, ferrihydrate, gibbsite, boehmite) and amorphous; hydroxyls on edges and broken lattices of 1:1 clay minerals (kaolinite, halloysite) and mixed layer clay minerals (2:1 clay minerals with iron and aluminum hydroxides between the layers) arises from adsorption (protonation) and desorption (deprotonation) of ions on the mineral surfaces, with changes in pH. The most important potential determining ions are hidrogen ($H^+$) and hydroxyl ($OH^-$). The variable charge minerals are found mainly in Ferralsols, Acrisols, Nitosols, Luvisols, Cambisols and Andosols.

The charge of these minerals and soils varies in sign and magnitude with pH, electrolite concentration and kind of counter-ion (Parfitt, 1978). The reaction which occurs on the surface of an iron oxide, when pH changes (Keng and Uehara, 1974 and Bouden et alii, 1980) is as follow:




Net Positive charge-protonation | Net zero charge | Net Negative charge-deprotonation

When pH decreases (more $H^+$) positive charge are created by protonation of hydroxyl groups on oxihydroxides and when pH increases (more $OH^-$), net negative charges develop. The zero point of charge (ZPC) is the pH at which there is a balance between positive and negative charges. Thus by lowering the pH we increase the anion exchange capacity (AEC) and vice-versa, the cation exchange capacity (CEC).

A simple way to determine the charge characteristics of soils with variable charge is by measuring the pH in water and in neutral salt solution as 1 N KCl and calculate the $\Delta pH = pHKCl - pHH_2O$. If $\Delta pH$ is negative the soil is negatively charged and vice-versa, if $\Delta pH$ is positive the soil colloids are positively charged.

In clays of permanent charge $\Delta pH$ is always negative because pH in KCl is lower than in $H_2O$, as shown in the following reaction (Sanchez, 1976):

Surface of Colloid

$$]\text{-}H + H_2O \rightleftharpoons ]\text{-}H + H_2O$$

$$]\text{-}H + KCl \rightleftharpoons ]\text{-}K + Cl^- + H^+$$

In positively charged colloids pH in $H_2O$ is lower than pH in KCl.

Most soils, even in tropical soils have a dominance of negative charged colloids. Mostly oxidic (goethitic and or hematitic + gibbsitic) soils present dominance of positive charge in subsurface horizon (low organic matter content), which according to Tessen and Jusop (1983) is due to isomorphous substitution of $Fe^{3+}$ by $Ti^{4+}$ in iron oxihydroxides.

Van Raij and Peech (1972) titrated different Brazilian and other soils and determined the charge over a wide pH range. As shown in Figure 2, the soils exhibit a great degree of variable charge and with the exception of B horizon of the Acrorthox (Acric Ferralsol), all horizons present a predominance of negative charges at field pH.

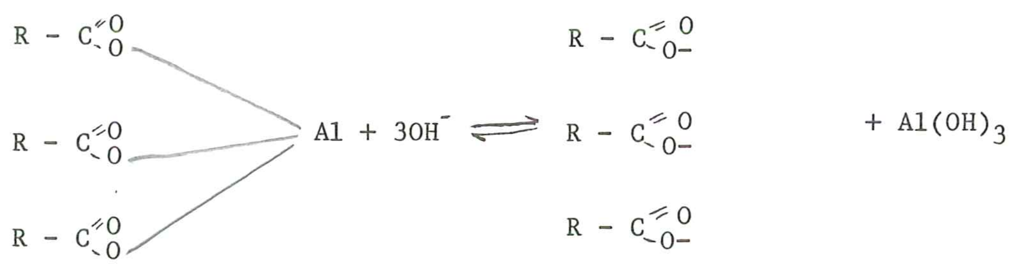
2.3 Other Sources of Charge in Soils

a) The pH-dependent charges of organic matter

Hydrogen of carboxylic, phenolic and other organic radicals may be dissociated with increase in pH, originating negative charges, as shown by the reaction:

$$R\text{-}COOH + OH^- \rightleftharpoons R\text{-}COO^- + H_2O$$

The organic radicals complexed by aluminum, iron, manganes and other metallic cations, originate negative charges. The following reaction (Coleman and Thomas, 1967), illustrates the precipitation of $Al^{3+}$ complexed by a carboxyl radical:




The pH-dependent charges of organic radicals are responsable for considerable percentage of negative charges and thus of CEC of tropical soils, as well as of soils of other regions.

b) Adsorption of divalent or trivalent cations

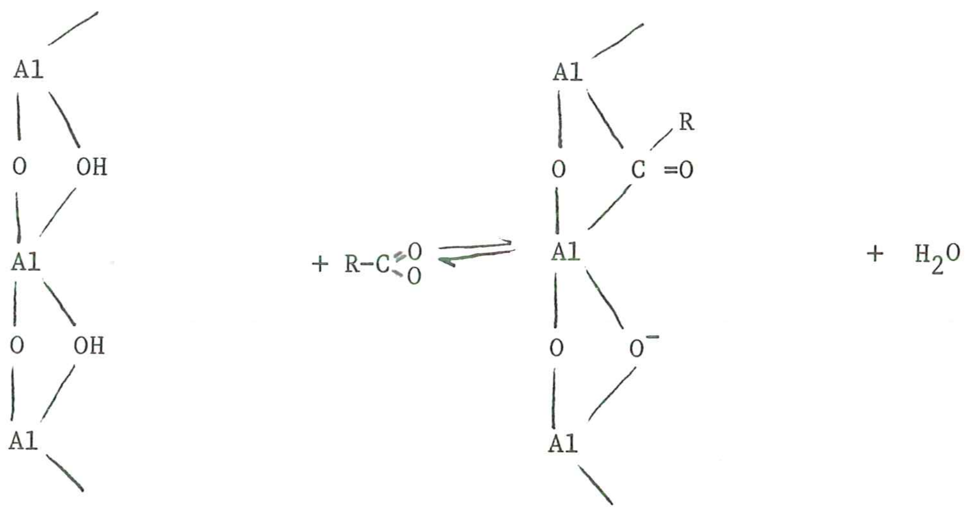
Divalent ($Mg^{++}$, $Ca^{++}$) and trivalent ($Al^{3+}$) cations may be adsorpt at negative soil colloidal charges and originate a positively charged surface, which seems to be important in aggregating soil particles by a ion bridge (Baver et alii, 1972), particularly in presence of organic complexes when cation ($Ca^{++}$) serve as bridges to form clay-organic complexes.

c) Adsorption of anions by oxihydroxids

The adsorption of organic (radicals) and inorganic anions on oxihydroxides may originate charges, as demonstrated by the following reaction (Parfit, 1978):

$$\begin{bmatrix} FeOH \\ FeOH \end{bmatrix}^{0} + HPO_4^{2-} \rightarrow \begin{bmatrix} FeO \searrow \; \nearrow O \\ \quad\; P \\ FeO \nearrow \; \searrow O \end{bmatrix}^{-1} + OH^{-} + H_2O$$

According to Sanchez (1976) the reaction between organic matter and oxihydroxide surfaces originates negative charge withouth changing the pH:




This reaction shifts the pH-charge curve shown on Figure 2 to the left and the pH at zero point of charge is lower. This probably is the reason why the zero point of charge of surface horizons is at lower pH than at subsurface horizons.

## 2.4 Cation Exchange Capacity

The cations hold at the negative charges of soil colloids (organic and mineral) are in equilibrium with cations in soil solution. When this equilibrium is changed, as by applaying $K^+$ fertilizer, the higher concentration of $K^+$ in solution will replace cations from the exchange site, as $Ca^{++}$. Using the mass action equation we can represent the reaction as follows:

$$Ca_{\frac{1}{2}} X + K^{+} \overset{k}{\rightleftharpoons} KX + \tfrac{1}{2}Ca^{++}, \text{ where}$$

$Ca_{\frac{1}{2}} X$ and $KX$ = cations at exchange sites (mE/100g)
$K^{+}$ and $\frac{1}{2}Ca^{++}$ = cations in solution (mmoles/l)

$k = \frac{KX}{Ca_{\frac{1}{2}}X} \cdot \frac{\sqrt{Ca^{++}}}{K^{+}}$ in which k is a selectivity coefficient, affected by the following factors:

a) Concentration of cations - the competition for a exchange site increases with increase of concentration of a specific cation.

b) Type and position of charge - cations hold on surface charge are more easily exchanged than on internal charges. Some charges are specifically occupied by specific cations in some minerals, as $K^{+}$ in illite. The replacement of them requires high energy.

c) Nature of cations - depends on the cations ionic ratio and hydration degree. Mostly the energy of retention follows the sequence:
$Al^{3+} > Ba^{++} > Sr^{++} > Ca^{++} > Mg^{++} > Rb^{+} > K^{+} > NH_4^{+} > Na^{+} > Li^{+}$
Ionic ratio and degree of hydration is important in cations of the same valence. $Na^{+}$ is hold with less energy than $K^{+}$ because of its large ionic ratio and degree of hydration.

d) Type of colloid and pH - as seen before clay minerals of permanent and pH-dependent charges will affect CEC (Table 1) differently at different pH.

## 2.5 Anion Exchange Capacity (AEC)

Since a small number of net positive charges are found in soils dominated by net negative charges, some anions are hold by this charges and to some extent can be exchanged. In oxidic soils, as some Ferralsols and Andosols with net positive charges, anions are retained more than cations and so cations are leached out.

Phosphate, silicate and sulfate are very strongly adsorpt to positively charged oxide sufaces, particularly at low pH and thus are not exchangeable. Phosphate concentration is normally low in deeply weathered and acid soils and this associated to their high P adsorption capacity, represents a serious problem of soil management (Fox and Searly, 1978; Klamt et alii, 1983) showed that the P adsorption of Brazilian Ferralsols is very high (Figure 3) and is highly correlated with crystalline and amorphous forms of iron and aluminum oxihydroxides (Syers at alii, 1970; Fox and Searle, 1978).

## 3. IMPROVEMENT OF CHEMICAL PROPERTIES BY SOIL MANAGEMENT

Many highly weathered tropical and sub-tropical soils as Ferralsols, Acrisols, Dystric Nito-, Cambisols and Andosols have very low cation exchange capacity and sometimes very high aluminum saturation (Table 2). Leaching of cations applied has fertilizers is very high.

To improve the retention of cations and base saturation and reduce aluminum saturation, we should elevate the CEC. This may be attained by application of lime, to elevate pH ($\pm$ 6.0) and expose the pH dependent charges and or manage the soils such that a reasonable concentration of organic matter is maintained.

Liming with dolomitic rocks, besides increasing CEC decreases the concentration of exchangeable aluminum and phosphorus adsorption, increases the availabity of $Ca^{++}$ and $Mg^{++}$, mostly low in deeply weathered soils. The author believes that in high management agricultural systems, with correction of the chemical limitations of the soils, besides a great increase in crop production (grains) we have a tremendous increase in plant roots and dry organic matter, which if incorporated in the soil, will maintain favorable chemical conditions and prevent degradation of physical properties. Farmers in tropical environment, particularly small farmers, should also be encouraged to produce and use manure. The adoption of sound management system to reduce losses of organic and mineral colloids by soil erosion, will also help to maintain the organic matter in soils.

Deep rooting of annual crops cultivated in highly weathered soils may be limited by Al toxicity or lack of Ca in the sub-soil (Ritchey et alii, 1980 and 1982). Thus lime and fertilizers in these soils should be applied deeper, to permit deep rooting and expand the soil volume to be explored for water and nutrient uptake. Increase in yields were obtained by increase rooting depth in Brazilian savanna Ferralsols (Ritchey et alii, 1982).

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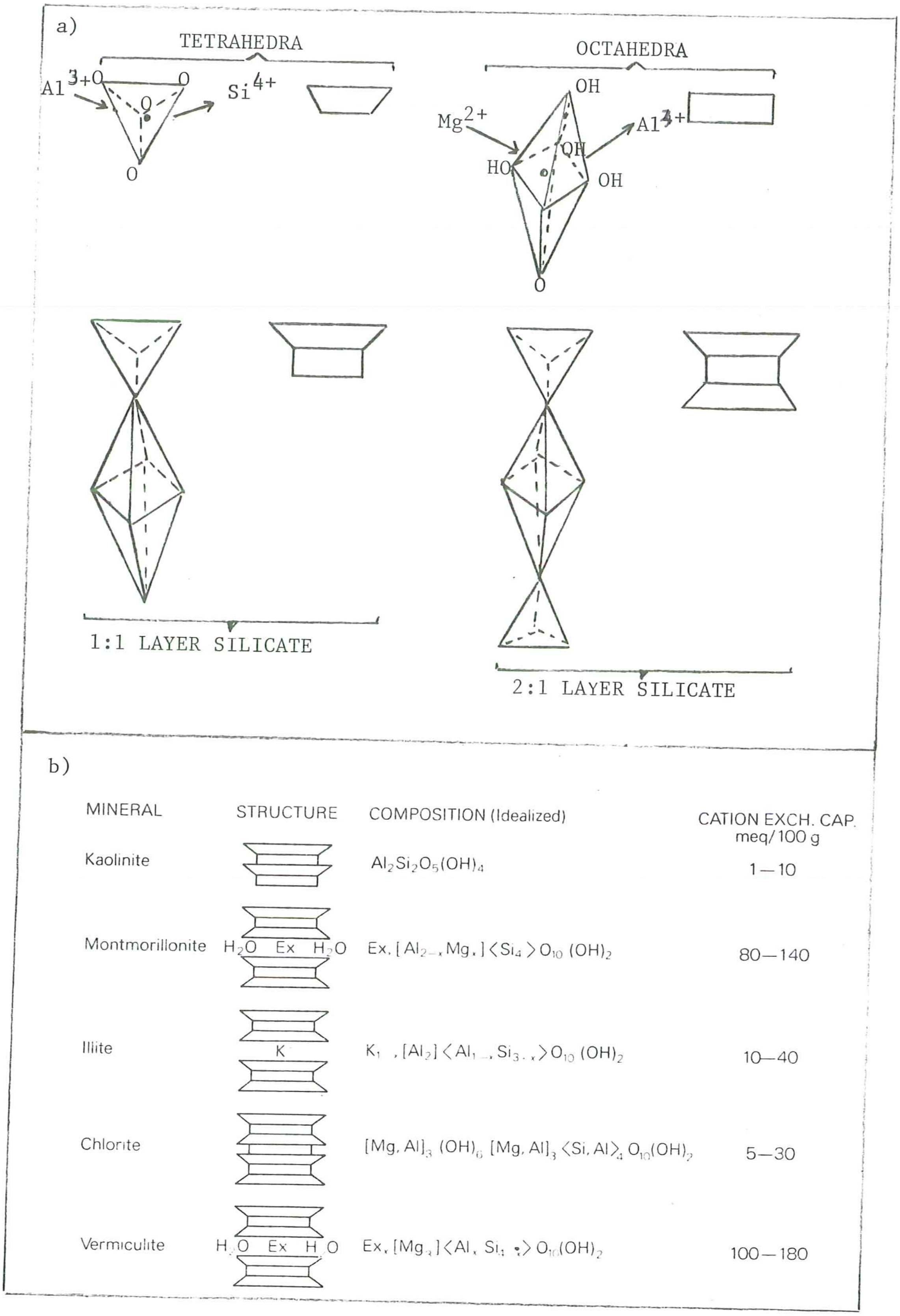


Figure 1. a)Structural characteristics and isomorphous substitutios in tetrahedra and octahedral layers;b) Structure,composition and CEC of principal clay mineral groups (Berner,1971).

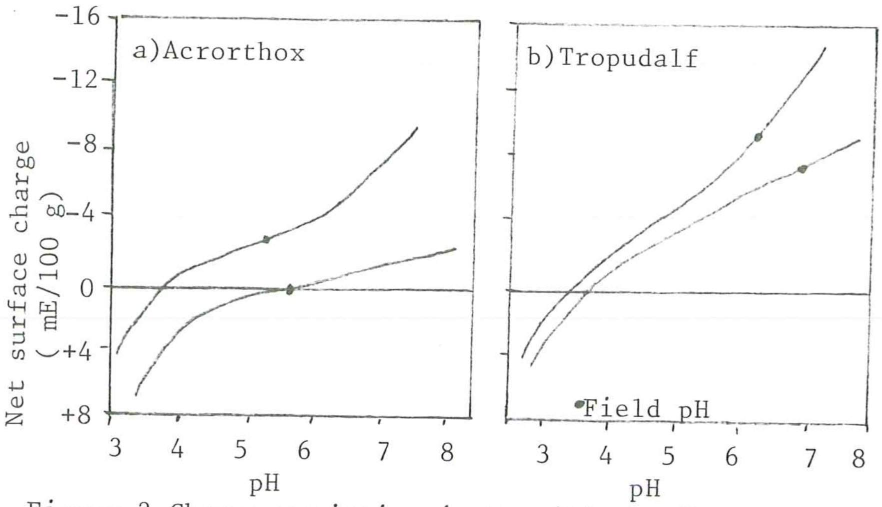


Figure 2. Charge variation in Brasilian soils as determined by changes in pH (After Van Raij and Peech, 1972).

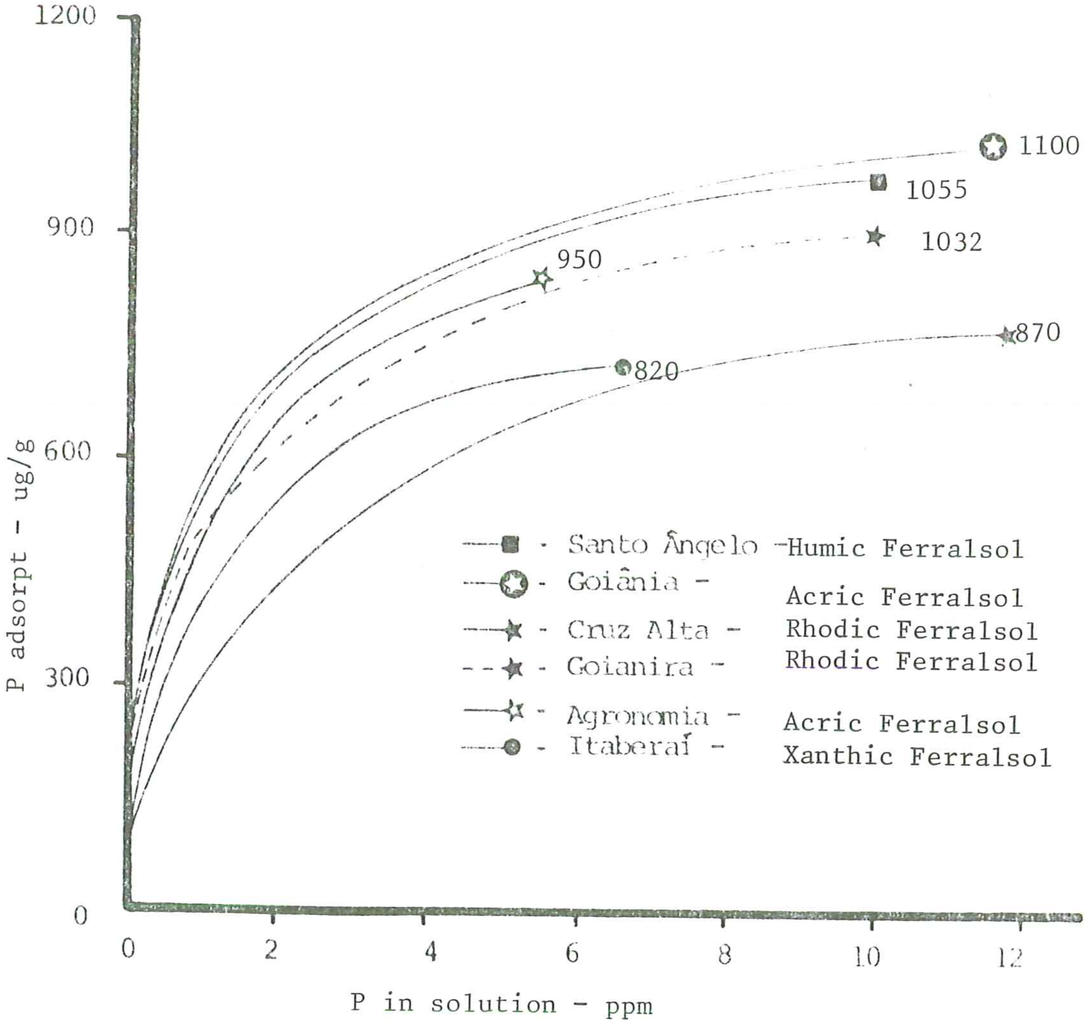


Figure 3. P adsorption isotherms and adsorption maxima in representative Brazilian Ferralsols (Klamt et alii, 1981).

TABLE 1. CATION AND ANION EXCHANGE CAPACITY OF CLAY MINERALS SEPARATED FROM SOILS OF KENYA AND OF KENYAN SOILS, IN meq/100 g (SANCHEZ, 1976).

| Material | Cation Exchange Capacity | | | | Anion Exchange Capacity |
|---|---|---|---|---|---|
| | Permanent | Varible | Total | Soil clay | |
| Montmorillonite | 112 | 6 | 118 | - | 1 |
| Vermiculite | 85 | 0 | 85 | - | 0 |
| Illite | 11 | 8 | 19 | - | 3 |
| Kaolinite | 1 | 3 | 4 | - | 2 |
| Gibbsite | 0 | 5 | 5 | - | 5 |
| Goethite | 0 | 4 | 4 | - | 4 |
| Allophane | 10 | 41 | 51 | - | 17 |
| Peat | 38 | 98 | 136 | - | 6 |
| Songhor soil, 60% clay, montmorillonitic | 44 | 3 | 47 | 75 | 3 |
| Ishiara soil, 64% clay, kaolinitic | 7 | 10 | 17 | 26 | 4 |
| Chinga soil, 62% clay, amorphous | 6 | 32 | 38 | 61 | 20 |
| Gathaithi soil, 12% clay, organic | 8 | 30 | 38 | 100 | 7 |

TABLE 2. CHEMICAL PROPERTIES OF SOME BRASILIAN SOILS (DATA FROM ISRIC, 1985)

| Soil | Region | Horizon | Depth (cm) | clay (%) | C | ΔpH | CEC | Sum of Bases | BS | Als |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | meq/100g | | % | |
| Acric Ferral-sol | Sao Paulo (Grass) | Ap | 0-26 | 61 | 2.47 | -0.5 | 7.7 | 0.5 | 6 | 50 |
| | | BW1 | 75-215 | 62 | 0.80 | +0.1 | 0.7 | 0.2 | 10 | 0 |
| Xanthic Ferral-sol | Amazon (Forest) | Ah | 0-7 | 84 | 2.64 | -0.2 | 6.9 | 1.5 | 21 | 79 |
| | | BW2 | 85-132 | 92 | 0.35 | -1.0 | 2.6 | 0.3 | 13 | 85 |
| Rhodic Ferral-sol | Planalti-na (Sa-vanna) | Ah | 0-13 | 44 | 2.26 | -1.0 | 7.3 | 3.0 | 41 | 41 |
| | | BW1 | 76-128 | 43 | 0.86 | -0.5 | 3.4 | 0.3 | 15 | 83 |
| Humic Ferral-sol | Parana (Crops) | Ap | 0-22 | 82 | 2.58 | -0.4 | 12.2 | 1.6 | 13 | 35 |
| | | BW2 | 65-120 | 82 | 0.50 | -0.9 | 5.8 | 0.6 | 7 | 53 |
| Eutric Nitosol | Sao Paulo (Crops) | Ap | 0-15 | 55 | 2.84 | -1.0 | 17.7 | 13.7 | 77 | 2 |
| | | Bt2 | 75-150 | 82 | 0.60 | -1.3 | 10.7 | 8.9 | 84 | 4 |

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# Mineralogical Composition of Tropical Soils

by E. Klamt*

## INTRODUCTION

The morphological, physical and chemical properties of the soils in the Tropics, as seen in the former lectures are very closely related to the nature and constitution of their mineral mass. The mineralogical composition is also a important parameter used to defferentiate soil classes in most soil classification system and a index used to evaluate the weathering stage of soils.

Kaolinite, gibbsite, amorphous material (allophane), interlayer clay minerals, quartz, hematite and goethite are the most common minerals in the clay fraction of humid and sub-humid tropical soils. Permanent charged minerals as montmorillonite, vermiculite, illite and chlorite occur in less weathered soils of unstable surfaces as mountains and floodplains and in semi-arid and arid regions.

In this hand-out a short overview is presented about the mineralogy of oxidic and/or Kaolinitic soils of well drained upland humid and sub-humid tropical regions opposed to the predominantly 2:1 type clay minerals found in soils of semi-arid and arid or geomorphologically unstable regions.

## THE OXIDIC SOILS

Oxidic soils occur either on very old and stable surfaces as on the Sul Americana surface of Central Brasil (Fewer, 1956) and similar ones in Africa or on younger surfaces, when developed from parent rocks rich in weatherable minerals (Rodriques and Klamt, 1976; Paramanenthan and Lim, 1978).

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The mineralogical composition varies from gibbsite [Al(OA)3] and (Fig. 1) goethitic (FeOOH) to gibbsitic (Fig. 2) and hematitic (Fe2O3) and gibbsitic and goethitic + hematitic soils, with variable amounts of amorphons minerals (allophane), Kaolinite and mixed layer clay minerals (Paramananthan and Lim, 1978; Herbillon, 1980). Factors as high rates of Fe release, low organic matter content, low pH, high soil temperature and low soil moisture favor formation of hematite and vice-versa of goethite (Schwertmann, 1985).

Differences in mineralogical composition related to the age and stability of geomorphic surfaces vary within and between distinct regions. Soils in higher laying (1000-1200 m) and older erosional surfaces in Central Brasil (Fewer, 1956; Cline and Buol, 1973) contain more gibbsite (Table 1) than soils on the younger and lower in altitude (800-1000) erosional surface (Rodrigues and Klamt, 1978). The fact that soils in the humid Amazon region are less desilicated and more Kaoli-itic than the Central Brasil soils is probably also related to the lower stablility and age of the geomorphic surfaces (Klamt et alü, 1981; Irion, 1984).

Extensive deposits of bauxite [Al(OH)3] and deeply weathered saprolite in the Amazon region are covered by yellow Kaolinitic clay (Xanthic Ferralsol). Sombroek (1966) considers these sediments as material deposited in a Plio-Pleistocene lake. But Irion (1984) states that the clay minerals of the Amazon soils, with the exception of the Pleistocene and Recent alluvial plains, are formed in situ. Much more research is needed to permit a better understanding of the genesis and characteris-ics of these soils.

Another stricking feature in some of these oxidic soils is the presence of 2:1 clay minerals as mica, vermiculite, pyrophyllite together with Kaolinite, gibbsite, iron oxihydroxides (goethite, hematite), as shown in Fig. 3, because the environmental conditions and stability of these assemblage of minerals varies greatly from one to another. Since the content of 2:1 clay minerals mostly increases with depth it seems to indicate that pedogenesis, which is more intense in surface horizons, plays a important role in the distribution of clay minerals in these soils. The precipitation of aluminium and iron hydroxides in the interlayers of these minerals and/or surface coating seem to proportionate resistance to weathering in acid conditions (Le Roux, 1973).

The amorphous minerals which occur in high amount in some soils (Table 1) have not been investigated in details. Their composition is mainly SiO2 and Al2O3. It may well be similar to the non to para-crystalline alluminosilicates such as allophane and allophane like constituents which constitute most of the clay fraction of Andosols (wada, 1980). Their SiO2 / Al2O3 molar ratios vary from 1.0 to 2.0 like in allophanes (Rodrigues and Klamt, 1978). The selective dissolution with KOH 0.5N used to extract amorphous materials, as proposed by Jackson, 1969, may also extract some silica and aluminium from crystalline minerals and thus causing a overestimation of this component.

Properties as presence of stable sand (pseudo-sand) and silt (pseudo-silt) size aggregates, low cation exchange capacity (very low permanent charges and more variable charges), high phosphorous adsorption capacity, low availability of some nutrients and presence of others in toxic levels, characterize oxidic soils. They belong mainly to GIBBSI and ACR great groups of OXISOLS (Soil Taxonomy, USA, 1975) and AGRIC FERRALSOLS (FAO-UNESCO, 1974 Soil Map of the World).

KAOLINITIC Soils

Most of the Ferralsols, Acrisols, Nitosols, Luvisols and Cambisols found on well drained uplands of the humid and sub-humid tropics are of low activity clay and the main mineralogical component is Kaolinite (Table 2). Smaller amounts of goethite, hematite, gibbsite amorphous alumino-silicates, quartz, mixed layer clay minerals, mica, illite and vermiculite make up the mineral assemblage of these soils (Juo, 1980; Herbillon, 1980).

The crystallinity, size and morphology of Kaolinite flakes is very variable (Herbillon, 1980). The crystallinity of Kaolinite in soils of the Amazon region decreases with increase in iron oxide content, originating a "fire clay" like Kaolinite, with smaller crystal size than the well crystallized Kaolinites (Kitagawa and Möller, 1980). This Kaolinite with small and disordered crystals has higher phosphorous adsorption capacity than well crystallized Kaolinite (Môller and Klamt, 1984).

Mixed layer silicates with a structure similar to vermiculite or montmorilonite, with incomplete inter-layers of iron and aluminum oxihydroxides, are common in these soils. Their unit cell thickness is between 10 and 40 A°. It expands partially with glicol and to some extend collapses by heating and so can be differentiated from chlorite, vermiculite and montmorilonite (Dixon and Jackson, 1962). Sometimes its x-ray peaks almost disappear by heating. This chloritization proportionates stability to weathering in acid conditions (Le Roux, 1973). When the hole clay fraction is submitted to x-ray diffratometry, its presence as well as of mica and vermiculite can hardly be identified. With subfractionation of the <2.0 ) fraction their presence can be easily recognized, as shown in Figure 4. Clay minerals of 2:1 type mostly are found in the coarser clay fractions, while Kaolinite, gibbsite and interlayer clay minerals in the smaller clay fractions (Möller and Klamt, 1982). The extraction of the interlayer material with sodium citrate (Fink, 1965) indicates that it is mainly composed of aluminium (Table 3). The higher amounts of K extracted in the B horizon is probably related to its higher content of mica.

Slow release of $K^+$, $Ca^{++}$ and $Mg^{++}$ by weathering of the small amounts of 2:1 clay minerals in tropical soils seem to be a important source of these elements for crop production (Arkcoll et alü, 1985) and may explain the success of shifting cultivation. With time nutrients are released and brought to the soil surface by deep rooting natural crops (organic recycling of elements). Clay minerals as illite and mica when in process of alteration may immobilize considerable amounts of $K^+$ applied as fertilizers and restore partly its structure.

Many lowland soils in tropical regions, although poorly drained and with unfavorable conditions for leaching out cations, are Kaolinitic, because the sediments from which they form are originated by erosion of

Kaolinitic upland soils.

## TROPICAL SOILS WITH 2:1 CLAY MINERALS

Tropical soils found on unstable surfaces, as on mountaineous areas (Lithosols, Rankers, Rendzinas), some lowland poorly drained soils (Fluvisols, Gleysols) and soils of semiarid to arid regions (Vertisols, Solonets, Planosols, Luvisols, Vertic Cambisols) present high concentration of 2:1 clay minerals, as montmorillonite and vermiculite, because environmental conditions are not favorable and/or time has not been long enough to originate kaolinite and/or oxihydroxides.

These soils have higher cation exchange capacity and higher reserve of nutrients, higher specific surface and water retention capacity than oxidic and kaolinitic soil. Their mineralogical composition and chemical properties are similar to similar soils of temperate and colder regions.

TABLE 1. Mineralogical composition of some Central Brasil and Amazon Ferralsols (Rodrigues and Klamt, 1978 and Klamt et alii, 1981).

| Location | Soil | Horizon | Amorphous material* | Gibbsite** | Kaolinite** | Hematite* | Goethite** | Others** |
|---|---|---|---|---|---|---|---|---|
| | | | % | | | | | |
| Central Brasil (Higher Surface) | Acric Ferralsol | Ah | 9 | 39 | 25 | 4 | 14 | 6(Q)*** |
| | | BW2 | 6 | 44 | 23 | 4 | 11 | 10(Q,I) |
| Central Brasil (2nd Surface) | Rhodic Ferralsol | Ah | 16 | 10 | 55 | 14 | tr*** | 5(Q,M) |
| | | BW2 | 13 | 13 | 53 | 14 | tr | 7(Q,M) |
| Amazon | Xanthic Ferralsol | Ah | 24 | tr | 56 | tr | 11 | 5(Q) |
| | | BW2 | 28 | tr | 57 | tr | 12 | 1(Q) |

* Extracted with boiling KOH 0.5N (Jackson, 1969).

** Semi-quantitative estimation from intensity of x-ray diffractrogram peaks.

*** Q = Quartz, I = mixed layer clay minerals, M = mica, R = rutile and tr = traces.

TABLE 2. Mineralogical composition of the clay fraction of representative tropical soils (Data from ISRIC, 1985)

| Soil | Country | Clay Mineralogy | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Kaolinite | Mica/Illite | Mixed Layer | Gibbsite | Goethite | Hematite | Quartz |
| Rhodic Ferralsol | Brasil | xxx | - tr | | x | tr | tr | |
| Orthic Acrisol | China | xxx | tr tr | x | x | - | tr | |
| Ferralic Cambisol | Colombia | xxx | - x | - | x | - | - | |
| Xanthic Ferralsol | Gabon | xxx | - - | x | x-xx | - | - | |
| Orthic Ferralsol | Zambia | xx | tr tr | - | x | x-tr | - | |
| Rhodic Ferralsol | Malaysia | xxx | - - | x | x | - | - | |
| Dystric Nitosol | Mozambique | xxx | - - | x-tr | x | x-tr | tr | |

*** Dominant

** Clearly present

* Present

tr Identified

TABLE 3. Composition of the internal layer of a chloritized vermiculite (clay fraction of a Humic Ferralsol) and the effect of its remotion on the CEC of the clay (Möller & Klamt, 1982)

| Horizon | Depth | me/100g | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | CEC of clay | | |
| | | $Al^{+++}$ | $Fe^{++}$ | $Mg^{++}$ | $K^{+}$ | without treatment | with treatment | difference |
| Ap | 0- 15 | 79 | 1.4 | 0.4 | 0.5 | 12.9 | 16.8 | 3.9 |
| BW2 | 60-180 | 66 | 1.2 | 0.7 | 3.8 | 12.3 | 14.9 | 2.6 |

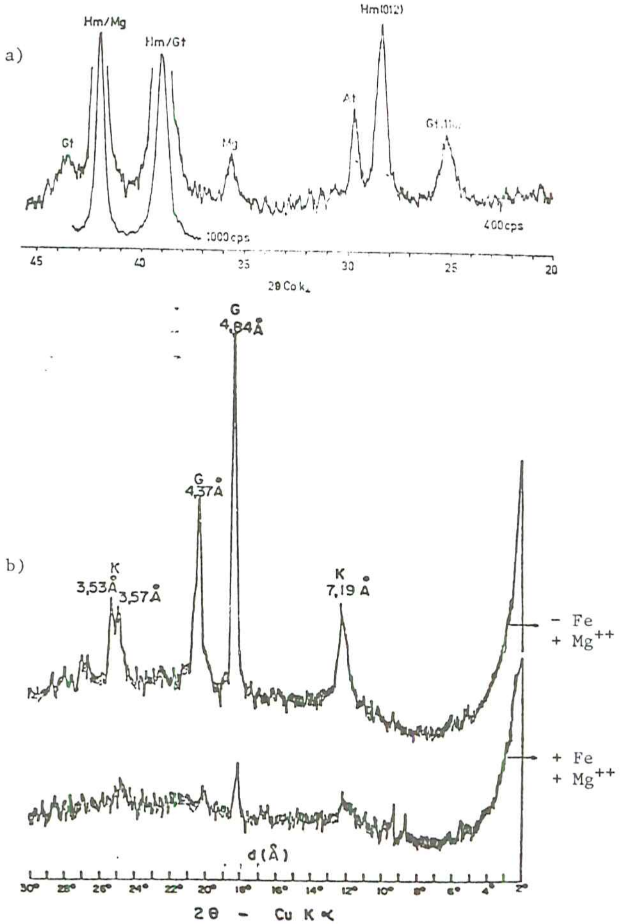


Figure 2. X-ray diffractograms of the clay fraction of $Bw_2$ horizon of a ACRIC/RHODIC FERRALSOL from Brasil. with oxidic (Gibbsitic + Hematitic)mineralogical composition:a)After 5 M NaOH concentration treatment for Fe and b)$Mg^{++}$saturated samples with and without Fe remotion(G= Gibbsite, Gt=Goethite, Hematite, K=Kaolinite and Mg=Magnetite (Kämpf and Klamt, 1984).

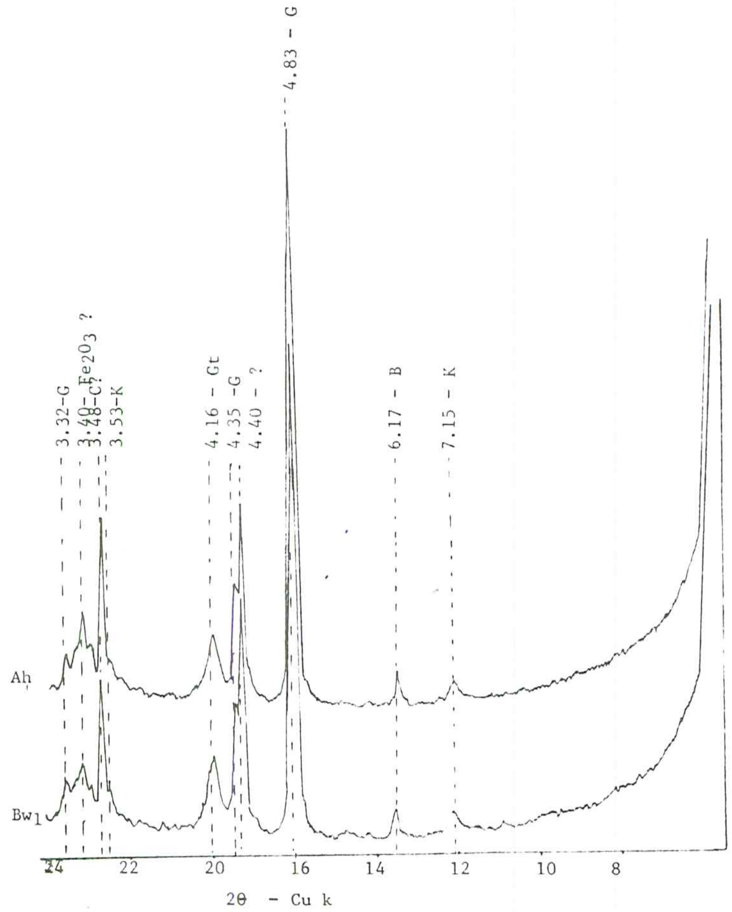


Figure 1 . X- ray diffractograms of Ah and $Bw_1$ horizons of ACRIC FERRALSOL from Jamaica, with oxidic mineralogical composition (Gibbsitic and goethitic): Ar=Aragonite, B=Boehmite,C=Corundum,G=Gibbsite, Gt=Goethite, K=Kaolinite (ISRIC,1985).

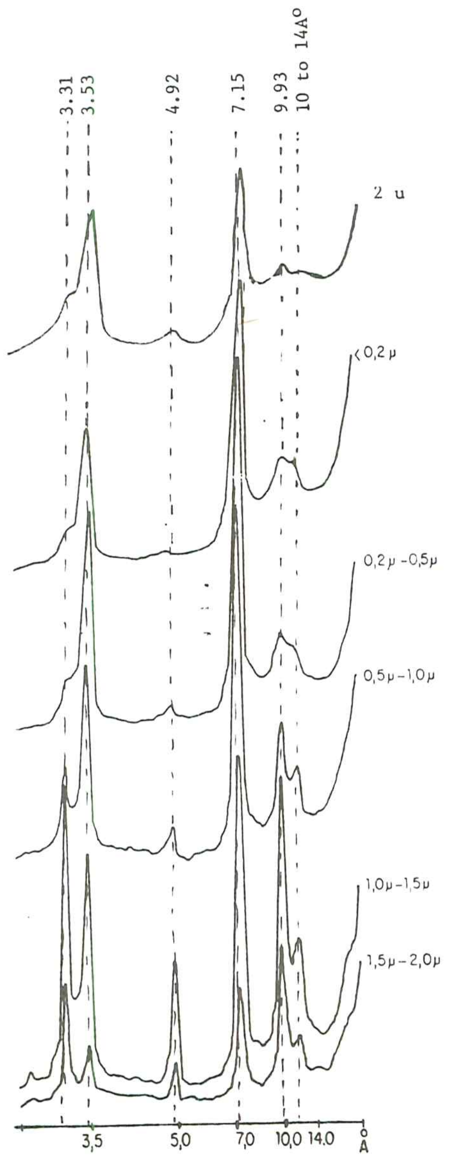


Figure 4. X-ray diffractograms of the clay fraction and defferrated clay subfractions of $Bw_2$ horizon of a HUMIC FERRALSOL , kaolinitic mineralogical composition(Kaolinite :7.15 and 3.53 A°, mica:9.93,4.92 and 3.31 A°, chloritizated vermiculite:10 to 14 A° ),after Möller and Klamt, 1982.

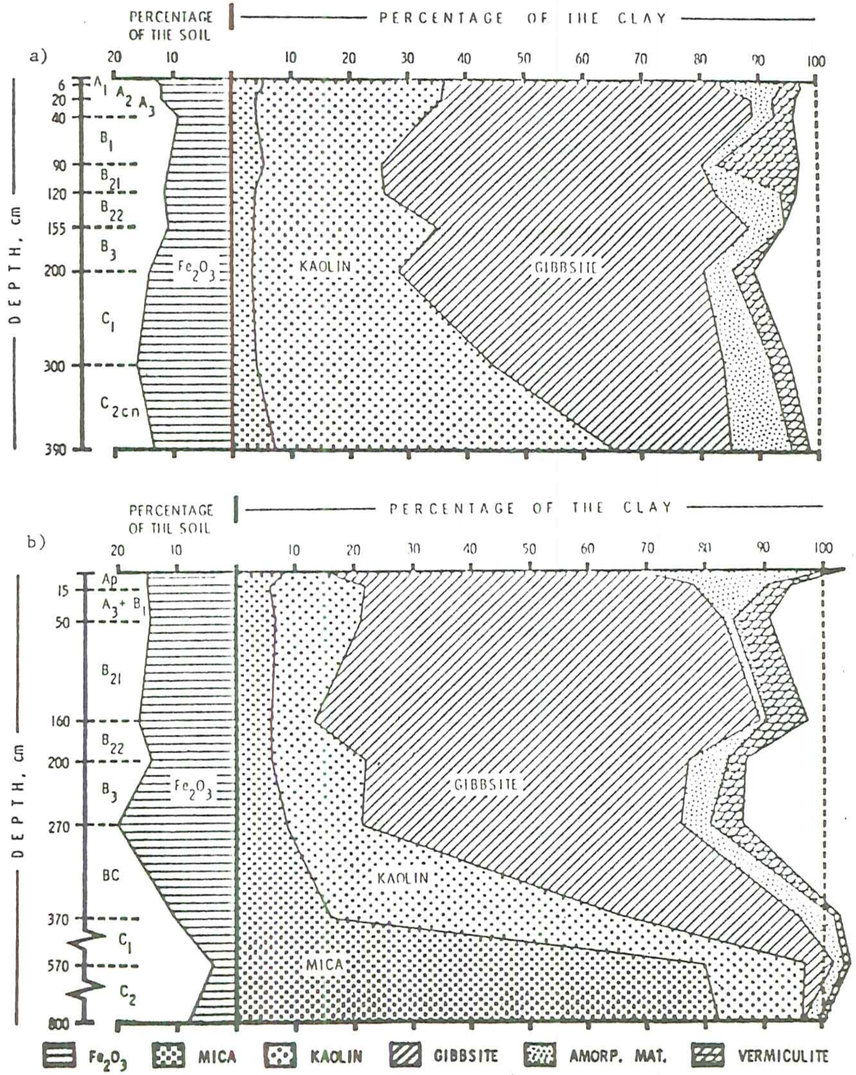


Figure 3. Mineralogical composition of the clay fraction of two (a,b) Central Brasil FERRALSOL (Dark Red Latosols) based on semi-quantitative analysis of x-ray peak intensities and thermodifferential analysis of defferrated samples (Moniz and Jackson, 1967).

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# GENESIS AND PRESENT SOIL FORMING PROCESSES IN THE TROPICS

by E. Klamt*

## INTRODUCTION

Soils are natural bodies formed by action of climate, organism and topography on the parent material during a specific time. Soil formation depends upon a capacity factor, related to the susceptibility to alteration of minerals of parent material; and, a intensity factor, related to the intensity of action of climate, organism and topography during a period of time.

Soil distribution in tropical regions, as in most other regions, is very complex because the capacity and intensity factors of soil formation vary from place to place. The understanding of these factors, which sometimes is difficult, particularly in deeply weathered soils of the tropics, is important to study the characteristics and distribution of soils for soil survey and land evaluation purposes.

In this manuscript a brief review will be given about the transformation of primary minerals of rocks into secundary minerals and their further transformation in soils and analyse the main present soil forming processes in the tropics.

## WEATHERING OF PRIMARY MINERALS

The susceptibility of a mineral to weathering depends upon its structure, types of chemical bonding and degree of stability (Ollier, 1969; Wolast, 1967). As an example lets consider the alteration of K-feldspar; $KALSi_3O_8$. Its structure consists of a tridimensional network of $Si^{4+}$ tetrahedra with approximately ¼ of them isomorphically substituted by $Al^{3+}$. To balance the charge of the structure a equivalent number of $K^+$ ions exist in its structure.

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According to Wollast (1967) who studied the weathering of K-feldspar by suspending ground samples of orthoclase in buffered solutions of different pH, the first reaction is the replacement of $K^+$, which balances the charge originated by isomorphous substitution of $Al^{3+}$ for $Si^{4+}$, by $H^+$ from solutions (aq):

$$H^+aq + K\text{-feldspar} \rightarrow H\text{-feldspar} + K^+aq$$

The source of $H^+$ can be carbonic acid formed by bacterial decay of soil organic matter, from plant rootlets absorbing $K^+$ from the mineral and replacing it by $H^+$ or from water itself. In the latter case the weathering reaction is known as hydrolisis (Berner, 1971).

The rate of this reaction was a function of pH. Since H-feldspar is very unstable it breaks down rapidly releasing $Si^{4+}$ and $Al^{3+}$ to solution. Due to release of basic cations the pH in most weathering conditions of primary minerals is above 5.0. In this pH aluminum cannot built up in solution because it precipitates as $Al(OH)_3$, mostly on the surface of the primary mineral (Fig. 1). The release of $Si^{4+}$ ($H_4SiO_4$) to solution also decreases with time, as shown in Figure 2, probably due to some chemical reaction.

Wollast (1967) stated that the $Al(OH)_3$ which precipitates on the surface of the mineral forms a protective layer, which slows down the weathering reaction. The rate of dissolution was than assumed to be diffusion-controlled throught this surface layer. The final product of weathering depends on the environment, particularly upon the flow of water relative to dissolution.

At high rates of flow of water (high rain intensity and good drainage conditions) relative to dissolution, bases ($K^+$) and $Si^{4+}$ ($H_4SiO_4$) are leached out and gibbsite is formed by crystallization of $Al(OH)_3$:

$$KAlSi_3O_8 + H^+ + 7H_2O \rightarrow Al(OH)_3 + K^+ + 3H_4SiO_4$$

Gibbsite is formed only in environments very low in soluble silica (< 1.0 ppm$SiO_2$), as shown by the stability diagram of minerals in $Al_2O_3$-$SiO_2$-$H_2O$ systems, in Figure 3 (Kittrick, 1969). This diagram also shows that kaolinite is stable in systems with concentration of $pH_4SiO_4$ from 4.7 (1.0 ppm) to 2.8 (96 ppm $SiO_2$) and montmorillonite when the concentration of $pH_4SiO_4$ is above 2.8 (96 ppm $SiO_2$).

At lower water flow rates in relation to disolution bases are leached out but enough $H_4SiO_4$ is maintained to permit formation of Kaolinite, by the reaction:

$$KALSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5\,(OH)_4 + 2K^+ + 4H_4SiO_4$$

This seems to be the most common condition in tropical environments, since most soils are kaolinitic, even though kaolinite may be formed by alteration of 2:1 clay minerals in soils. Kaolinite is probably formed by silification of amorphous $Al(OH)_3$.

At water flow rates approaching stagnancy cations ($K^+$) and silica ($H_4SiO_4$) are maintained in the weathering environment and than illite is formed by the reaction:

$$3KALSi_3O_8 + 2H^+ + 2H_2O \rightarrow KAL_2ALSi_3O_{10}(OH)_2 + 2KOH + 6H_4SiO_4$$

Primary minerals rich in $Mg^{2+}$ will originate montmorillonite or vermiculite, instead of illite. In environments where solubility of $Al^{3+}$ is high (low pH) and $Si^{4+}$ and $Al^{3+}$ dissolve at nearly the same rates and solutions are kept undersaturated with both elements; kaolinite is probably formed through the reaction between $H_2O$, $Al^{3+}$ and $Si^{4+}$ in homogeneous media:

$$H_2O + 2AL^{3+} + 2H_4SiO_4 \rightleftarrows Al_2Si_2O_5(OH)_4 + 9\ H_2O$$

Iron when liberated from the primary minerals mostly originates ferrihydrite which by dehydration and internal rearrangement forms hematite or by dissolution and crystallization from solution forms goethite (Schwermann, 1985).

According to Jackson (1965) some primary minerals may be transformed to secundary clay minerals by rearrangement of elements in the solid phase, as for example the replacement of $K^+$ from interlayers of mica by $Mg^{2+} + H_2O$, and produce vermiculite. The reaction commonly occurs in the presence of a source of exchangeable $Ca^{2+}$ or $Mg^{2+}$, such as (Ca, Mg) $CO_3$.

WEATHERINGH OF SECONDARY MINERALS IN SOILS

The secondary minerals found in soils as montmorillonite, vermiculite, illite, chlorite are transformed to kaolinite and/or gibbsite and kaolinite to gibbsite mostly by dissolution and crystallization from solution, in a similar form as the model presented for primary minerals. Rearrangement of elements in solid phase or solid-solution phases may also occur.

It is difficult to viznalize the transformation of 2:1 minerals to kaolinite and/or gibbsite withouth a dissolution phase, because the structure of these minerals are quite different. But the partial dissolution of tetrahedral layers of 2:1 clay minerals may originate kaolinite, a 1:1 type clay mineral.

Other reactions as the precipitation of aluminum and iron oxyhydroxides in interlayer position of montmorillonite and vermiculite, forming chloritization is a common phenomena in acid tropical soils. These chloritizated minerals are resistant to weathering in acid conditions.

The synthesis of clay minerals as kaolinite from $H_2O-Al_2O_3-H_4SiO_4$ systems, which could explain its formation through a dissolution phase is easily achieved at high temperatures, but at normal environmental conditions (temperature and pressure) the reaction is restrict (Kittrich, 1970). Synthesis of ferrihydrite, lepidocrocite, goethite, hematite and magnetite (Schwertmann, 1985) are easy to achieve, as well as of gibbsite (Kittrich, 1969; Gardner, 1970).

The literature is rich on informations about the stability of minerals in systems of different composition and environmental conditions, as the example shown in Figure 3 (Loughnan and Bayliss, 1961; Kittrick, 1969 and 1970; Gardner, 1970).

The determination of soil weathering index or stage based on mineralogical composition was proposed by Jackson et alii, 1948. Since than mineralogical composition has been used to study the sequence of alteration of clay minerals in soils of the tropics and their weathering stage (Klamt and Beatty 1972; Rodrigues and Klamt, 1978). Loss of bases and silica and relative concentration of aluminum, iron and titaneum are indicative of weathering (Table 1). A consistent decrease in $SiO_2$, Ki and Kr occurs from montmorillonitc to oxidic soils.

Most of the surfaces and soils in the tropics have undergone cycles of erosion and deposition, such that it is difficult to determine the nature and composition of the soil parent material for genesis studies. Abrupt transitions between soil horizons and/or saprolite, stone lines, buried horizons are indicatives of these processes (Schwertmann et alii, 1983). Most of these soils were also subjected to different cycles of climatic and thus biological changes (Bigarella, 1964).

The sediments and soils originated from erosional and depositional processes occur in a great variety of characteristics due to the variation in the original material and subsequent weathering. Red and friable material seem to predominate in Central/South Brasil and developed from basic rocks (basalt), while yellowish in the Amazon region and coastal areas from more acid material and more humid contions. In many regions caulinitic/hematitic soils occur on gibbsite/goethitic saprolite. This mineralogical discordances are very difficult to explain by simple transformation of gibbsite to kaolinite by resilication or by deep weathering and goethite to hematite by dehydration, as many times it is stated and accepted (Schwertmann et alii, 1983).

The erosional and depositional processes described before and thus the existence of geological discordances, may explain these mineralogical discontinuities. A seccond or another possibility is the weathering of the primary minerals existent in the saprolite or rocks subjacent to soils, to gibbsite and goethite, while the overlying kaolinitic and hematitic and/or goethitic soil is stable at the present environmental conditions. The fact that these deeply weathered soils are very permeable and water infiltrates and flows through them freely to the weathering front, leaching out bases and silica, liberated by the dissolution of the unstable primary minerals and creating conditions favorable for gibbsite formation. Goethite is probably formed in this environmental conditions because of slow release of Fe, low pH and high soil humidity.

## PRESENT SOIL FORMING PROCESSES IN THE TROPICS

Tropical soils with paleogenetic characteristics are presently been subjected to pedogenetic processes with considerable changes in their morphological, chemical, mineralogical and biological properties (Schwermann et alii, 1983). The main process are:

a) Accumulation of organic matter

Accumulation of humus on surface horizons originating Ah horizons with variable concentration of organic carbon and thickness is a very active process. It can be better identified in regions of higher precipitation and/or lower temperature, which mostly is observed with increase in elevation.

b) Yellowing effect

Many soils in the tropics and subtropics have thick dark epipedons (mostly Umbric) over yellowish top B-horizon grading to redder horizons with depth. This process is associated with the former because the decomposition of the organic matter furnishes electrons to reduce the iron oxides (hematite). The reduced iron can be removed from the profile but most of it reprecipitates as goethite, wich is a more stable form in this acid and humid environment (Schwermann, 1971; Kämpf and Schwertmann, 1983). The transformation of hematite to goethite occurs via dissolution and not through rehydration (Schwertmann, 1971).

c) Hydromorphism and plinthite formation

The actual hydric regime has an improtant function in soils with paleogenetic characteristics. Two types of hydromorphism can be identified: 1) one related to perched water table which can be identified localy in platos (Rodrigues and Klamt; 1978), slopes and in valleys (soils with clay of low permeability); 2) related to true higher ground water table, found in low laying areas.

The effect of these forms of hydromorphism are similar: reduction of iron oxides, mainly hematite, its remotion from the soils or reprecipitation as goethite. When water from these areas emerge at the surface at creeks and slopes, $Fe^{2+}$ oxidizes and originates deposits with ochre colours, consisting of low crystalline lepidocrocite or ferrihydrite (Schwertmann et alii, 1983).

Organic matter plays an important function in this process because it furniches $O_2$ and electrons by its decomposition necessary to reduce iron. Mottled zones are produced in the soil profiles subjected to hydromorphism, with grayish matrix and red hematitic mottles, which are probably residual and not formed in situ due to iron concentration. In red (2.5YR 4/6) B22t horizons of Gleyic Luvisol developed from triassic sandstone, in southern Brasil, grayish reticulate areas occur, from which iron has been removed. Vertical tubes in the red sandstone below, filled with sand and clay and containing 0,25 % C, present a grayish center and a white rim in the sandstone. It seems clear that the iron was reduced and removed from the white rim probably due the presence of organic matter.

Hydromorphic soils with residual hematite of older soils, occurring as mottles, are widespread in tropical and subtropical areas. This mottled horizons are frequently described as plinthite and supposely originated by Fe migration in the profiles and concentrated in the mottles. The residual character of hematite should also bee considered as one alternative in the conception of genesis of plinthite.

Couto and Sanzonowicz (1984) reported the existence of seasonally high water tables (40-60) in very deep, friable and homogeneous Yellow Red Latosols in Central Brasil. They concluded that the low content of organic matter and nutrients inhibit development of microorganism and thus iron reduction. But when nutrients and/or sacarose are added, reduction of iron occurs rapidly.

d) Formation of Ferralsol/Acrisol/Nitosol Sequences

In many tropical and subtropical regions Ferralsols occur in flat interfluves and Nitosols or Acrisols in the more or less dissected adjacent slopes. They seem to have formed from the same parent material. A double-water flow model of soil development was proposed by Moniz and Buol (1982) to explain the formation of this sequence of soils. According to this model Ferralsols are formed in thick permeable sediments on nearly level surfaces where lateral water flow does not occur and the base water table is to deep to affect the solum. The argillic horizon of Acrisols and Nitosols on the slopes below is formed by saturation and dessication induced pressure of lateral-water flow as relief becomes steeper. The lateral-water flow, even not admitted by the authors, probably also removes clay from the top horizon originating the required textural gradient for argillic horizon, although very few or no clay skins are formed in some soils, probably because little vertical clay movement occurs.

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TABLE 1. ELEMENTAL COMPOSITION OF THE CLAY FRACTION OF $Bw_2$ AND Ack HORIZONS (WEIGHT %) OF DISTINCT TROPICAL SOILS (Klamt et alii, 1985).

| Soil | Mineralogical Composition | Country | Elemental composition of clay weight % | | | | | | Molar ratios | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $K_2O$ | $TiO_2$ | MnO | $SiO_2/Al_2O_3$ (Ki) | $SiO_2/R_2O_3$ (Kr) | $Al_2O_3/Fe_2O_3$ |
| Acric Ferralsol | Gibbsite ($Bw_2$) | Jamaica | 2.5 | 47.3 | 17.9 | 0.04 | 2.13 | 0.14 | 0.09 | 0.07 | 4.14 |
| Humic/ Acric Ferralsol | Ferritic ($Bw_2$) | Brasil | 7.3 | 18.1 | 34.2 | - | 4.87 | 0.15 | 0.69 | 0.31 | 0.83 |
| Rhodic Ferralsol | Kaolinitic ($Bw_2$) | Brasil | 28.2 | 27.1 | 22.8 | - | 2.71 | 0.15 | 1.77 | 1.15 | 1.86 |
| Pellic Vertisol | Montmorillo-nitic (Ack) | Thailand | 52.8 | 25.4 | 9.0 | 0.1 | 1.0 | 0.5 | 3.5 | 2.9 | 4.4 |

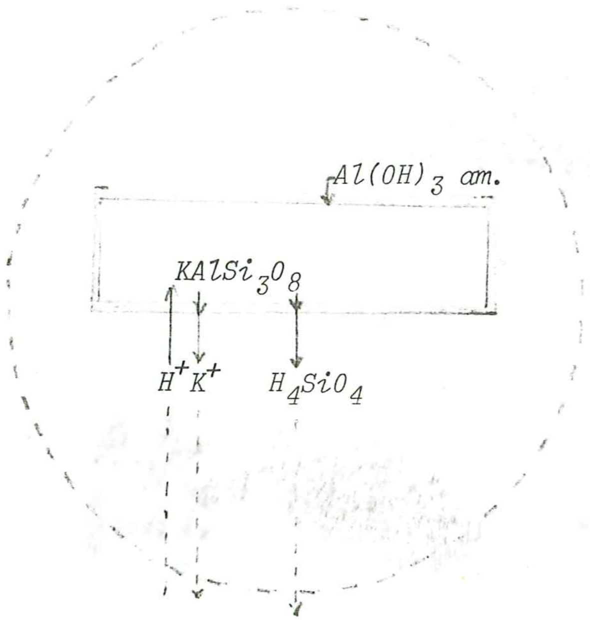


*Figure I.First reactions of K - feldspar weathering in buffered solutions (Wollast,1967;Berner,1971).*

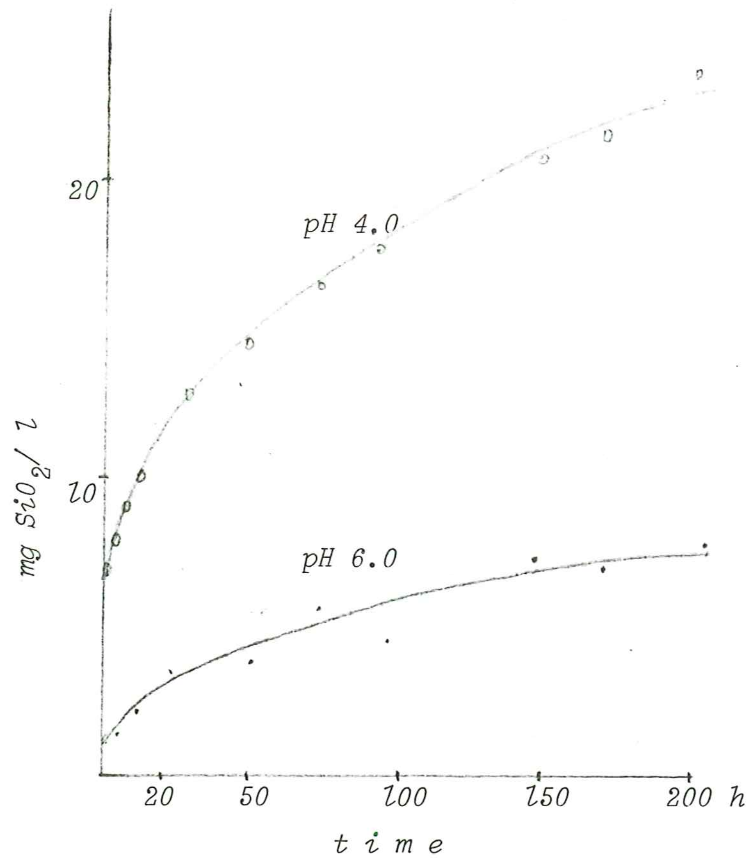


*Figure 2a. Changes in silica concentration with time at pH 4 and 6 in a weathering solution containing 5% feldspar (Wollast, 1967).*

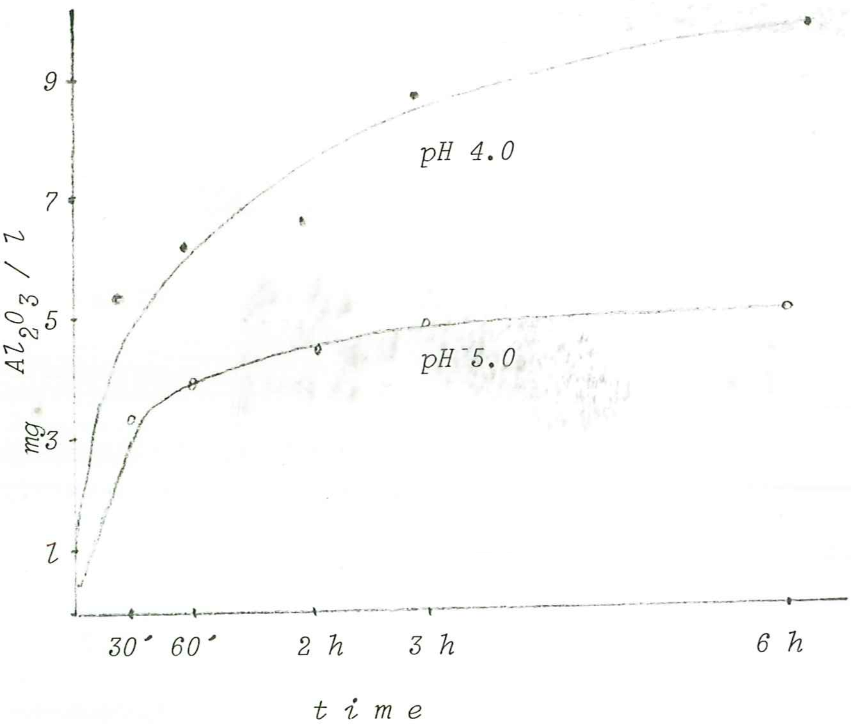


*Figure 2 b. Changes in aluminna concentration with time at pH 4.0 and 5.0 in a weathering solution containing 10% feldspar (Wollast, 1967).*

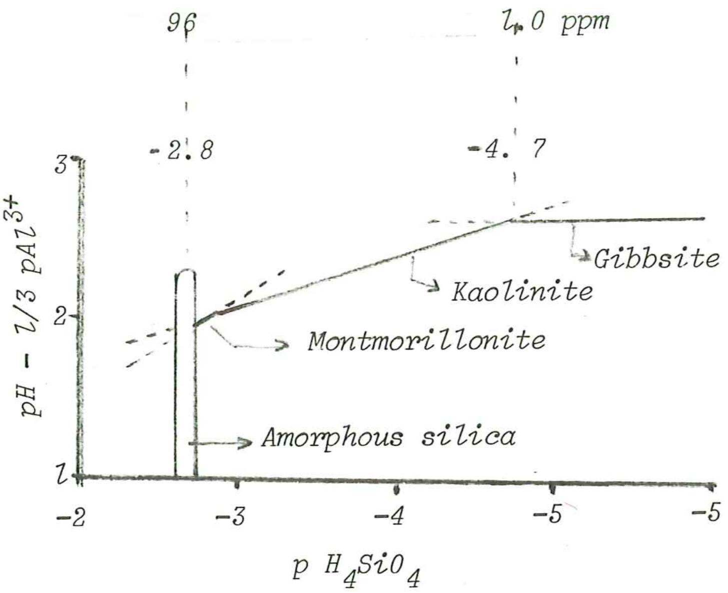


*Figure 3. Stability diagram of minerals in $Al_2O$ - $SiO_2$ - $H_2O$ systems at 25°C and 1 atm. (Kittrick, 1969).*

85-2230/64 EK/nb

# SOIL TAXONOMY - SOME DIFFICULTIES OF ITS APPLICATION TO TROPICAL SOILS

## INTRODUCTION

Soil Taxonomy was developed to classify the soils of the United States, but open to comprise the soils of the world. Presently it is the most used system for correlation with many national systems and for international communication between soil scientists.

Since the system was developed to classify soils of the United States and the basic concepts and diagnostic criteria defined on United States soils, it presents weaknesses when applied to tropical soils. The most serious shortcomings are related to:

- Imperfections in definition of diagnostic criteria,
- Poor development of taxa in some soil classes (Oxisol),
- Limiting availability of analytical and diagnostic data,
- Differences in methodology of soil analysis,
- Impossibility to carry out some special analysis (mineralogy, micro-morphology).

The diagnostic criteria of taxa of Oxisols and Ultisols and Alfisols of low activity clays, which do not occur extensively in the United States, were not adequately tested during the development of the system and for these soils the system presents weaknesses in most categorical levels.

## PROBLEMS AT SOIL ORDER LEVEL

The most severe classification problem for soils with low activity clays is the correct placement of pedons with a subsurface horizon that fulfills the textural requirement for argillic horizon but clay skins and other acessory characteristics are so weakly expressed that consistent quantification is doubtful. So, the distinction of Oxisols from Ultisols and Alfisols of low activity clay based on present diagnostic oxic or argillic horizon is very complex because of the mutual exclusivity of the argillic and oxic horizon and the confusing definitions of exchange properties (cation exchange capacity and base saturation at pH 7.0 or 8.2 - annex 1).

In a soil classification excercise performed by Kaufmann (1985) on Mozambique soils, which present a weakly developed argillic horizon on top of an oxic horizon, an international group of experienced soil scientists had difficulties in placing these soils at the order level (Table 1).

PROBLEMS AT SUBORDER LEVEL

The use of soil moisture and temperature regimes as diagnostic criteria to define suborders of Oxisols, Ultisols and Alfisols is problematic, mainly because of absence of consistent data and/or availability of data of atmosferic conditions only. Surprisingly soil scientists had no problems in placing soils in this categorical level in the classification excercise (Table 2) performed by Kaufmann (1985).

PROBLEMS AT GREAT GROUP LEVEL

Taxas at great group level were poorly defined for most suborders (Table 3) of Oxisols, if compared to classes of Ultisols, Alfisols and Inceptisols, at this level (USA, 1975). The GIBBSI and SOMBRI groups are rare and so with the exceptions of ORTHOX, there are few choices left.

In the classification excercise performed by Kaufmann (1985) experts had no major difficulties in placing soils in this level (Table 2). The "restgroup" HAPL was most frequently chosen, probably because of absence of other choices. The placement of soils in the EUTR great group of Oxisols is problematic because of confusion with the base saturation (BS) criteria (BS at CEC pH 8.2 $<$ 35% - annex 1).

PROBLEMS AT SUB-GROUP LEVEL

At this level the choices in Oxisol order are also very poor (Table 3), if compared with Ultisol, Alfisol and Inceptisol orders (USA, 1975). Because of lack of other choices the Typic sub-group was most frequently chosen in the classification excercise (Table 2) performed by Kaufmann (1985). The TROPEPTIC sub-group, referring to a pedal macrostructure more strongly developed than the normal weak structure of Oxisols, has been assigned especially to profile MOC3 (Table 2), although it does not present this type of structure in the Oxic B horizon.

FINAL REMARKS

The distinction of soils which occur in a specific moisture and temperature regime can be difficult down to the Family level. In the USTIC and ISOHYPERTHERMIC region of Central Brasil it was impossible to distinguish different soils as Dusky and Dark Red Latosols (Rhodic Ferralsols), Yellow Red

Latosols (Orthic Ferralsols) and Yellow Latosols (Xanthic Ferralsols) since all are kaolinitic, clayey, isohyperthermic TYPIC HAPLUSTOX (Brasil, 1976). The introduction of Rhodic and Xanthic sub-groups in the great groups of Oxisol order, as proposed by many Brazilian soil scientists, will partially solve this problem.

The newly developed KANDIC horizon concept: a horizon with ECEC of less than 12 me/100 g clay or CEC pH 7.0 of less than 16 me/100 g clay and clay increase with depth as required in argillic horizon in a vertical distance of 15 cm or less (Moormann and Buol, 1981), seems promising to overcome the conflicting presence of both argillic and oxic horizons. According to this proposition, soils with more than 40% clay in the top 18 cm, are oxic irrespective of having a kandic horizon or not, and soils with less than 40% clay in the top 18 cm and having a kandic horizon are included in the KANDIC Great Groups of Ultisols and Alfisols if BS is respectively less or more than 35%.

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Table 1 - Overview on first order classification according to the ST system of three soils from Mozambique.

| Pedon | Oxisol | Ultisol | Alfisol | Mollisol | Inceptisol |
|---|---|---|---|---|---|
| MOC 1 | 6 | 4 | 3 | - | - |
| MOC 2 | 3 | 5 | 4 | - | - |
| MOC 3 | 5 | 6 | 3 | - | - |

Table 2 - Classification of 3 Mozambican pedons according to Soil Taxonomy (1975), executed by an international panel

| Pedon nr. | Order | Suborder | Great Group | Subgroup |
|---|---|---|---|---|
| | - Oxisol | - Ustox | - Haplustox | - Typic (4) |
| A2/MOC1 | | | | - Rhodic |
| | | | | - Tropeptic |
| | - Ultisol | - Ustult | - Paleustult | - Oxic (2) |
| | | | | - ...... (2) |
| | - Alfisol | - Ustalf | - Paleustalf | - Rhodic |
| | | | | - Oxic |
| | - Oxisol | - Ustox | - Haplustox | - Typic (2) |
| | | | | - Acric Rhodic |
| | - Ultisol | - Ustult | - Paleustult | - Typic |
| L1/MOC 2 | | | | - Rhodic Orthoxic |
| | | | | - Oxic |
| | | | | - ...... (2) |
| | - Alfisol | - Ustalf | - Paleustalf | - Rhodic |
| | | | | - Oxic (2) |
| | | | | - Rhodic Oxic |
| | - Inceptisol | - Tropept | - Dystropept | - Ustoxic |
| | - Oxisol | - Ustox | - Eutrustox | - Typic |
| | | | - Haplustox | - Typic |
| | | | | - Tropeptic (3) |
| L2/MOC 3 | - Ultisol | - Ustult | - Paleustult | - Oxic (2) |
| | | | | - Rhodic Oxic (2) |
| | | | | - ...... (2) |
| | - Alfisol | - Ustalf | - Paleustalf | - Oxic (2) |
| | | | - Rhodustalf | - ...... |

TABLE 3. Key to suborders, great groups and sub-groups of oxisol order of Soil Taxonomy (USA, 1975).

| ORDER | SUBORDERS | GREAT GROUPS | SUB-GROUPS |
|---|---|---|---|
| | AQUOX | GIBBSIAQUOX | - |
| | | PLINTHAQUOX | TYPIC |
| | | OCHRAQUOX | TYPIC |
| | | UMBRAQUOX | TYPIC |
| | TORROX | - | TYPIC |
| OXISOL | | | |
| | HUMOX | SOMBRIHUMOX | - |
| | | GIBBSIHUMOX | TYPIC |
| | | HAPLOHUMOX | TYPIC |
| | | ACROHUMOX | TYPIC E PETRO FERRIC |
| | USTOX | SOMBRIHUMOX | - |
| | | ACRUSTOX | TYPIC |
| | | EUTRUSTOX | TYPIC E TROPEPTIC |
| | | HAPLUSTOX | TYPIC, TROPEPTIC, ULTIC |
| | ORTHOX | SOMBRIORTHOX | - |
| | | GIBBSIORTHOX | TYPIC |
| | | ACRORTHOX | TYPIC, HAPLIC, PLINTHIC |
| | | EUTRORTHOX | TYPIC, HAPLOHUMIC, SOMBRIHUMIC, TROPEPTIC |
| | | UMBRIORTHOX | TYPIC, TROPEPTIC |
| | | HAPLORTHOX | TYPIC, AQUIC, EPI-AQUIC, QUARTZISPAMMENTIC, TROPEPTIC, ULTIC |

Annex 1

## Overview on the exchange properties criteria used in ST

**SOIL TAXONOMY**

**Oxic horizon**

- ECEC ⩽ 10 me/100 g clay (for both analytical procedures)
- CEC (7) ⩽ 16 me/100 g clay

**Ultisol**

- BS (8.2) < 35% at a depth of (about) 180 cm
- Often used in the assumed correlation: 35% BS (8.2) ≈ 50% BS (7)

**Mollic horizon**

- BS (7) > 50%

**Oxic subgroup**

- CEC (7) ⩽ 24 me/100 g clay in the major part of the argillic horizon

**Acric (sub)group**

- CEC < 1.5 me/100 g clay (for both analytical procedures)

**Haplustox**

- BS (7) < 50% when clayey
- BS (7) < 35% when loamy

THE BRAZILIAN SYSTEM OF SOIL CLASSIFICATION

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Contents





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1) FAO = The legend of the World Soil Map - volume I - FAO/Unesco, 1974
ST = Soil Taxonomy - USDA/SCS, 1975



# THE BRAZILIAN SYSTEM OF SOIL CLASSIFICATION

## 1. INTRODUCTION

Brazilian soil science is young. In early soil studies (before 1947) soils were mainly classified (grouped) in relation to parent material or geomorphological units. In 1947 national soil science and survey institutions were founded. A programme of reconnaissance soil surveys of Brazil started with the survey of the state of Rio de Janeiro in 1954.

For the soil map legend and the definition of soil classes the old USA soil classification system has been used.

The great group level was used to describe the soils in uniform cartographic units, however, depending on soils and region also higher or lower taxonomic classes were used.

At present about 70% of Brazil has been mapped at the exploratory-reconnaissance level and 30% at reco-level and a minor percentage at more detailed levels.

## 2. GENERAL CHARACTERISTICS OF THE SYSTEM

The National Soil Survey and Conservation Services (SNLCS-EMBRAPA) is at present coordinating the elaboration of the Brazilian system. Having taken the central concepts from the old USA system it has modified criteria, created subdivisions and intergrades during the numerous soil surveys. Although the 2nd approximation of the system has been published, it is not yet in conditions to be reproduced or transcribed, since it is still in development. The system was designed to include all the soils of Brazil, but it is an incomplete and open system, in which new classes may be incorporated. It is a multi-categorical and descending system. Its base is morphogenetic, since characteristics which express pedogenetic processes are used. For this purpose morphological, physical, chemical and mineralogical properties are used.

## 3. DIAGNOSTIC HORIZONS AND OTHER DIAGNOSTIC PROPERTIES

### 3.1 DIAGNOSTIC HORIZONS

The relative stable B-horizon was selected as diagnostic horizon in early stage. The definition of surface and subsurface diagnostic horizons were made in the early sixties, based on the 7th Approximation of the USA soil classification system. However, the Brazilian system passed through many changes and improvements. The diagnostic horizons presently used in Brazil and compared with the equivalent horizons of the FAO (1974) and Soil Taxonomy (1975) are represented in Table 1.

## 3.2 OTHER DIAGNOSTIC PROPERTIES

### Soil colour

Particularly in Latosols soil colour was used as an important criteria to define soil classes. At a regionale scale colour is associated (correlated) with other properties, such as iron oxides/hydroxides, magnetic susceptibility of the soil, land use, climatic conditions, geomorphology. At a nationale scale soil colour as a high level criteria is under discussion.

### Activity of clay (T)

The activity of clay refers to the CEC of the clay fraction. It is calculated from the CEC of the soil after subtraction of the contribution of organic carbon.
The following equation is used:

$$\text{CEC (100 g clay)} = \text{CEC (100 g soil)} - (4.5 \times \%C) \quad \times 100/\% \text{ of clay}$$

For more precise procedure, the graphic method proposed by Bennema (1966) should be used. Two classes of activity of clay are used:

Ta = soils with CEC > 24 meq/100g clay, and
Tb = soils with CEC < 24 meq/100g clay.

### High Al saturation (Allic)

The term "Allic" is used to define soil classes with Al saturation > 50% and a minimum of 0.3 meq of exchangeable Al.
The formula:

$100.Al/S+Al$ [2] is used to calculate it.

### Base saturation (V)

Equivalent definition as in ST and FAO.
Eutrophic refers to V > 50%, dystrophic is V < 50%

### Sodic

Sodic refers to E.S.P.[3] > 15% in the lower part of the B or C horizon.

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2) Al extracted with 1N KCl in meq/100g soil
S is sum of exchangeable cations, in meq/100g soil
3) ESP = Exchangeable Sodium Percentage



### Solodic

Solodic refers to E.S.P. between 6 and 15%.

### Saline

Saline indicates the presence of salts, expressed by an EC[4] > 4mS.

### Carbonatic

Carbonatic refers to soils with more than 15% $CaCO_3$, but without a Calcic horizon.

### Abruptic

'Abruptic' refers to an abrupt textural change from the A to B horizon. If the A horizon has < 20% clay, the clay increase in a distance of 7.5 cm should be 100% and if the A horizon has > 20% clay, the clay increase in 7.5 cm should be of 20% in absolute value (as 22% to 42%).

### Textural classes

The textural class of the B horizon is used for subdivision, i.e. heavy clay > 60% clay, clayey 35-60, medium 15-35, sandy < 15%, silty > 50% silt.

### Other properties

Gilgai, slickensides, clay skins, (para) lithic contact, durinodules, plinthite, drainage and soil reaction as defined in ST or the soil survey manual are also used as diagnostic properties.

### Phases

Although most soil survey performed in Brazil are at the reconnaissance or more general level and the adequate taxonomic units at these levels are far from soil series, phases of relief, substratum, natural vegetation, rock outcrops and concretions has been used.

### Intergrades

Frequently termed as "latosolic" (Cambisols, Terra Roxa Estruturada, and Red yellow Podzolic), "cambic" (Latosols), "podzolic" (Latosols, Cambisols); "vertic" (Planosols, Non-calcic Brown) and others, are used to indicate integration between groups of soils.

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4) ECs = electrical conductivity of a saturated soil past

## 4. SOIL CLASSES AND THEIR DEFINITIONS

As no final/official publication on the Brazilian system exists yet, Table 2 has been prepared to show in a simplified version the system as it is in use.

The legend of the 1:5.000.000 scale soil map of Brazil (EMBRAPA-SNLCS, 1981) as well as the publication "bases for reading soil maps" (EMBRAPA-SNLCS, 1981) form the base for Table 2. Other publications used are listed in the annex literature, numbers 2, 3, 4, 5, 6, 7, 8, 9, 11, and 13. The diagnostic properties for further subdivision of classes on a lower level are given as well. The system on the lower levels is "open", no established lower class definitions are given.

Some examples of how these diagnostic properties on a lower level are used in soil surveys:

Example 1. A red yellow latosol with a thick dark organic carbon rich surface horizon with > 50% aluminium saturation in the diagnostic horizon, clayey texture, vegetation of subtropical humid forest and found on undulating slope would be classified as:

Red Yellow Latosol Humic Allic clayey phase humid subtropical forest undulating relief.

Example 2. A greyish brown podzolic soil with > 50% base saturation and parts of the profiles presenting rock structure and high concentration of weatherable minerals, cation exchange capacity after correction for organic carbon 24 meq/100g of clay (Ta), abrupt textural change, moderate A horizon, medium texture at the B horizon, vegetation of tropical forest and gently undulating slope, would be classified as:

Greyish Brown Podzolic Eutrophic Cambic Ta, abruptic moderate A sandy/medium texture phase tropical forest gently undulating relief.

Example 3. A Rendzina with clayey texture and occurring under semi deciduous subtropical forest and rolling relief is classified as:

Rendzina Clayey phase semi deciduous subtropical fores rolling relief.

In this case, since the type of surface diagnostic horizon (Chernozemic A) and the high base saturation and high activity of clay are properties used to define the soil class, they cannot be used for further subdivisions of classes in lower categorical levels.



## 5. CORRELATION BETWEEN SOIL CLASSES OF BRAZILIAN, FAO AND ST SYSTEMS

A correlation between Brazilian, FAO, ST soil classification systems has been made, based on the classification of about 400 soil profiles described and classified in Brazilian soil survey reports.

In table 3A results are presented for the first level soil classes. In table 3B results are presented for the Latossolos subclasses. The number of profiles classified according to a specific class is presented in brackets after the class name in table 3B. The number was omitted when just one profile has been classified in a class.

A reasonable comparison can only be made on the first level (table 3A). For instance, most of the Latosols of Brazilian system fit into the Ferralsol unit of FAO World Soil Map legend and into the Oxisol order of Soil Taxonomy.

Comparison on the second level is already difficult and confusing (table 3B). A wide scattering of classes was observed when the Brazilian types of Latossolos were classified on the second level of FAO and on suborder and great groups of Soil Taxonomy. A similar scattering was observed in other classes, a.o. Red Yellow Podzolic, Terra Roxa Estruturada, Reddish Brunizem and Litossolos.

This scattering is inevitable as criteria for subdivision on the second or lower levels are different. E.g., for the Latossolos the colour with iron oxide content is used in the Brazilian system; while presence of plinthite, an umbric A horizon low CEC and colour are used in FAO system; moisture regime on second level, and presence of gibbsite or plinthite, base saturation, CEC, etc. on third level are used in the Soil Taxonomy.

## 6. THE BRAZILIAN SYSTEM IN PRACTICE - TOPICS OF DISCUSSIONS

In this paragraph the applicability of the Brazilian system for soil surveying, soil evaluation and scientific work will be discussed mainly on typical tropical soils.

### Soil mapping

The high level classification of soils in the field is remarkable quickly done and showing a reasonable uniformity. This is probably caused by the fact that not a rigid classification key procedure is followed but still a quick "central concept" approach.

The central concepts of a Latosol, a Podzolico or a Terra Roxa Estruturada in terms of morphology are rather well memorized and serves as a reference base for the soil surveyor. (The latosol being very deep with little horizonation and a very weak macrostructure, the Podzolico being not very deep with clear horizonation due to colour and textural differentiation, and the Terra Roxa Estruturada with a well developed blocky structure.)

The naming of intergrades is simple but the procedure is subjective and results will probably be more heterogeneous.

In the comparison of soil profiles on country or world scale, it appears for instance that soil colour at present in use as a differentiating criterium on a high level is discussable.

The large degree of freedom in coining/characterizing a soil on a lower level is also an advantage for soil mapping on a regionale scale.

For soil mapping on a regionale scale the FAO and ST system has disadvantages:

- FAO: having only two taxonomic levels
- rigid key procedure, creating high risk for conflicting results
- necessity for standardized analytical data

## Soil Evaluation

The classification system is based, besides the profile morphology, on chemical characteristics. Therefore, soil evaluation on chemical characteristics can be reasonably executed. Physical soil evaluation is weak, being not based on measured or observed characteristics but realized in a presumed generalized way. For instance (simplified), Latossolos having favourable physical characteristics; Podzolicos having less favourable rooting possibilities and being more erodable; and Terra Roxa Estruturada having good rooting possibilities but erodable, etc..

The land capability classification based on the morphological and chemical properties, due to the large scale of maps, is adequate for regional planning. In some regions the soil survey informations have been transfered to extension agencies and used for agricultural development, but as a hole they are subutilized.

## Scientific work

As already indicated above it seems that the advantages of the system at present is more in mapping soils distribution on a regional scale than being a system which make comparison and correlation on country or world scale possible.

For instance, the colour and iron oxides content for subdivision of the Latossolos in the highest level is from the genetic viewpoint a weak grouping criterium, since colour is more related to the type of iron oxide. Even though iron oxide rich Latossolo Roxo presents a very strong small granular structure, which is sometimes described as "coffee powder" structure, most physical and chemical properties are not related to the type and content of iron oxides.

On a routine base the 'ataque sulfurico' ( total analysis of elements by dissolution with $H_2SO_4$) is executed. The results and the derived Ki and Kr[5] values are however very little used in the system. There is a need to check on a large number of profiles, the usefulness of this analysis for classification purposes.

The 'CEC corrected for organic matter' (T value) is very little used as a classification criteria, e.g. further subdivision of the Latossolos.

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5) Ki = $SiO_2/Al_2O_3$
Kr = $SiO_2/Al_2O+Fe_2O_3$



Table 1. - Equivalences between diagnostic horizons of FAO, Soil Taxonomy and Brazilian system of soil classification and specific criterion used in Brazil

| Systems of classification | | | Specific or additional criterion |
|---|---|---|---|
| FAO | Soil Taxonomy | Brazilian | used in Brazilian system |
| | | - Surface Diagnostic Horizons - | |
| Mollic A | Mollic Epipedon | Chernozemic A | equivalent definitions |
| Umbric A | Umbric Epipedon | Proeminent A | equivalent definitions |
| - | Anthropic " | Anthropic A | equivalent definitions |
| Histic A | Histic " | Turfoso A | equivalent definitions |
| Ochric A | Ochric " | Moderate A | equivalent definitions, but excludes horizons with properties of weak A horizon |
| - | - | Weak A | surface horizon with < 0.58% organic carbon, light colours with dry values 5 and without development of structure or weak structure |
| - | - | Humic A | corresponds to the richer in organic carbon and thicker segment of umbric epipedon |
| | | - Subsurface diagnostic horizons - | |
| Argillic B | Argillic horizon | textural B | equivalent definitions, but textural gradient or the ratio of clay content of B horizon/A horizon is: a) > 1.5 if A horizon has > 40% clay; b)>1.7 if A horizon has 15 to 40% clay; c)>1.8 if A horizon has < 15% clay. When the B horizon presents well developed blocky or prismatic structure and/or clay skins, the former textural gradient is not required |
| Natric B | Natric horizon | Natric B | equivalent definitions |
| Spodic B | Spodic horizon | Spodic B | equivalent definitions |
| Cambic B | Cambic horizon | Incipient B | similar definitions, but to distinguish from Latosolic B, should have weatherable minerals, CEC of clay > 13 me/100g after correction for organic carbon, silt/clay ratio >0.7; $SiO_2/Al_2O_3$ ratio > 2.2 and 5% or more by volume of rocks fragments or saprolite |

Table 1. (continuation)

| Systems of classification | | | Specific or additional criterion |
|---|---|---|---|
| FAO | Soil Taxonomy | Brazilian | used in Brazilian system |
| | - Subsurface diagnostic horizons - | | |
| Oxic B | Oxic horizon | Latosolic B | similar definitions, but the Latosolic B is at least 50 cm thick; has a silt/clay ratio $<$ 0.7; CEC of the clay fraction after deduction of the contribution of organic matter is $<$ 13 meq/100g of clay; $SiO_2/Al_2O_3$ ratio (Ki) of the clay fraction $<$ 2.2 normally less than 2.0; very strong, very small to small granular structure or weak to moderate subangular blocky; great stability of aggregates, with high degree of flocculation and low content of water dispersable clay |
| Plinthite | Plinthite | Plintic horizon | Presence of plinthite as defined in Soil Taxonomy in more than 25% by volume, in a layer of 15 cm thick or more |
| - | - | Gley horizon | similar to hydromorphic properties of FAO system. Is a subsurface horizon with gleyic properties, as: 1) dominant neutral (N) hues or bluer than 10Y; 2) saturation of water at some period of the year, or artificially drained, with evidence of reduction processes or of reduction and segregation of iron reflected by: a) mottles of chromas 2 or less, b) if mottles are not present and the value is $>$ 4, the chroma is $<$ 1 and if the value is 4 or more, chroma 1 or less |
| Albic E | Albic horizon | Albic horizon | equivalent definition |
| Calcic horizon | Calcic " | Calcic " | equivalent definition |
| - | Petrocalcic horizon | Petrocalcic horizon | equivalent definition |
| Sulfuric horizon | Sulfuric horizon | Sulfuric horizon | equivalent definition |
| - | Salic horizon | Salic horizon | equivalent definition |
| - | Fragipan | Fragipan | equivalent definition |
| - | Duripan | Fragipan | equivalent definition |



Table 2 - Key to soil classes of high level in use at present and diagnostic properties used for further subdivision of the classes in lower categorical levels

| Soil classes of high level | Diagnostic properties for subdivision of classes of high level |
|---|---|
| A. Mineral soils, non hydromorphic, with latosolic B horizon below any diagnostic A horizon except turfoso (histic) A, and: | - Humic A (Humic) or criptohumic A horizon (criptohumic = presence of high amounts of organic carbon, but with light colours); |
| 1) dusky red to dark red colors, high concentration of $Fe_2O_3$ ($>$18%), high magnetic susceptibility and efervescence with $H_2O_2$<br>**Latossolo roxo**<br>(dusky red Latosol) | - Base or Al saturation (Eutrophic, Dystrophic, Allic)<br>- Presence of plinthite (not satisfying definition of Plinthic B horizon), concretions, cohesiveness of soil mass (plinthic, concretionary, cohesive) |
| 2) Dusky red to dark red colours, medium to high concentration of $Fe_2O_3$ (9-18%) when texture is clayey or $\%Al_2O_3/\%Fe_2O_3$ $>$1.0 and $<$ 2.0 when of medium texture and without magnetic susceptibility and no effervescence with $H_2O_2$<br>**Latossolo Vermelho Escuro**<br>(dark red Latosol) | - Intergradational properties (Podzolic, cambic)<br>- Typès of A horizon (Proeminent, moderate ....)<br>- Textural class<br>- Phases of vegetation and relief |
| 3) Yellow red colour, medium to low concentration of $Fe_2O_3$ ($<$9%) when of clayey texture or $\%Al_2O_3/\%Fe_2O_3$ $>$ 2 when of medium texture<br>**Latossolo Vermelho Amarelo**<br>(Yellow Red Latosol) | |
| 4) Yellow colours, low concentration of $Fe_2O_3$ and developed from materials poor in bases and iron<br>**Latossolo Amarelo**<br>(Yellow Latosol) | |
| 5) Latosols with brown colours, found in regions of cold and humid climate and high altitude<br>**Latossolo Bruno**<br>(Brown Latosols) | |
| 6) Latosols with very high content of $Fe_2O_3$ ($>$35%)<br>**Latossolo Ferrifico**<br>(Ferrific Latosols) | |

Table 2 - (continuation)

| Soil classes of high level | Diagnostic properties for subdivision of classes of high level |
|---|---|
| B. Mineral soils, with textural B horizon, low activity clay, low textural gradient between B/A, moderate to strong prismatic or blocky structure, clay skins on peds and: | - Base or Al saturation<br>- Intergradational properties (Latosolic)<br>- Type of A horizon<br>- Textural class<br>- Phases of vegetation and relief |
| 1) Developed from basic rocks, dusky red to dark red colours, high $Fe_2O_3$ content, high magnetic susceptibility and effervescence with $H_2O_2$ **Terra Roxa Estruturada** | |
| 2) Not developed from basic rocks, dark red colours, lower content of $Fe_2O_3$, low magnetic susceptibility and effervescence with $H_2O_2$ **Terra Roxa Estruturada Similar** | |
| 3) Developed from basic rocks, brown colours **Terra Bruna Estruturada** | |
| 4) Not developed from basic rocks, brown colours **Terra Bruna Estruturada Similar** | |
| C. Mineral soils with textural B horizon, mostly with abrupt textural change | - Base or Al saturation<br>- Presence of fragipan<br>- Intergradational properties (Latosolic, Cambic)<br>- Activity of clay (Ta and Tb)<br>- Type of A horizon<br>- Textural class<br>- Phase of vegetation and relief |
| 1) B horizon with yellow to red colour, well drained soils **Podzolico Vermelho Amarelo** (Red Yellow Podzolic) | |
| 2) Greyish brown colour, somewhat poorly to poorly drained **Podzolico Bruno Acinzentado** (Greyish Brown Podzolic) | |
| 3) With Plinthite in B horizon, buth not satisfying the requisites to a Plinthic B horizon **Podzolico Plintico** (Plinthic Podzolic) | |



Table 2 - (continuation)

| Soil classes of high level | Diagnostic properties for subdivision of classes of high level |
|---|---|
| D. Mineral soils with a spodic B horizon | - Base or Al saturation<br>- Type of A horizon<br>- Textural class<br>- Phase vegetation and relief |
| 1) Non hydromorphic **Podzol** | |
| 2) Hydromorphic **Podzol Hidromorfico** (Hydromorphic Podzol) | |
| E. Mineral soils with a Chernozemic A horizon, high activity clay, mostly with reddish colour and: | - Textural class<br>- Phases of vegetation and relief |
| 1) Cambic B horizon **Brunizem** | |
| 2) Textural B horizon **Brunizem Avermelhado** (Reddish Brunizem) | |
| F. Mineral soils with a textural B horizon, high activity clay, reddish colour, moderate to strong prismatic or blocky structure, proeminent A horizon, high Al saturation **Rubrozem** | - Intergradational properties (Cambic, Latosolic)<br>- Textural class<br>- Phases of vegetation and relief |
| G. Mineral soils with a reddish textural B horizon, high activity clay, normally with eutrophic weak or moderate A, with or without a calcic or carbonatic horizon **Bruno não Calcico** (Non Calcic Brown) | - Intergradational properties (Litholic, Planosolic, Vertic)<br>- Type of A horizon<br>- Textural class<br>- Phases of vegetation and relief |
| H. Mineral soils, hydromorphic, with a textural B horizon, mostly with abrupt textural change, occur on level to gently undulating surfaces **Planossolo** (Planosol) | - Plinthic or Solodic properties<br>- Base or Al saturation<br>- Activity of clay<br>- Type of A horizon<br>- Phases of vegetation and relief |

Table 2 - (continuation)

| Soil classes of high level | Diagnostic properties for subdivision of classes of high level |
|---|---|
| I. Mineral soil, mostly hydromorphic, with a natric B horizon, abrupt textural change, high activity clay<br>**Solonetz Solodizado**<br>(Solodized Solonetz) | - Base saturation or presence of soluble salts<br>- Presence of fragipan<br>- Type of A horizon<br>- Textural class<br>- Phase of vegetation and relief |
| J. Mineral soils with a salic horizon, with enrichment of soluble salts at the surface horizon<br>**Solonchakos solos salinos indiscriminados**<br>(Indiscriminated saline soils) | - Geomorphic surface in which saline soils are found as: "mangrove", ocean coast |
| K. Mineral soils with an incipient (cambic) B horizon, well to imperfectly drained<br>**Cambissolo**<br>(Cambisol) | - Intergradational properties (Latosolic, Vertic) or Humic horizon<br>- Base or Al saturation<br>- Activity of clay<br>- Type of A horizon<br>- Textural class<br>- Phases of vegetation, substratum and relief |
| L. Mineral soils with a plinthic B horizon, low activity clay, hydromorphic, mostly with abrupt textural change<br>**Laterita hidromorfica**<br>(Groundwater laterite) | - Base or Al saturation or soluble salts (solodica)<br>- Presence of fragipan<br>- Type of A horizon<br>- Textural class<br>- Phases of vegetation and relief |
| M. Mineral soils with a gley horizon, hydromorphic, weak textural gradient between horizon and:<br>1) Thick, dark surface horizon, with high organic carbon content<br>**Gley Humico**<br>(Humic Gley)<br>2) Lighter in colour and lower content of organic carbon in surface horizon<br>**Gley Pouco Humico**<br>(Low Humic Gley)<br>3) Sulfuric horizon<br>**Gley Thiomorfico**<br>(Thyomorphic Gley) | - Base or Al saturation<br>- Activity of clay<br>- Type of A horizon<br>- Textural class<br>- Phases of vegetation and relief |



Table 2 - (continuation)

| Soil classes of high level | Diagnostic properties for subdivision of classes of high level |
|---|---|
| N. Mineral soils with 30% or more of clay, with cracks in some periods of the year, slickensides or compression surfaces<br>**Vertissolo**<br>(Vertisols) | - Carbonatic or calcic horizon<br>- Type of A horizon<br>- Phases of vegetation and relief |
| O. Weakly developed mineral soils, without subsurface diagnostic horizon, hydromorphic or not | |
| 1) AR or AC horizon sequence, with underlying unweathered or wethered rocks<br>**Litossolo**<br>(Lithosols) | - Presence of a Humic A horizon, base or Al saturation, activity of clay, type of A horizon, textural class, phases of vegetation, substratum and relief |
| 2) AC horizon and developed from saprolite or pediment deposits or other reworked material<br>**Regossolo**<br>(Regosols) | - Base or Al saturation, presence of fragipan, type of A horizon, textural class and phases of vegetation and relief |
| 3) AC horizon sequence and developed from quartzic sands and:<br>a) Non hydromorphic<br>**Areias Quartzosas**<br>(Quartzic Sands)<br>b) Hydromorphic<br>**Areias Quartzosas hidromórficas**<br>(Hydromorphic Quartzic Sands) | - Base or Al saturation, type of A horizon and phases of vegetation and relief |
| 4) AC horizon sequence, with Chernozemic A horizon and weathered from limestone<br>**Renzina** | - Textural class, phases of vegetation and relief |
| 5) AC horizon, developed from fluvial sediment, which shows stratification<br>**Solos Aluviais**<br>(Alluvial Soils) | - Base or Al saturation, activity of clay, type of A horizon, textural class and phases of vegetation and relief |
| P. Hydromorphic soils developed from organic material<br>**Solos Orgânicos**<br>(Organic Soils) | - Presence of sulfur (Thyomorphic), base or Al saturation and phases of vegetation and relief |

Table 3A - Tentative correlation between soil classes of high level of Brazilian, FAO and Soil Taxonomy systems

| Brazilian | FAO | Soil Taxonomy |
|---|---|---|
| Latossolos | Ferralsols | Oxisols |
| Podzolico Vermelho Amarelo (red yellow podzolic) | Acri-, Luvi-, Nitosols | Ulti-, Alfisols |
| Terra Roxa Estruturada (structured red earth) | Nitosols | Alfi-, Ulti-, Mollisols |
| Brunizem avermelhado (reddish Brunizem) | Phaeozem/Kastanozem/ Chernozem Luvisol | Alfi-, Mollisol |
| Cambissolo | Cambi-, Fluvisol | Inceptisol |
| Vertissolo | Vertisols | Vertisols |
| Litossolos | Phaeozem, Lithosols Rankers, Cambisols | Inceptisols, Entisols |
| Regossolos | Rego-, Cambisols | Entisols |
| Areias quartzosas (Quartz sands) | Areno-, Regosols | Entisols, Inceptisols |
| Solos aluviais | Fluvisols | Entisols |
| Solos orgânicos | Histosols | Histosols |
| Laterita hidrómorfica | plinthic Acri-, Luvi-, Ferralsols | plinthic-, aquic-, oxi-, ulti-, Alfisols |
| Glei | Gleysols gleyic Luvi-, Acrisols | aquic Incepti-, Molli-, Entisols |



Table 3B - Tentative correlation between subclasses of Brazilian Latossolos soils and FAO and Soil Taxonomy systems

| Brazilian system | FAO World Soil Map legend | Soil Taxonomy |
|---|---|---|
| Latossolo Roxo (Dusky Red Latosol) | Rhodic(10), Humic(3), Acric, Ferralsol | Haplorthox(6); Acr orthox(4) Ustox; Eutr orthox(4), Ustox |
| Latossolo Vermelho Escuro (Dark Red Latosol) | Rhodic(8), Humic(4), Acric(3) orthic(2) Ferralsol | Hapl orthox(6) Ustox(2) Humox; Acr orthox(4) ustox(2); Eutr orthox ustox |
| Latossolo Vermelho Amarelo (Yellow Red Latosol) | Orthic(19), humic(16), xanthic(7), Acric(2), plinthic Ferralsols and Dystric Nitosols(2) | Hapl orthox(20) ustox(4) Humox(3); Acr orthox(12) Ustox(5) humox(3); Sombri humox(2) orthox; Umbri orthox(7); Torrox(2); Eutrustox |
| Latossolo Bruno (Brown Latosol) | Humic Ferralsol(4) | Haplo Humox (2) Acro Humox (2) |
| Latossolo Ferrifico (Ferrific Latosol) | Humic Acric Ferralsol | Acro Humox |

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# INTERPRETATION OF SOIL SURVEY DATA FOR LAND EVALUATION

## INTRODUCTION

Studies of soil morphology, genesis, classification and survey are of limited value if the informations obtained are not used for land evaluation and improvements in the use of soils for agriculture, urbanization, recreation and public services (roads, railroads, airports). For most of these uses of soil information, there are specific systems of interpretation of data and land evaluation.

The land capability classification system of the Soil Conservation Service-USDA (Klingebiel and Montgomery, 1961) has been used by the Brasilian Soil Survey Service for soil surveys interpretations until 1965. After 1965 the system of land suitability evaluation for agriculture proposed by Bennema et alii (1964) and modified by Beek (1975) and by Ramalho Filho et alii (1983) has been used.

The purpose of these manuscript is summarize the system of land suitability evaluation for agriculture, presently used in Brasil.

## LEVELS OF MANAGEMENT

In this system the land suitability classes for agriculture were stablished for three levels or systems of management:

A - Low management level, without use of capital, machinery, soil conservation practices and technical information.

B - Intermediate management level, with modest use of capital and research data of management, improvement and conservation practices.

C - Advanced management level, with intensive application of capital and research informations.

The systems or levels of management B and C do not consider irrigation in evaluating the land suitability. For cultivated pasture and forestry a B level of management is used, because some fertilizers and land management practices are used, which is not the case for natural pasture.

The lands which suitability can be improved by application of fertilizers, drainage, erosion control, protection against flooding, remotion of stones are classified according to the limitations which persist after the improvements possible in each level of management. In the case of management level A, the classification is based on the natural land (soils) conditions.

These management levels form three of the six types of land utilization (Table 1). The other three types are N = natural pasture; P = cultivated pasture and S = forestry.

## GROUPS OF LAND SUITABILITY

It is a cartographic artifice which identifies on the map the most intensive type of utilization of the land. The groups 1, 2 and 3 indicate land suitable for cultivated crops, 4 = cultivated pasture, 5 = natural grassland and/or forestry and 6 = preservation of flora and fauna. As shown on Figure 1, the suitability of land for agricultural production or the intensity of land use decreases from group 1 to 6.

## SUBGROUPS OF LAND SUITABILITY

By evaluating togheter the classes of land suitability and the levels of management, subgroups of land suitability are formed. The grouping at subgroup level is mostly used as legend in the land suitability maps as shown in Figure 2. The symbol 2(a)bc means that this land has restrict (a) suitability at low management level (A) and fair at intermediate and advanced management levels (B, C).

## CLASSES OF LAND SUITABILITY

The classes of land suitability express the suitability or not of a specific soil for a specific type of utilization (land use) and in a defined level of management. They reflect the degree of intensity by which limitations affect the land use. The classes are:

| | |
|---|---|
| GOOD | Soils without limitation for crop production at a specific management level. This class is expressed by using capital letters for the management levels A, B and C for cultivated crops, P = planted pasture, S = forestry and N = natural pasture. |
| FAIR (REGULAR) | Lands which present moderate limitations for sustained agricultural production are placed in this class. Small letters are used as symbols to represent this class on maps: a, b, c, p, s and n. |
| RESTRICT | Lands which present strong limitation for sustained crop production at the three levels of management are placed is the restrict class. On maps this class is represented as small letters between brackets: (a), (b), (c), (p), (s) and (n). |
| UNSUITABLE | Lands without suitability for any kind of agricultural production are placed in this class. This class does not have any symbol. |

## ESTABLISHING SUITABILITY CLASSES

To analyse the agricultural conditions of land, a soil without limitations of fertility, water and oxygen deficiences, erosion hazards and mechanization restrictions is taken as hypothetical reference. Degrees of limitation are established to define the intensity by which the characteristics of a soil deviates from this hypothetical soil.

The five factors considered to evaluate the agricultural conditions or potential of land are:

- Deficiences in fertility (Table 2),
- Deficiences in water,
- Excess of water or deficience of oxygen,
- Susceptibility to erosion, and
- Mechanization restrictions.

The degrees of limitation for each factor are rated as: N = null, L = slight, M = moderate, F = strong and MF = very strong.

Soil characteristics as texture, structure, effective depth, cation exchange capacity, base saturation, organic matter content, pH, water retention capacity and environmental conditions as temperature, humidity, precipitation, light intensity, topography, stoniness, drainage, vegetation coverage are used to define the degrees of limitation for each of the five factors and to establish the land suitability class. Guide tables were prepared for each region with different environmental conditions (humid tropics, subtropics, semi-arid) to enter the degrees of limitation and determine the land suitability class, subgroup and group, as shown on Table 3.

## LIMITATIONS OF THE SYSTEM

This system is adequate to evaluate the land suitability for agriculture at reconnaissance soil survey level and gives the general potential of the land for regional agricultural development projects. For rural development and technical assistance to farmers, the system is not adequate.

The establishment or definition of the degrees of limitations (fertility, excess or deficience of water, erosion susceptibility and restrictions to mechanization) of a specific land (soils) is still very qualitative and subjective. It is necessary to develop more research to better define the factors which limit crop production and analyse the effect of different soil management practices on the yeld of crops and environment conservation.

## APPROACHES USED ON MORE DETAILED SURVEYS AND RURAL DEVELOPMENT PROGRAMS

In some semi-detailed soil surveys performed in southern Brasil besides preparing the soil survey map and land suitability maps, interpretative tables were prepared with a short description of the characteristics of the mapping units, its actual and potential utilization, expected yelds for different crops and management practices to be adopted to attain high yelds and soil conservation. Table 4 illustrates in a summarized form this interpretations (Klamt, 1978). Extension agencies, rural development institutes and farmers were pleased with this kind of information.

Simplified informations about alternative use of soils of different regions, based on the main factors which limit crop production and affect soil conservation were also prepared for extension and rural development agencies, as shown on Table 5, for soils of steeply sloping areas of southern Brasil

(Klamt and Stammel, 1984). Extension agents participated in the elaboration of this informations, which are important in their day to day activities.

Similar information has been produced for steeply sloping areas with stones, for gently sloping areas with very deep and highly leached soils and for sandy soils in gently sloping areas.

More research and information is needed to interpret detailed soil survey maps and develop more objective and precise systems of soil evaluation for tropical regions.

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Figure 2. Land suitability map of part of Ariquemes County, Rondonia State, Brasil.

Scale 1:50.000

TABLE 1. Symbols of land suitability groups and classes in relation to the management levels and types of land utilization.

| Suitability groups and classes | Management Systems A short cycle | A long cycle | B short cycle | B long cycle | C short cycle | C long cycle | Types of Land Utilization |
|---|---|---|---|---|---|---|---|
| 1 - Good | A | A | B | B | C | C | Cultivated crops |
| 2 - Fair | a | a | b | b | c | c | |
| 3 - Restrict | (a) | (a) | (b) | (b) | (c) | (c) | |
| 4 - Good | - | - | - | P | - | - | Cultivated pasture |
| Fair | - | - | - | P | - | - | |
| Restrict | - | - | - | (P) | - | - | |
| 5 - Good | - | N | - | S | - | - | Natural pasture and forestry |
| Fair | - | n | - | s | - | - | |
| Restrict | - | (n) | - | (s) | - | - | |
| 6 - Unsuitable | - | - | - | - | - | - | Preservation of natural environments |

FIGURE 1. Alternatives of land utilization according to the groups of land suitability.

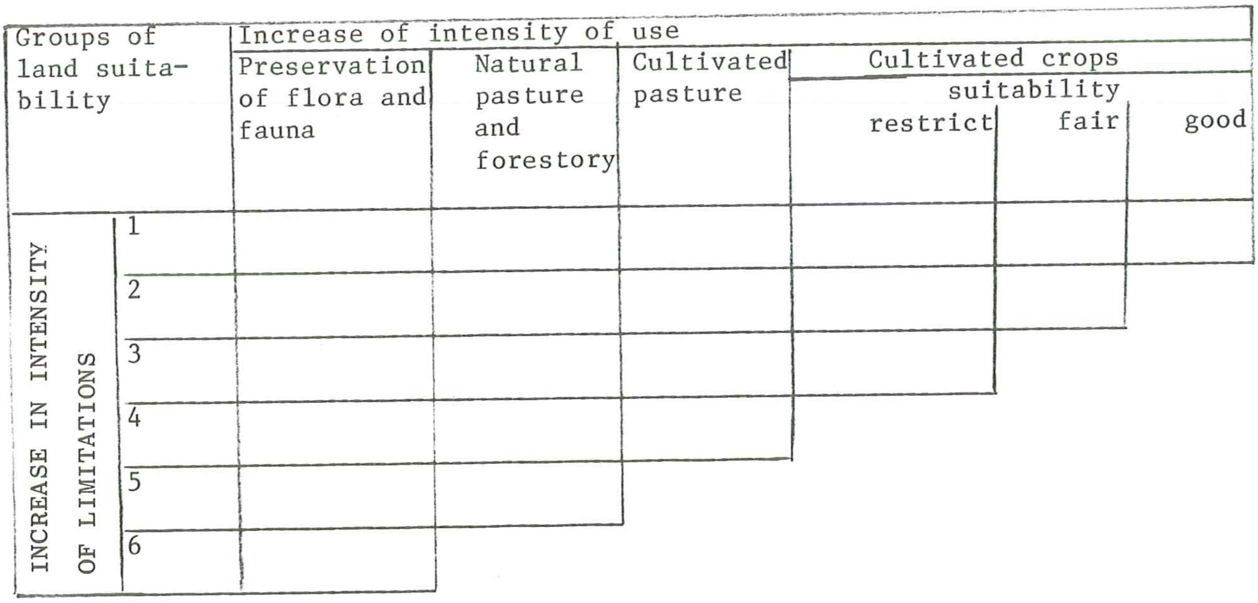

TABLE 2. Degrees of limitation for fertility deficiences

| | |
|---|---|
| N-Null- | Soils with high nutrient status: BS > 80 %, sum of bases > 6 me/100g soil, free of Na and exch. Al. |
| L-Slight- | Soils with good nutrient status: BS > 50 %, sum of bas > 4 me/100g soil, low Na and Al saturation. |
| M-Moderate- | Soils with limited nutrient availability: BS > 30 %, sum of bases > 2 me, NaS < 15 % and/or medium AlS. |
| F-Strong- | Soils with very low nutrient status: low BS, sum of bases and high AlS or NaS > 15 %. |
| MF-Very strong- | Soils with very high concentration of Na or S (Saline or thionic soils). |

TABLE 3. Part of the guide table used to evaluate the land suitability in humid tropical regions.

| Agricultural Suitability | | | Degrees of limitations of land conditions for the A, B and C levels of management | | | | | | Indicated type of Utilization |
|---|---|---|---|---|---|---|---|---|---|
| Groups | Sub Groups | Classes | Fertility Deficiences | | | Water Deficiences | | | |
| | | | A | B | C | A | B | C | |
| 1 | 1ABC | Good | N/L | N/L | N | L | L | L | Cultivated Crops |
| 2 | 2abc | Fair | L/M | L | L | M | M | M | |
| 3 | 3(abc) | Restrict | M/F | M | M | M/F | M/F | M/F | |
| | 4P | Good | - | M | - | - | M | - | |
| 4 | 4p | Fair | - | M/F | - | - | M/F | - | Cultivated Pasture |
| | 4(p) | Restrict | - | F | - | - | F | - | |
| | 5S | Good | - | M/F | - | - | M | - | Forestry and Natural Pasture |
| 5 | 5s | Fair | - | F | - | - | M/F | - | |
| | 5(s) | Restrict | - | MF | - | - | F | - | |
| | 5N | Good | M/F | - | - | M/F | - | - | |
| | 5n | Fair | F | - | - | F | - | - | |
| | 5(n) | Restrict | MF | - | - | MF | - | - | |
| 6 | 6 | Unsuitable | - | - | - | - | - | - | Preservation of flora and fauna |

Degrees of Limitation: N = Null, L = Slight, M = Moderate, F = Strong and MF = Very strong.

TABLE 4. Interpretation of the present conditions and potential soil use (Klamt, 1978).

| Mapping Unit | Soil Class | Characteristics of Soil | Present Use | Types of Utilization | Yelds Expected | Management Practices |
|---|---|---|---|---|---|---|
| A1 to das Canas | Dystric Nitosol | Deep, well drained, red soil with low BS ε CEC, gently sloping | Natural pasture with seasonal production | A. Cultivated pasture ε crops | A. 2 Animals -600 kg/ ha year | A. Liming, fertilization, soil conservation, hay production |
| | | | | B. Improvement of natural pasture | B. No data | B. Introduction of new species, fertilization |
| | | | | C. Natural pasture | C. 0.7 animals-87 kg/ha year | C. Without improvement |

TABLE 5 Alternatives of use, management and conservation of steeply sloping areas, without stones.

| Slope (%) | Depth | | |
|---|---|---|---|
| | > 75 cm | 30-75 cm | < 30 cm |
| 0-3 | Annual crops, horticulture | | Preservation of natural vegetation, reforestation, perennial pasture |
| 3-8 | Annual crops in contour, terracing | Open annual crops alternating with dense crops in contour, terracing | |
| 8-15 | Open annual crops alternating with dense crops in contour and terracing | Open alternating with dense crops, pasture, in contour and terracing | |
| 15-30 | Open and dense crops, pasture, fruits, in contour and surface covering | Dense crops, pasture, fruits, forestry, in contour and surface covering | |
| 30-50 | Preservation of natural vegetation, forestry, fruticulture, permanent pasture | | |
| > 50 | Preservation of natural vegetation, reforestation | | |

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# AGRICULTURAL DEVELOPMENT IN THE TROPICS - A CHALLENGE

by E. Klamt

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## INTRODUCTION

The rural population in the tropics, with a few exceptions, presents low socio-economical and educational levels. Any sound agricultural development program designed to the tropics has to take into account this reality. Education is thus a essential part of any technological transference and rural development program in the tropics.

To approach the present subject, development programs carried out in different regions in Brasil will be described and when necessary methods used and goals to be achieved criticised and alternative ways to face the problems discussed.

## OPERATION ARMADILLO - A RURAL DEVELOPMENT PROGRAM BASED ON SOIL STUDIES

### The problem

In 1824 European colonizers began to settle at the Depressão Central and Encosta Inferior do Nordeste regions of Rio Grande do Sul State, Brasil (Figure 1). At the end of the century descendents from these colonizers moved to the Planalto Médio, Missões and Alto Uruguai regions, where mainly Rhodic Ferralsols occur, under semideciduous forest. The land occupations, as in the former settlement, progressed through three main steps:

a) Clearance of the forest (natural fertility was reasonable high due to nutrient recycling by trees),

b) Cultivation to exhaustion of nutrients by crops or soil erosion, and

c) Shifting to new areas and renewal of the process.

In 1940, descendents from these farmers, began to move to western Santa Catarina and later to western Paraná and southern Mato Grosso do Sul States, where they also replaced forest by shifting cultivation. Today many descendents of the European colonizers are found in the Amazon region.

Soil Studies - The basis to solve the problem

In 1967 a extension program called "Operation Armadillo" (Armadillo is an animal which digs holes in soils) was initiated in Rio Grande do Sul State, which general aim was increase agricultural production through recuperation of soil fertility.

The technical knowledge and planning of the program came from the Master of Science Course initiated in 1964 at the Soil Science Department of Federal University of Rio Grande do Sul. Research to support the program consisted of:

a) Characterization of main soils, mapping, classification and land evaluation,
b) Correlation of analytical methods to determine exchangeable K, Ca, Mg and Al; organic matter (to estimate N content); available P and K and lime requirements.
c) Calibration of the selected methods by field experiments, on different types of soil and crops, to test the response of plants to increasing levels of nutrients detected by the analytical methods.

Based on the calibration studies, tables for fertilizer and lime recommendations were prepared. As examples, Figure 2 shows the P calibration curve obtained for soils of different texture, Table 1 the recommendation of P and K derived from calibration data and Table 2 presents the amount of lime to be applied to a soil, to reach ph 6.0, based on the calibrated SMP buffer method (Mielnicsuk et alii, 1971 and Rolas, 1981).

The field experiments conducted to calibrate soil analytical methods showed that by increasing the nutrient status of the soils, through application of fertilizers and by eliminating the toxic levels of Al and Mn through application of lime, the production of main cultivated crops could be at least triplicated (Table 3).

Planning and Developing the Extension Program

Enthusiastic with the results, soil scientists consulted the rural extension agency and cooperatives and together an agricultural development program was set up, which main goals were (Volkweiss and Klamt, 1969; Klamt, 1970):

a) Training extension agents in basic soil science (characteristics, distribution, limitations and potential of main soils), soil sampling, fertilizer and lime recommendation and plant and soil management for high yields;

b) Education of farmers on modern agricultural practices: fertilizing, liming, soil and plant management.

c) Change the shifting cultivation into a permanent agricultural production system,

d) Elevation of agricultural production and consequently improve farmers socio-economical status, and

e) Promote the integration between institutions and technical personnel responsable for agricultural development agencies.

Steps followed in the development of the program:

a) Training of extension agents,

b) Selection of farmers to serve as leaders to divulgate the program. Demonstration fields were planned on the selected farms as well as field days. A scheme of the demonstration fields is shown on Figure 3.

c) Soil sampling on demonstration fields

d) Soil analysis - Table 4 illustrates the general fertility status of the soils, at that time.

e) Recommendation of fertilizers and lime,

f) Establishment of demonstration fields,

g) Divulgation of the results by field days, to which neighbour farmers were invited to get acquainted with the program.

The success of the project was fantastic, particularly after 1968, when Brasilian Bank offered special credit for lime and fertilizers, by which farmers could pay back the loans in five years and with low interest rates. Table 5 presents some indexes used to demonstrate the evolution of the program. In 1970 already thousands of farmers joined the project and it spread rapidly to Santa Catarina e Paranã States.

Results of the Project

a) The production of some crops, as soybeans, increased tremendously,

b) Price of land increased,

c) Limestone grinder factories florished,

d) The system of transportation, storage and distribution of fertilizer, lime and grains was tremendously improved,

e) Farmers were settled on their land, and

f) Degradation of physical properties and soil erosion was increased.

INTEGRATED PROJECT OF SOIL CONSERVATION AND USE

Due to intensive use and inadequate soil management technics (burning of residue, disking and ploughing with to high humidity and using heavy machinery) to which Ferralsols were subjected, their physical properties began to degrade rapidly and soil erosion increased. In the end of the seventies, the yields of the main crops began to decrease because of defficient rooting and drought problems, in spite of use of fertilizers and lime.

To overcome the problem, an integrated project of soil conservation and use was initiated in 1978, by the same institutions which developed the "Operation Armadillo". Besides the traditional terracing, management practices as no-tillage, minimum tillage, crop rotation, straw and green legume crops incorporation, mulshing, subsoiling, manure incorporation, are practices being introduced to farmers, by using demonstration fields, to recover and maintain soil chemical and physical properties, for high crop production and erosion control (Wünsche et alii, 1980).

RIO FORMOSO IRRIGATION PROJECT

Hundred of thousands of hectares of lowland annually flooded are found bordering the Araguaia River and its affluents in Goiás and Mato Grosso States, in Central Brasil. Since the flooding occurs in the rainy season, this area can be used only for extensive grassing in the dry season.

An irrigation project was designed to transfrom into paddy rice, an area of 34.000 ha at the flood plains of Rio Formoso, a tributary of the Araguaia River. A network of dikes to protect against the flooding and of irrigation and drainage channels were constructed to manage water.

When the initial 6000 ha of the project was established, planners began to look for farmers to run it. Soon they realized that the poor people living in the neighbourhood were not adequate and so farmers from Rio Grande do Sul State, with a long tradition in cultivating irrigated rice, were settled on the area.

The huge amount of capital invested in the project, to benefit a small group of farmers imported from an already developed region, in our point of view was a bad investment. A program of agricultural development similar to the "Operation Armadillo", which would benefit thousands of farmers, would have been a better alternative, with a similar output in terms of increasing crop production and with socialization of the limited capital available in Brasil.

## AGRICULTURAL DEVELOPMENT OF NORTEASTERN SEMI-ARID REGION

Great amounts of capital have been invested in irrigation projects, to achieve agricultural development of the poor semi-arid region of northeastern Brasil. Because of deficient drainage, soils became salinized after a few years of cultivation, in many of the irrigaton projects.

A small percentage of rural population benefit from these high cost projects and the poverty of the region has increased, in spite of massive application of resources. Better results would have been achieved by concentrating efforts in educating farmers on how to take advantage of the natural environmental conditions. Enough humidity is available in the 3 to 4 months rainy season to grow one reasonable crop. Many species of grasses and legumes grow fantastically in this region. The excess in the rainy season could be transformed in hay and stored in hay stacks. Wells could be open or small dams of low cost built at farms to supply water to men and animals. By sound soil-water-crop management yields of cultivated crops could easily be triplicated. Simple and low cost alternatives would have been more easily assimilated and accepted by the farmers. And again, if the production of thousands of farmers is slightly improved, the total output would be higher and not only a privileged minority would have benefit from the resources.

## DEVELOPMENT OF THE AMAZON REGION

The tropical forest of the Amazon region is being replaced by cultivated crops and grassland, stimulated by government and private colonization projects and by farmers not bound to official projects. Most of the soils of the region present low availability of nutrients and when exposed by clearance to high solar radiation and heavy rains, degrade rapidly and are very susceptible to erosion.

Is transferring to this weak environment an agricultural system which men has used to develop other regions, the best alternative for its development? Probably not! This environment will probably react negatively to usual farming systems.

Studies should be concentrated on crops and animals occurring naturaly in the region, to intensify their reproduction and development, such that its controlled exploration can be a reasonable economic activity without modifying too much the natural environment. Animals as tapir, turtle, fish (pirarucú, tambaqûi tucunaré, surubin, pintado) and others, which reproduction and growth could be intensified and meat of them sold to national or international markets in natura or transformed into stockfish (pirarucú); instead of substituting the forest by grassland and race cattle. The experience of New Zealand, in which the forest which covered the hilly regions was replaced by grassland to race sheeps, in substitution to the naturally adapted harts; which they are beginning to race now, because of their high quality meat production, should be taking as example.

Soils of high agricultural potential ,as Terra Roxa Estruturada (Nitosols), Eutrophic Red Yellow Podzolic (Luvisols), Dusky Red and Yellow Red Latosols (Ferralsols) may be used for crop production, particularly with species with good ground coverage as rubber trees, cacao, palm oil, pepper, guaraná and others; in agricultural systems by which the natural environment is affected as little as possible.

Unfortunately the reality is different. Many soils without or with low potential, as Areias Quartzosas (Arenosols), Podzols, Yellow Latosols (Ferralsols), are being transformed into agricultural land. After a few unsuccessful crops, farmers move to new areas, so that destruction of the Amazon forest is in process and not too much will remain in the end of the century.

## FINAL REMARKS

In agricultural development programs as in most other aid projects, men has the natural tendence to transfer to his similars, his believes, political tendencies, culture and technical knowledge, mainly to warrant the continuity of his type of life. By this behaviour many cultures have been destructed, even in name of God; and many aid projects failed, because the experience and culture of the people to be helped, have not been taken into account. The same happens with nature, when experiences are transferred from one region to another, without taking into account differences in environmental conditions, it will be negatively affected.

It is difficult to understand why men is unable to design development programs adequate to people and environment of different regions, with all the knowledge availabe in the present century.

Production of cultivated annual crops and grassland can be tremendously increased in most tropical countries, if available knowledge is transfered to farmers. Unfortunately in many cases preference is given to reclamation of new land, instead of directing the development plans to increase production on land already in use.

Nevertheless more research must be concentrated on the development of farming systems for tropical and subtropical regions, such that sustainable farming may be developed with as low as possible inputs for reasonable crop production, without degradation of the environment (soils). Development of simple systems for collection of water and maintenance of soil humidity and favorable soil physical conditions, soil erosion control, storage of nutrients or protection of nutrients againts leaching, are of urgent need in tropical conditions.

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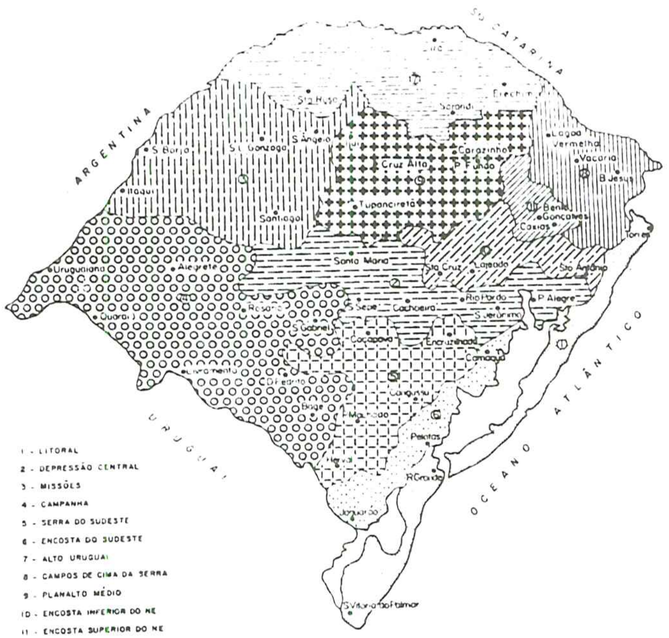


Figure 1. Physiographic regions of Rio Grande do Sul State, Brasil.

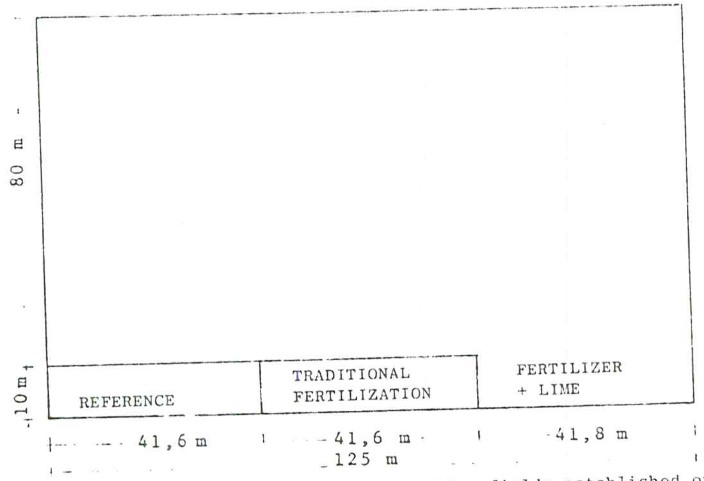


Figure 3. Illustration of the demonstration fields established on farms.

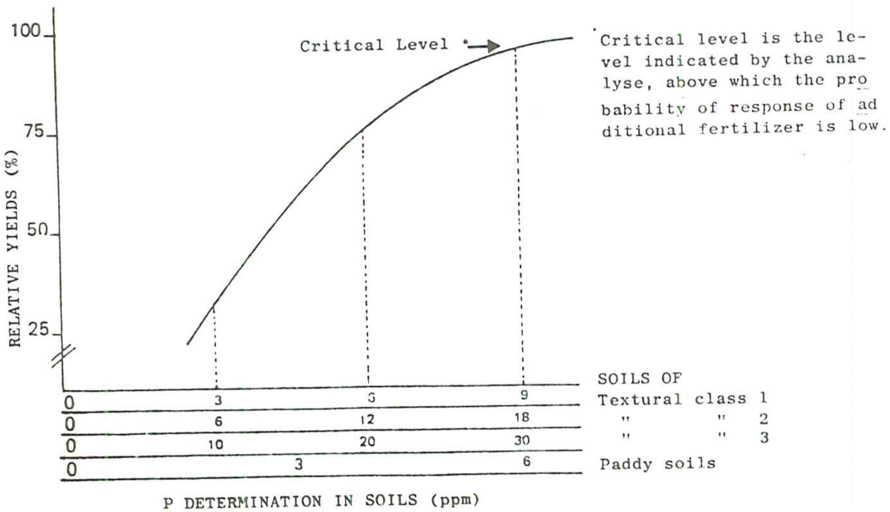


Figure 2. Interpretation of P analyses based on critical levels in relation to soil types, determined by calibration experiments (Data from ROLAS, 1981).

| ANALYSES / INTERPRETATION | | | POTASSIUM (K) – ppm | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | VERY LOW 0 a 20 | | LOW 21 a 40 | | MEDIUM 41 a 60 | | HIGH + 60 | |
| TEXTURAL CLASSES[1] | | | $P_2O_5$ kg/ha | $K_2O$ kg/ha | $P_2O_5$ kg/ha | $K_2O$ kg/ha | $P_2O_5$ kg/ha | $K_2O$ kg/ha | $P_2O_5$ kg/ha | $K_2O$ kg/ha |
| 1 | 2 | 3 | | | | | | | | |
| 0,0 a 3,0 | 0,0 a 6,0 | 0,0 a 10,0 | 120 | 120 | 120 | 80 | 120 | 40 | 120 | 0 |
| 3,1 a 6,0 | 6,1 a 12,0 | 10,1 a 20,0 | 60 | 120 | 60 | 80 | 60 | 40 | 60 | 0 |
| 6,1 a 9,0 | 12,1 a 18,0 | 21,1 a 30,0 | 0 | 120 | 0 | 80 | 0 | 40 | 0 | 0 |
| + 9,0 | + 18,0 | + 30,0 | 0 | 120 | 0 | 80 | 0 | 40 | 0 | 0 |

(Row heading: PHOSPHOROUS (P) – ppm)

[1] 1. Clayey soils ( more than 40% clay), 2. Medium texture (20 to 40 % clay), 3. Sandy soils (less than 20% clay).

Table 1 . Recommendation od P and K for correcting the fertility status of the soils based on calibration data (From ROLAS, 1981).

| pH | LIME (PRNT 100%)[1] | pH | LIME (PRNT 100%) |
|---|---|---|---|
| SMP | t/ha | SMP | t/ha |
| 6,7 | 0 | 5,7 | 4,7 |
| 6,6 | 0,5 | 5,6 | 5,3 |
| 6,5 | 1,0 | 5,5 | 6,0 |
| 6,4 | 1,5 | 5,4 | 6,6 |
| 6,3 | 1,8 | 5,3 | 7,3 |
| 6,2 | 2,3 | 5,2 | 8,1 |
| 6,1 | 2,7 | 5,1 | 8,9 |
| 6,0 | 3,2 | 5,0 | 9,8 |
| 5,9 | 3,8 | 4,9 | 10,6 |
| 5,8 | 4,2 | 4,8 | 11,5 |
| | | < 4,7 | 12,0 |

[1]Total relative neutralization effect or power of 100%.

Table 2. Lime recommendation to elevate the soil pH to 6.0.

| C R O P S | T R E A T M E N T S | | |
|---|---|---|---|
| | REFERENCE (Kg/ha) | WITH FER-TILIZER (kg/ha) | WITH FER-TILIZER + LIME (Kg/ha) |
| MAIZE - grains | 1.500 | 5.190 | 6.560 |
| WHEAT - grains | 800 | 1.500 | 2.200 |
| SOYBEAN - grains | 900 | 2.500 | 3.200 |
| GRASSLAND - dry matter | 2.000 | 4.000 | 12.000 |

Table 3. Yields obtained in experiments conducted by the Soil Science Department of UFRGS (Volkweiss and Klamt, 1969).

| C H A R A C T E R I S T I C S | 1967 | 1968 | 1969 | Totais |
|---|---|---|---|---|
| 1. Number of farmers assisted........ | 91 | 850 | 1.207 | 2.148 |
| 2. Number of soil analysis performed.. | 2.319[1] | 2.252 | 2.239 | 6.810 |
| 3. Area of land recuperated ( ha)..... | 100 | 3.042 | 5.315 | 8.457 |
| 4. Terraces constructed (ha).......... | 134 | 1.100 | 4.211 | 5.455 |
| 5. Lime used (tons).................. | 334 | 11.371 | 15.480 | 27.185 |
| 6. Chemical fertilizers used (tons)... | 19 | 1.220 | 2.551 | 3.790 |
| 7. Selected maize seeds used (kg)..... | 645 | 19.819 | 25.366 | 45.830 |
| 8. Selected seeds of wheat used in the program (kg)...................... | - | 52.321 | 258.491 | 310.812 |
| 9. Total investment in Cr$............ | 22.516, | 1.114.992, | 280.556, | 3.418.064 |

[1] A survey of the fertility status of the soils was performed in the beggining of the program (Data from Klamt, 1970).

Table 5. Evolution of the soil fertility recuperation program in the great Santa Rosa region (six Counties).

Table 4. Relative frequence of soil samples of Missões and Planalto Medio Region of RS, distributed in different levels of nutrients.

| Number of Samples/ Region | Soil Propertie | Relative frequence (%) and levels of nutrients | | | |
|---|---|---|---|---|---|
| | | Very low | Low | Medium | High |
| 535 Samples of Missões Region | pH | 48,4 (< 5,0) | 37,0 (5,1-5,5) | 14,0 (5,6-6,5) | 0,6 (> 6,5) |
| | P (ppm) | 83,7 (< 4,0) | 13,6 (4,1-8,0) | 1,5 (8,1-12,0) | 1,2 (> 12,0) |
| | K (ppm) | 3,3 (< 21) | 18,0 (21-40) | 22,5 (41-60) | 56,2 (> 60) |
| | Organic matter (%) | - | 48,2 (< 2,5) | 51,4 (2,6-5,0) | 0,4 (> 5,4) |
| | Lime requirement (t/ha) | 3,1 (< 1,5) | 65,7 (1,5-6,0) | 27,5 (6,1-12,0) | 3,7 (> 12,0) |
| 7.756 Samples of Planalto Medio Region | pH | 65,3 | 24,7 | 7,8 | 0,2 |
| | P | 87,9 | 9,3 | 1,4 | 1,4 |
| | K | 2,5 | 18,2 | 23,5 | 55,8 |
| | Organic matter | - | 48,1 | 50,8 | 1,1 |
| | Lime requirement | 2,5 | 58,2 | 29,2 | 10,1 |

Data from: Klamt, Mielniczuk and Schneider, 1983.

# DEGRADATION OF PROPERTIES OF RED BRAZILIAN SUBTROPICAL SOILS BY MANAGEMENT*

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## S U M M A R Y

Brazilian Red Subtropical soils, classified mainly as Latosols (Oxisols), Terra Roxa (Ultisols and Alfisols) and Reddish Brunizem (Mollisol) present in their natural conditions adequate physical properties for crop production, expressed by the presence of waterstable aggregates, adequate aeration porosity, low resistance to root penetration and high water infiltration rates. Even though these soils present, in general, P deficiencies, high acidity and exchangeable Mn and Al, the yields are high in the first years of cropping.

A decrease in the size of water-stable aggregates, macroporosity, water infiltration rates and increase of resistence to root penetration, soil density (compaction), and soil erosion occur after inadequate management of these red soils, particulary under intensive cropping and use of heavy equipment. The erosion and inedequate management increases the depletion of nutrients.

Management practices as no-tillage, minimum tillage, crop rotation with use of dense and deep rooting species, straw and green legume crops incorporation, mulching, fertilization with industrial fertilizers or manure and liming have been used successfully to upgrade these soils and maintain good physical and chemical properties for high crop production and erosion control.

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## INTRODUCTION

Brazilian subtropical region extends from the southern part of Mato Grosso do Sul (MS) state to Rio Grande do Sul (RS) state (Fig. 1). The type of climate is Cfa, according to Köppen's classification. The annual mean temperature decreases from 20 - 22°C in MS to 15,9 - 17,6°C in RS. Rains are well distributed during the year and the annual mean precipitation varies from 1.100 - 1.700 mm in the northern section to 1.600 - 1.900 mm in the south (Table 1). Small periods of drought may occur in summer (December-February) months in the south and during the winter ( june-August) in the north. Frosts are common, particulary in the southern part of the region.

- Insert Fig. 1 and Table 1 -

The red soils occur on a series of successive plateaux descending in small gradients toward the Paraná and Uruguai rivers (westward), which are of Neo-Mesozoic and Tertiary planation surfaces carved on a basaltic formation (Madeira Neto et alii, 1982). The red soils developed mainly on sediments derived from basalt and diabase of Serra Geral Formation, of Juro-Cretaceous age (BRASIL, 1974), the largest vulcanic mass of the world (Fig.1). On the gently undulating to undulating upland areas Dusky-Red and Dark-Red Latosols (Oxisols) occur. On the more stable portions of the areas dissected by rivers, with general rolling to hilly slopes, Terra Roxa Estruturada (Ultisols and Alfisols) and Reddish Brunizems (Mollisols) are found (BRASIL, 1960; 1971; 1973 a, b; 1975).

The natural vegetation was by large semideciduos forest, but areas with grassland were also present; they have largely been replaced by agriculture. The land occupation initiated approximately one hundred years ago, by European colonizers and progressed through three main steps: a) clearance of forested areas , where, due to recycling of nutrients by trees, the natural fertility was high; b) cultivation to exhaustion of nutrients by crops or soil erosion; c) shifting to new areas and renewal of the process. After 1950, with the introduction of motomechanization, the areas covered by grassland were also replaced by agriculture, particulary with soybean-wheat crop sequence, and rapidly exhausted, even thou based on local research, to restore the fertility of chemically exhausted soils, with lime and fertilizers, was set out in Rio Grande do Sul (Volkweiss and Klamt, 1969). The results, expressed by increased crop productivity, were fantastic and the techniques spread rapidly to other states. The farmers were again settled on their land. Degradation of the soils physical properties was increased, as well as the soil erosion, due to inadequate management and, consequently, the yields began to decrease.

The scope of this paper is the description of the properties of red Brazilian subtropical soils in their natural conditions, the chemical and physical degradation by inadequate management and present alternatives to upgrade them and maintain good physical and chemical properties, for high crop produciton and erosion control.

PROPERTIES OF BRAZILIAN RED SOILS

The properties of Brazilian red soils are related to the nature and constitution of the mineral soil mass. The Latosols (Oxisols), with kaolonite, hematite or goethite, gibbsite, amorphous materials and aluminous chlorite or interstratified clay minerals, as main minerals (Klamt & Beatty, 1972; Kämpf & Klamt, 1978; Pombo et alii, 1982; Kämpf & Schwertmann, 1982; Möller & Klamt, 1982), present low cation exchange capacity of the clay fraction (< 13 mE/100g), low sum of bases, most of them are acid and have high exchangeable Mn an Al (Table 2). Due to the presence of 1:1 type of clay minerals and oxides and hydroxides, the P sorption capacity is high. Their morphological characteristics express deep profiles, with A-B-C horizon sequence and diffuse transition, well developed fine granular, grumous, weak blocky or massive structure, very friable moist consistence, aggregates with great stability and low values of water - dispersable clay in the subsurface horizons (Beatty & Klamt, 1972; BRASIL, 1973 a, b; BRASIL, 1975).

- Insert Table 2 -

The Terra Roxa Estruturada with low base saturation (Ultisol) presents mineralogical and chemical composition similar to the Latosols, but textural gradient, well structured B horizons, with clay skins on aggregates.

The Terra Roxa Estruturada with high base saturation (Alfisol) and Reddish Brunizem (Mollisols), in addition to the



minerals present in the former soils, show also different amounts of montmorillorite, vermiculite and mica (Klamt & Beatty, 1972; Curi, 1975; Queiroz, 1980). Their pH, sum of extractable bases, cation exchange capacity and base saturation are medium to high, but exchangeable aluminum and manganese are low (Table 2). The profiles are not as deep as that of the former soils, the horizon sequence is A-B-C with textural gradient between the A and B horizon and clay skins on structural aggregates of the B horizon. The structure is moderate to strong, medium subangular and angular blocky, the consistency is friable (BRASIL, 1973 a, b; 1975).

DEGRADATION OF THE PROPERTIES OF RED SOILS

Chemical Properties - Red Latosols (Oxisols) and Terra Roxa Estruturada Similar (Ultisols) present, in their natural conditions, low concentration of nutrients and poor chemical properties for plant growth. A survey performed by Porto (1970) at the Missões and Planalto Medio regions of Rio Grande do Sul showed (Table 3), respectively, that 84% and 88% of the samples have very low concentration of available P (< 4,0 ppm), 48% and 65% very low pH (< 5,0) and 48% low (< 2,6%) organic matter. Most of the samples (56%) presented good levels of K (> 60 ppm), and 66% and 58% of them lime requirements of 1,5 to 6,0 t/ha.

- Insert Table 3 -

Without amendments, most Latosols have low productivity for cultivated plants, unless they were under forest, when they sustain reasonable yields for a few years; afterwards even K deficiencies appear. In the state of Rio Grande do Sul yields of common crops as corn, wheat, cassava, beans and soybeans decreased drastically in the 1950's. Farmers began to sell their land and migrate northward, toward Santa Catarina, Paraná and Mato Grosso do Sul. The exausted land stayed unused and grass called "barba de bode" (Aristida pallens) took over. The price of land decreased and the whole economy and development of the region covered by Latosols was affected.

Physical Properties - Latosols (Oxisols), according to soil Taxonomy (USA, 1975), "have relatively rapid permeability that combined with gentle slopes make them, as a group, highly resistant to erosion when cultivated". The experience with cultivating these soils in southers Brasil doesn't confirm this statement. The physical properties of these soils can be very rapidly degradated with inadequate management, particularly under intensive cropping, burning of crop residues, conventional tillage and use of heavy equipment. Farmers in Brazilian subtropical region grow soybean in summer and wheat in winter. Seedbed preparation, seeding, weed-insect-disease control and other management practices, grain harvesting and transportation require traffic of machinery and equipment on these soils fifteen or more times per year. The result is an increase in soil density and resistance of penetration at depths of 15 to 30 cm, with formation of plow pan, as data of da Silva (1980), presented on Table 4, demonstrate. The degradation occurs very rapidly when heavy equipment is used, since it was observed with one year of conventional tillage in a previously forested area, cleaned with bulldozer (Table 4). In addition to increases in soil density and resistance of penetration, the macroaggregates (> 1,0 mm) and organic matter content were reduced and microaggregates increased (Table 5). Machado and Brum (1978), analyzing experimental plots under native forest, native grassland and conventional tillage of a wheat-soybean sequence, found similar results.

- Insert Table 4 and 5 -

The degradation of these physical properties, particularly the formation of a more dense layer under the plow layer, causes a decrease in the water infiltration rates, as datas of da Silva et alii (1981), shown on Fig. 2, demonstrate. Water infiltration was reduced to 5 mm in two huors in areas under conventional tillage, when in this time the precipitation may attain 120 mm. Consequently, soil erosion reaches drastic proportions in this region.

- Insert Fig. 2 -

In a greenhouse experiment, Cintra (1980) demonstrated that the root system of most cultivated crops were not able to penetrate layers with more than 11 $kg.cm^{-2}$ to resistance to penetration (Fig. 3). In most red soils under conventional tillage, the resistance to penetration under the plow layer is higher than 11 $kg.cm^{-2}$ (Table 4).

- Insert Fig. 3 -



The absorption of plant nutrients also decreases with increasing levels of compaction, as data (Fig. 4) of Cintra (1980), demonstrate. The resistance of crops to drought periods decreases, due to the reduction of soil volume explored by the root system. Necrotic root systems seem to indicate that it is affected by oxigen deficiency in rainy days, since water is pershed above the compacted layer.

- Insert Fig. 4 -

The damage to the soil, loss of fertilizers and chemicals to control insects and diseases, pollution of dams and rivers and decrease of yields of crops are consequences of the degradation of the red subtropical soils.

RECUPERATION OF PROPERTIES OF DEGRADATED RED SOILS

Chemical Properties - Correlation of analytical methods to evaluate needs of fertilizers and lime of the chemically exhausted red subtropical soils and calibration of these methods in field experiments to determine the economic levels of these factors to be used for the main cultivated crops, were initiated in 1966, in southern Brazil (Murdock et alii, 1978 and Mielniczuk et alii, 1968). Tables of recommendation of lime and fertilizers were organized, based on the calibration and soil testing data, and distributed to the Rural Extension Service (Mielniczuk, Ludwick and Bohnen, 1971). Extensionists were trained to use this information (Volkweiss and Klamt, 1969). Increase of soil pH and reduction of exchangeable Al and Mn and restoration to reasonable levels of N, P, K, Ca, Mg and some microelements, were achieved by application of fertilizers and lime, according to the official recomendations; and, as shown in Table 6, the yields of cultivated crops were increased.

- Insert Table 6 -

The use of commercial fertilizers and lime is the most practicable form of recuperation of chemical deficiencies of soils in extensive farming. Small farmers may use animal manure in order to complex and reduce exchangeable $Al^{+3}$, reduce lime requirement and supply nutrients to cultivated crops (Ernani, 1981). The effect of animal manure on the yields of beans, corn, millet and oats is similar to that of soil testing laboratory mineral fertilizer reccomendation (Ernani, 1981; Holanda, 1981).

Beside these amendments, to maintain high levels of nutrients in soils, adoption of conservation practices by the farmers, is essencial.

Physical Properties - To overcome the degradation of physical properties and soil erosion, integral measures of soil conservation have to be used. Besides the tradicional terracing, mangement practices as no-tillage, minimum tillage (harrowing), crop rotation with use of dense deep rooting species, straw and green legume crops incorporation, mulshing, subsoiling, fertilization with industrial fertilizers and lime or manure, have been used successfully to recover and maintain good physical and chemical properties, for high crop production and erosion control (Wünsche et alii, 1980; Elts, 1977).

Subsoiling was not efficient in breaking compated sub-surface layers between furrows, but increased water infiltration rates and reduced soil erosion (Dalla Rosa, 1981). These results were also achieved by crop rotation, with use of dense and deep rooting species (Figure 3), straw and green legume crops incorporation and mulshing (Dalla Rosa, 1981). The advantage of using crop management instead of mechanical practices, is the effect of the former on improving aggregate stability and bulk density, besides water infiltration and soil erosion control.

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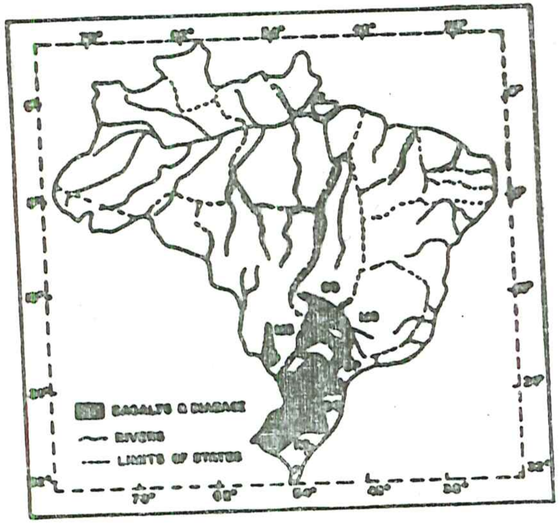


FIG. 1 - APPROXIMATE DISTRIBUTION OF THE BASALTS OF SERRA GERAL FORMATION AND LIMITS OF STATE ( RS = RIO GRANDE DO SUL , SC = SANTA CATARINA , PR = PARANÁ , SP = SÃO PAULO, MG = MINAS GERAIS , GO = GOIÁS AND MS = MATO GROSSO DO SUL ).

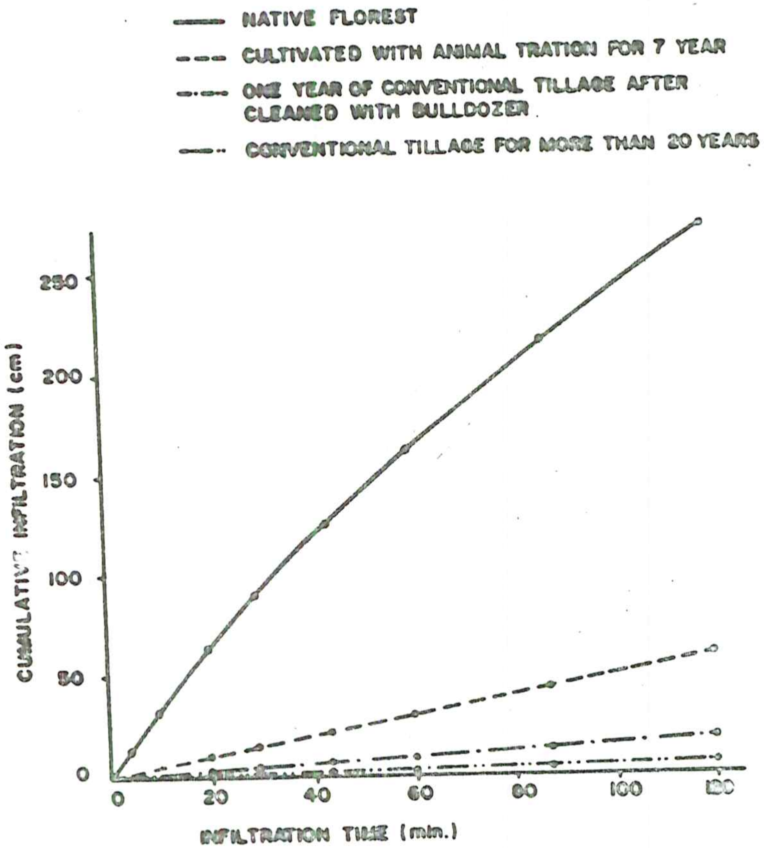


FIG. 2 - WATER INFILTRATION CURVES IN A DARK RED LATOSOL UNDER DIFFERENT TYPES OF LAND USE. DATA FROM DA SILVA ET ALII (1981).

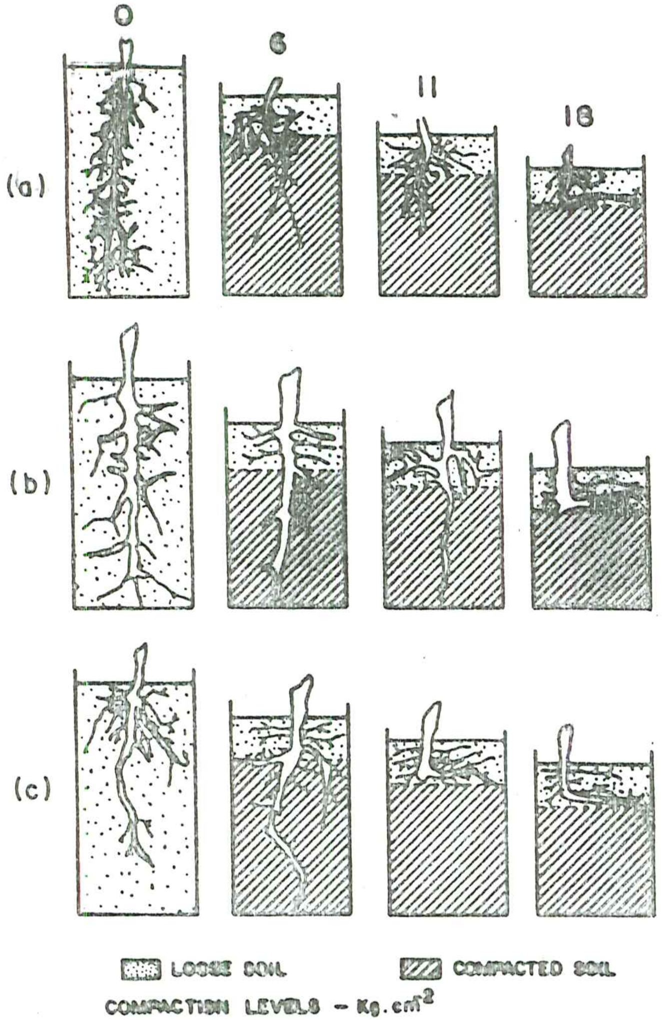


FIG. 3 – ILLUSTRATION OF COMPACTED SOIL LAYERS ON PENETRATION OF ROOTS OF (a) RAPSEED (BRASSICA NAPUS), (b) WHITE LUPINE (LUPINUS ALBUS) AND (c) SOYBEAN (GLYCINE MAX) DATA FROM CINTRA & MIELNICZUK (1983).

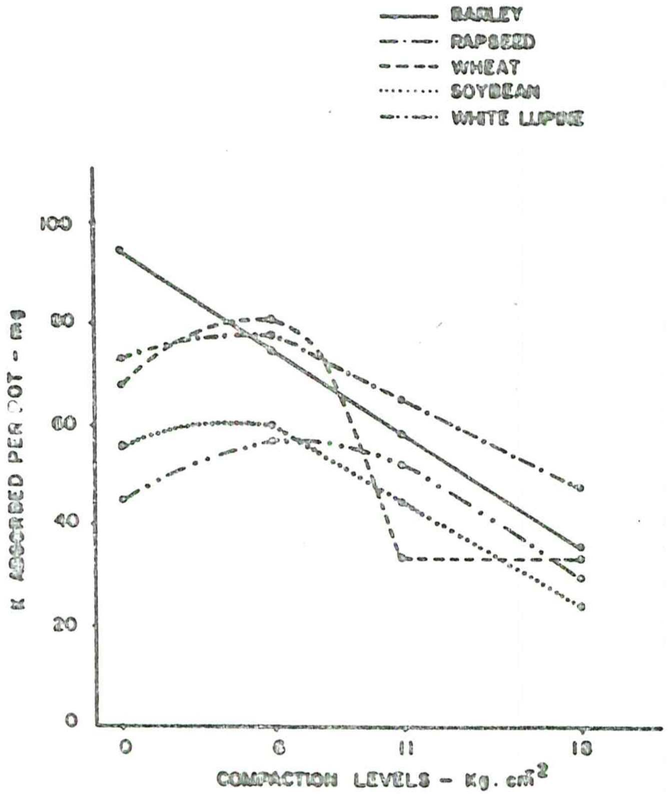


FIG. 4 – ABSORPTION OF K BY FIVE CROPS IN FOUR SOIL COMPACTION LEVELS (DATA FROM CINTRA, F.L.D., 1980).

Table 2. Some relevant properties of Brasilian Red Subtropical Soils.

| Soil and location | Horizon | Depth (cm) | pH (1:2,5) $H_2O$ | pH (1:2,5) KCl 1N | % C | Extractable bases mE/100 g | CEC at pH 7,0 mE/100g | Bases saturation % | Al saturation % | % Clay Calgon | % Clay Water | Extractable P (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dusky Red[1] Latosol PR - 16 | $A_1$ | 0-30 | 5,2 | 4,0 | 2,65 | 3,7 | 16,0 | 23 | 39 | 82 | 44 | 2 |
| | $B_{21}$ | 100-140 | 5,1 | 4,2 | 0,56 | 0,8 | 6,8 | 12 | 70 | 87 | 0 | < 1 |
| Dark Red[2] Latosol RS - 22 | $A_{11}$ | 0-30 | 4,8 | 3,7 | 1,36 | 1,7 | 10,5 | 16 | 56 | 42 | 14 | 4 |
| | $B_{21}$ | 120-180 | 4,6 | 3,7 | 0,60 | 0,7 | 7,5 | 9 | 79 | 58 | 1 | 2 |
| Terra Roxa RS - 43[2] | $A_1$ | 0-15 | 5,4 | 4,3 | 1,92 | 7,9 | 15,6 | 50 | 3 | 49 | 30 | 4 |
| | $B_{21}$ | 65-95 | 5,0 | 4,0 | 0,61 | 4,4 | 10,4 | 43 | 12 | 76 | 2 | 2 |
| Reddish Brunizem[3] SC - 024 | $A_1$ | 0-23 | 6,3 | 5,3 | 1,74 | 7,1 | 9,8 | 72 | 4 | 33 | 2 | 11 |
| | $B_2$ | 36-90 | 6,1 | 5,0 | 0,36 | 9,8 | 13,6 | 72 | 5 | 32 | 10 | 4 |

Data from [1] BRASIL, 1975; [2] BRASIL, 1973 and [3] BRASIL, 1973.

Table 1. Climatic characteristics of Brasilian subtropical region.

| Section | Annual mean precipitation (mm) | Annual mean temperature °C | Minimum mean temperature °C | Maximum mean temperature °C | Absolute minimum temperature °C | Absolute maximum temperature °C |
|---|---|---|---|---|---|---|
| Northen | 1100 - 1700 | 20 - 22 | 12 | 23 | -5 | 35 |
| Southern | 1600 - 1900 | 15,9 - 17,6 | 10 | 22 | -6 | 38 |

Data compiled from Madeira Neto et alii, 1982; BRASIL 1973 a, b; 1975; Moreno, 1961.

Table 3. Relative frequence of soil samples of Missões and Planalto Medio Region of RS, distributed in different levels of nutrients.

| Number of Samples/ Region | Soil Propertie | Relative frequence (%) and levels of nutrients | | | |
|---|---|---|---|---|---|
| | | Very low | Low | Medium | High |
| 535 Samples of Missões Region | pH | 48,4 (<5,0) | 37,0(5,1-5,5) | 14,0(5,6-6,5) | 0,6(>6,5) |
| | P (ppm) | 83,7 (<4,0) | 13,6(4,1-8,0) | 1,5(8,1-12,0) | 1,2(>12,0) |
| | K (ppm) | 3,3 (<21) | 18,0(21-40) | 22,5(41-60) | 56,2(> 60) |
| | Organic matter (%) | - | 48,2(<2,5) | 51,4(2,6-5,0) | 0,4(>5,4) |
| | Lime requirement (t/ha) | 3,1 (<1,5) | 65,7(1,5-6,0) | 27,5(6,1-12,0) | 3,7(>12,0) |
| 7.756 Samples of Planalto Medio Region | pH | 65,3* | 24,7 | 7,8 | 0,2 |
| | P | 87,9* | 9,3 | 1,4 | 1,4 |
| | K | 2,5* | 18,2 | 23,5 | 55,8 |
| | Organic matter | - | 48,1* | 50,8 | 1,1 |
| | Lime requirement | 2,5* | 58,2 | 29,2 | 10,1 |

Data from PORTO (1970).*Same levels as above.

Table 4. Data of gravimetric umidity, soil density and resistance to penetration in a Dark-Red Latosol under different land use.

| Land use | Depth (cm) | Gravimetric umidity (%) | Soil density $g \cdot cm^{-3}$ | Resistance to penetration $kg \cdot cm^{-2}$ |
|---|---|---|---|---|
| Native Forest | 2 - 7 | 35,0 | 0,89 | 1,46 |
| | 10 - 15 | 30,8 | 1,13 | 2,55 |
| | 20 - 25 | 27,0 | 1,20 | 6,37 |
| | 30 - 35 | 27,2 | 1,37 | 7,60 |
| Seven years cultivated with animal traction | 2 - 7 | 35,4 | 1,04 | 1,62 |
| | 10 - 15 | 33,4 | 1,22 | 5,44 |
| | 20 - 25 | 31,8 | 1,14 | 7,76 |
| | 30 - 35 | 30,5 | 1,21 | 8,57 |
| One year under conventional tillage after clearance with bulldozer | 2 - 7 | 29,7 | 1,38 | 1,16 |
| | 10 - 15 | 35,3 | 1,44 | 2,43 |
| | 20 - 25 | 22,2 | 1,41 | 10,77 |
| | 30 - 35 | 20,5 | 1,34 | 11,23 |
| More than 20 years under conventional tillage | 2 - 7 | 36,0 | 1,17 | 1,20 |
| | 10 - 15 | 32,6 | 1,33 | 12,51 |
| | 20 - 25 | 37,3 | 1,22 | 11,30 |
| | 30 - 35 | 38,0 | 1,22 | 12,93 |

Data from DA SILVA, 1980.

Table [illegible]. Distribution of size of water stable aggregate and organic matter content in a Dark Red Latosol under different land use.

| Land use | Horizon | Depth (cm) | Macroaggregades (<1,0 mm) - % | Microaggregades (>1,0 mm) - % | Organic matter (%) |
|---|---|---|---|---|---|
| Native forest | $A_1$ | 2 - 15/20 | 90 | 10 | 4,0 |
| | $A_3$ | 15/20 - 35 | 70 | 30 | 2,0 |
| | $B_1$ | 35 - 60 | 69 | 31 | 1,5 |
| Seven year cultivated with animal traction | $A_p$ | 0 - 10 | 79 | 21 | 5,3 |
| | $A_3$ | 10 - 30 | 68 | 32 | 1,8 |
| | $B_1$ | 30 - 56 | 70 | 30 | 1,4 |
| One year conventionally tillaged, after clearance with bulldozer | $A_p$ | 0 - 15/30 | 41 | 59 | 3,2 |
| | $B_1$ | 15/30 - 55 | 42 | 58 | 1,2 |
| | $B_2$ | 55 - 110 | 28 | 72 | 1,0 |
| More than >20 years under conventional tillage | $A_p$ | 0 - 18 | 23 | 77 | 2,9 |
| | $B_1$ | 18 - 45 | 48 | 52 | 1,9 |
| | $B_2$ | 45 - 110 | 38 | 62 | 0,9 |

Data from Da Silva et alii, 1981.

Table 6. Effect of fertilizers and lime on yields of maize, wheat, soybean and pasture.

| CROP | TREATMENTS | | |
|---|---|---|---|
| | Testimony | With Application of Fertilizers | With Application of Fertilizers + Lime |
| | kg/ha | | |
| Maize | 1.500 | 5.190 | 6.560 |
| Wheat | 800 | 1.500 | 2.200 |
| Soybean | 1.200 | 2.500 | 3.200 |
| Pasture | 2.000 | 4.000 | 12.000 |

Data from Volkweiss and Klamt, 1969.

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# SOILS OF THE CERRADO REGION (CENTRAL BRAZIL)

## I.INTRODUCTION

The Cerrado region forms a vast continuous area (2.037.600 km$^2$) in Central Brazil, representing the continental divide of the three main rivers Amazon, São Francisco and Prata. It is bordered in the north and northwest by the Maranhão and Amazon basins, in the west and southwest by the Paraná basin; to the south it borders the southern Brazilian uplands and to the east and northeast the São Francisco river basin and the NE Brazilian uplands.

## 1. Geology and geomorfology

The region consists of a core of Precambrian crystalline rocks which are exposed or overlain by (partly folded) Paleozoic to Mesozoic sedimentaries; cenozoic surficial deposits are also common. Most of the area has been subjected to successive cycles of uplifting and erosion under alternating arid and humic climates; this originated a series of planations (which are in part pediplains) and dissections.

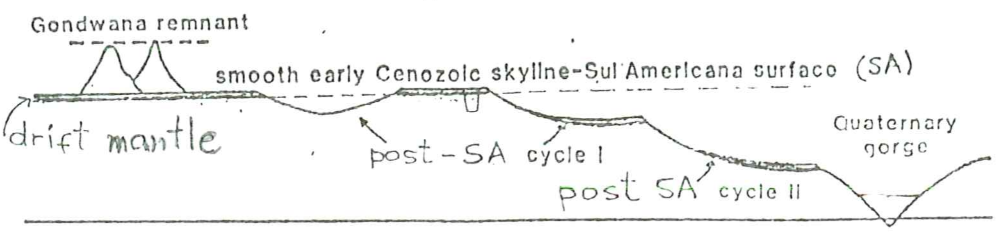
In the central part of the Cerrado region (within a radius of about 300 km around the Federal District) the landscape is dominated by large remnants of three ancient erosion surfaces; they form level to gently undulating plateaus, bordered by dissected areas (sometimes developed as escarpments). The oldest planation, the so-called Sul Americana surface (SA), reaches 1000 - 1200 m above sealevel and probably belongs to the Early-Tertiary erosion phase (ca. 65 million years BP). This surface, that used to cover the entire area, was dissected by fluvial as well as arid erosion processes, which caused the origination of a second (800-900 m) and later a third erosion level (ca. 700 m). Of these three the second level is probably the most extensive one. (Fig. 1)

Younger erosion forms are active in slowly removing the old surfaces, which are being entrenched by steep-sided river valleys with somewhat flat bottoms. The high plateaus, forming the main water divides, gradually decline in elevation and finally remain as hilly relicts, giving way to a landscape of progressively wider river valleys. (Fig.2). The main rivers, as the Araguaia and afluents, present extensive Pleistocene and Holocene floodplains.

## 2. Climate

The climate is characterized by moderate temperatures and a subhumid moisture regime. Rainfall is concentrated in the summer (about october to april) with a long dry season (4-6 months) during the winter. In most of the region the Aw or savanna-climate (Köppen) prevails. Mean annual temperature ranges from 19,8 to 23,6° C, and annual rainfall from ca. 800-2000 mm (Holland: ca. 750 mm). Strong winds are a characteristic feature of the winter season, mainly on the highest stream divides.

Fig. 1



### 3. Vegetation

Two main types of vegetation are found in the Cerrado region: savanna and forest, the savanna being the most important.

In tropical America the term savanna is applied to any grassland, with or without trees, natural or man-made. In the Cerrado region the whole sequence of savanna-formations is represented, each one having a typical name:

1) Campo limpo (treeless grassland);
2) Campo sujo (grassland with shrubs and scattered trees);
3) Campo cerrado (tall grassland with contorted trees);
4) Cerradão (dense woodland savanna).

Of these types the first two are found mainly on the highest stream divides, where conditions are unfavourable for tree growth (strong winds, drought and relatively low winter temperatures). Elsewhere the climate does not appear to have direct connections with the distribution of the cerrado complex.

NB: "Cerrado complex" is a general name for the entire sequence, of which, campo cerrado is the dominant type: it occupies an area of ca. 1,8 million $km^2$ (which is one fifth of the country).

The campo cerrado comprises a mixture of tall grasses and low contorted trees, 4-8 m high. Its areal distribution is dependent upon the soil conditions and therefore indirectly upon the morphology. Cerrado vegetation as a rule is found on soils of very to extremely low natural fertility and with excellent internal drainage; such soils are committed to certain morphological units (see fig. 3 Cerrado dominates the high plateaus and extends to gentle landforms on lower erosion surfaces as well as to steep sloping dissected areas, that border the erosion surfaces. Cerradão represents a transition to the forest vegetation.

In the Cerrado region two types of forest can be found:

1) Mesophytic forest (mainly semideciduous), occurring in most of the deeply entrenched river-valleys and on steep slopes in dissected terrain, more rarely on young erosion surfaces. Forests are practically absent on the highest erosion surfaces. Outside of these, they coëxist with cerrado vegetation on dystrophic soils and dominate on eutrophic soils.
2) Gallery forest, occurring only in the lowest (marshy) parts of valleys, directly near rivers, where drainage conditions are poor.

## II. THE SOILS IN RELATION TO THE ENVIRONMENT

The nature and distribution of the soils in the Cerrado region seems to be related to variations in topography, parent material and surface stability.

In general, the deepest, oldest, most strongly weathered Brazilian soils (practically devoid of weatherable minerals) are found on the oldest, most stable land surfaces, which are covered with cerrado vegetation; these are various kinds of Ferralsols (Latosols) and to a lesser extent also certain Arenosols (Quartz sands).

The occurrence of younger, less weathered and sometimes rich (eutrophic) soils is related to active landscape dissection (incision of streams), giving rise to younger landforms, covered by (semi)deciduous forests; these include Luvi- and Acrisols (Red Yellow Podzolics) and Nitosols (Terra Roxa).

On the escarpments bordering the plateaus Cambisols and Lithosols are found, as well as concretionary lateritic soils (only of local importance); these concretionary soils surround most of the plateaus, but are not usually found at any depth elsewhere on the plateaus.

On the lower surfaces dystric Latosols are found, generally shallower and less weathered than those on the surrounding higher areas. On (moderately inclined) valley sides and hills on these surfaces however, soils with argillic horizons occur; these may be eutrophic (Alfisols) if close to basic rocks or limestone, elsewhere they are dystrophic (mostly Ultisols). The parent material of these soils is often a relatively shallow colluvium (0.5 to 1 m) and stone lines may appear in the soil profile. Table 1 presents the distibution of soils in terms of area covered and Table 2 the main components of mapping units with Latosols (Ferralsols). Tables 3 and 4 present a summary of analytical data of the main soils of the Central Brasil plateau.

## III. LAND USE AND MANAGEMENT OF CERRADO SOILS

Acric Ferralsols have low natural fertility. Even after burning of the Cerrado vegetation they stay low fertil. The almost complete absence of Ca leads to short rooting systems of crop. Fertilization experiments with Zn gave increasing yields.
Clay textured Acric Ferralsols are better in use than sandy ones because they have no leaching of fertilizers.
Erosion risks because of land use are minimal.

Humic Ferralsols have moderate fertility and are being used in extensive pastures. Because the slopes are long (<5%), gully and sheet erosion are noticed.
Management treatment is mainly liming, to neutralize Al-saturation. Unsufficient liming shows fixation of P.

Orthic Ferralsols have low nutrient content. Because the vegetation is cerradao, the reserves are higher than those of Acric Ferralsols with cerrado vegetation. Burning down the forest increases the nutrient content for a few years.
Fertilizers bring high to very high productivity levels. First neaded nutrients are P, Ca, Mg. After some years of cultivation also K and S are neaded. Clay textured Orthic Ferralsols don't leach the fertilizers.
The topography is smooth.

Rhodic Ferralsols have medium fertility. The absence of serious limitations make them usefull for agriculture. Most of them were under natural forest vegetation and the recicling of nutrients explains their higher nutrient status.

Ferralic Arenosols have extremely low fertility. Because they leach almost all fertilizer, theyare used for grazing only.
The topography is undulating. Clearing the low open cerrado may cause severe erosion, which is difficult to control.

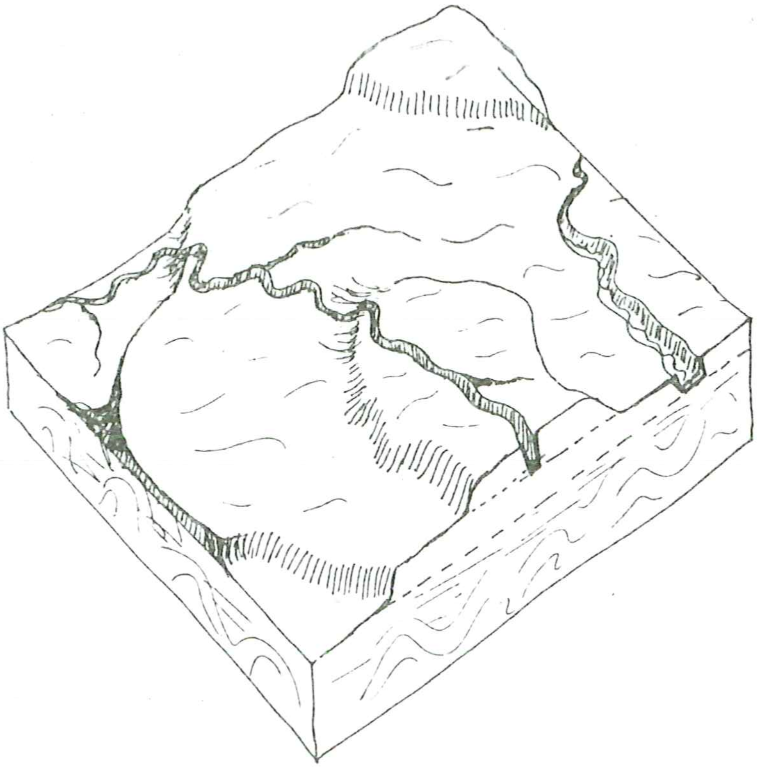


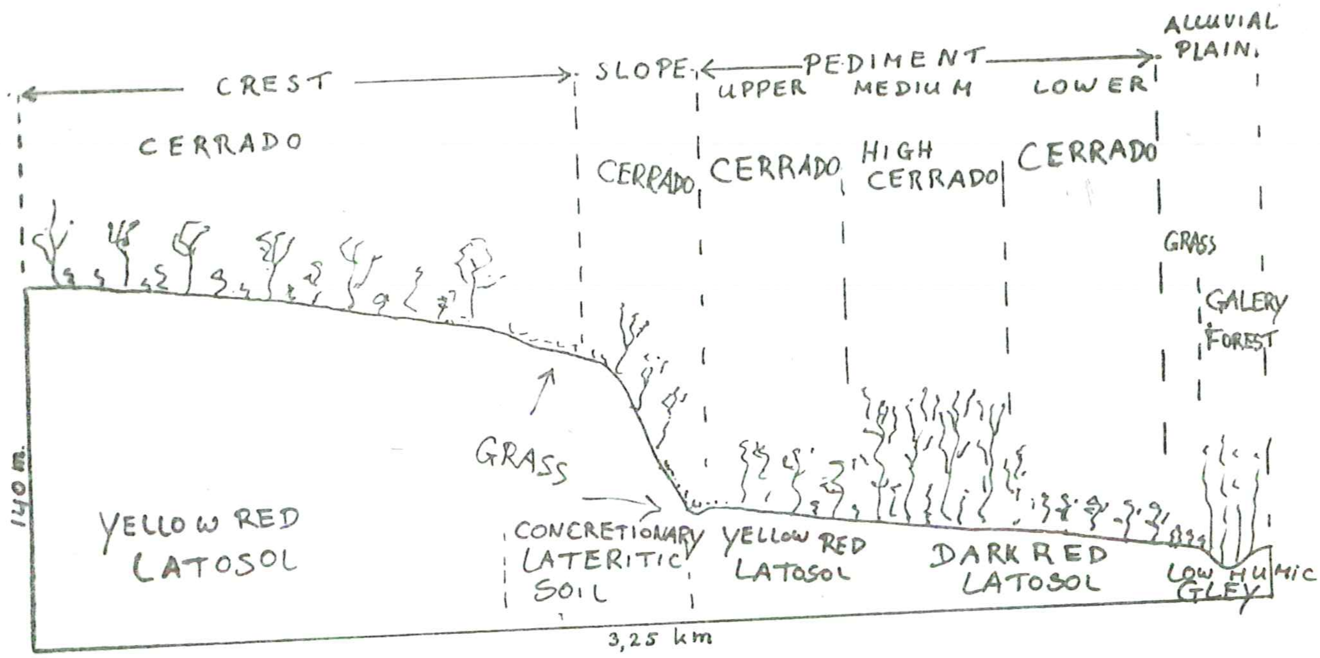
Fig. 2

Fig. 3

| Morphology | → | Soils | → | Vegetation |
|---|---|---|---|---|
| • level to gently undulating plateaus (old, stable erosion surfaces) | NO EROSION | • old, deeply weathered soils almost without weatherable minerals | | Cerrado complex |
| • steeply sloping dissected terrain | | | | |
| a) escarpments bordering the plateaus | REWORKED MATERIAL OF PLATEAUS | younger soils of low fertility (dystrophic) developed in poor parent materials | | Cerrado |
| b) river-valleys entrenched into the plateaus | IN SITU WEATHERING + SOIL RENEWAL BY EROSION | young soils of high fertility (eutrophic) developed in relatively rich parent materials under the present environment | | (semi) deciduous forest |
| • low, marshy areas in river valleys | POOR DRAINAGE CONDITIONS | hydromorphic soils | | gallery forest |

FIG.4

SEQUENCE OF SOILS IN THE FEDERAL DISTRICT




After Rodrigues and Klamt, 1978. Rev. Bras. Ci. Solo.

TABLE 1. MAIN KINDS OF SOIL IN THE CERRADO REGION

| BRAZILIAN CLASSIFICATION | FAO/UNESCO | SOIL TOXONOMY | % OF AREA |
|---|---|---|---|
| Latossolos | Ferralsols | Oxisols | 46,0 |
| Concrecionários Lateríticos | Acrisols<br>Ferralsols | Some Ultisols<br>Oxisols | 2,8 |
| Podzólicos | Acrisols<br>Luvisols | Ultisols<br>Alfisols | 14,3 |
| Terras Roxas | Nitosols | Alfisols | 1,7 |
| Cambissolos | Cambisols | Entisols<br>Inceptisols | 3,0 |
| Litólicos | Lithosols | Entisols | 7,3 |
| Areias Quartzosas | Arenosols | Entisols | 15;7 |
| Lateritas Hidro-mórficas | Luvisols/<br>Plinthic Acrisols | Ultisols<br>Alfisols<br>Oxisols | 6;0 |
| Gley | Gleysols | Inceptisols | 1,9 |
| Outros | - | - | 1,3 |

Table 2

PROPORTION OF AREA OCUPIED BY THE MAPPING UNITS WITH LATOSSOLO AS MAIN COMPUNENT IN THE CERRADO REGION

| MAIN COMPONENT OF MAPPING UNITS | SECUNDARY COMPONENTS | % OF AREA |
|---|---|---|
| Dark red Latosol, dystrophic<br>Latossolo Vermelho-Escuro distrófico | FAO: Acric Ferralsol<br>Soil Tax: Acrustox/Acrorthox<br>LVd AQd SCd SCd PV Cd | 17,8 |
| Dark red Latosol, eutrophic<br>Latossolo Vermelho-Escuro eutrófico | FAO: Rhodic/Humic Ferralsol<br>LEd AQd SCd PV Cd Rd | 0,7 |
| Latossolo Vermelho-Escuro eutrófico | PE Ce | 0,1 |
| Yellow red Latosol, dystrophic<br>Latossolo Vermelho-Amarelo distrófico | FAO: Acric/Orthic Ferralsol<br>S.T.: Acrustox/Acrorthox<br>LEd AQd SCd PV Cd Rd | 22,1 |
| Dusky red Latosol, dystrophic<br>Latossolo Roxo Distrófico | FAO: Acric Ferralsol<br>SCd HLd | 1,3 |
| Latossolo Roxo distrófico/eutrófico | FAO: Rhodic/Humic Ferralsol<br>AQd | 2,2 |
| Yellow Latosol, dystrophic<br>Latossolo Amarelo Distrófico | LVd PV | 1,8 |

Table 1.—Summary of selected analytical data for kinds of soil and their varieties most common in Planalto Central - Mean and standard deviations.

| Horiz.[1] | Nº of Sites[2] | pH H₂O | pH 1N KCl (range) | Sand % | Silt % | Clay Total % | Clay Water Disp. % | Organic Carbon % | Exch. Bases[3] me/100 g | CEC[4] me/100 g | Base Sat. % | Al Sat. % | $SiO_2$[5] / $Al_2O_3$ (Ki) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DARK RED LATOSOL dystrophic clayey forest | | | | | | | | | | | | | |
| A | 12 | 4.2—5.8 | 3.6—4.6 | 40±5 | 13±2 | 47±4 | 23±3 | 2.1±0.2 | 2.3±1.0 | 11.0±0.9 | 18±5 | 43±9 | 1.41±0.11 |
| B | 12 | 4.7—6.0 | 3.9—5.5 | 35±3 | 12±2 | 53±3 | 1±1 | 0.5±0.1 | 0.4±0.1 | 3.6±0.5 | 13±2 | 27±11 | 1.31±0.11 |
| IDEM dystrophic clayey *cerrado* | | | | | | | | | | | | | |
| A | 11 | 4.3—5.2 | 3.5—4.3 | 28±5 | 13±2 | 59±5 | 21±3 | 2.2±0.2 | 0.7±0.1 | 10.1±1.1 | 7±1 | 72±2 | 1.23±0.10 |
| B | 11 | 4.6—6.1 | 3.9—5.7 | 24±4 | 11±2 | 65±4 | 1±1 | 0.6±0.1 | 0.4±0.1 | 4.0±0.5 | 10±1 | 38±10 | 1.19±0.09 |
| IDEM dystrophic clayey *cerrado*, pH $H_2O$ < 1N KCl | | | | | | | | | | | | | |
| A | 8 | 4.5—5.5 | 4.3—4.9 | 22±5 | 21±3 | 57±6 | 16±4 | 2.3±0.2 | 1.2±0.3 | 8.8±0.7 | 14±3 | 37±7 | 0.64±0.09 |
| B | 8 | 4.9—6.2 | 5.6—6.7 | 20±5 | 15±2 | 65±6 | 11±2 | 0.6±0.1 | 0.5±0.1 | 1.9±0.3 | 32±5 | 0±0 | 0.55±0.09 |
| IDEM dystrophic loamy forest | | | | | | | | | | | | | |
| A | 8 | 4.1—5.2 | 3.7—4.7 | 78±3 | 7±1 | 15±3 | 10±3 | 0.9±0.1 | 1.8±0.3 | 6.2±0.5 | 29±5 | 35±7 | 2.03±0.07 |
| B | 8 | 4.4—4.9 | 3.6—4.1 | 73±3 | 7±1 | 20±2 | 10±2 | 0.3±0.0 | 0.3±0.1 | 3.0±0.2 | 10±2 | 80±3 | 1.95±0.05 |
| IDEM dystrophic loamy *cerrado* | | | | | | | | | | | | | |
| A | 11 | 4.5—5.3 | 3.7—4.3 | 79±2 | 6±1 | 15±1 | 9±1 | 0.9±0.1 | 0.7±0.1 | 4.6±0.7 | 16±2 | 59±5 | 1.87±0.10 |
| B | 11 | 4.4—5.5 | 3.8—4.6 | 73±2 | 7±1 | 20±2 | 5±2 | 0.2±0.0 | 0.3±0.1 | 2.1±0.2 | 16±3 | 70±4 | 1.82±0.03 |
| IDEM eutrophic clayey forest | | | | | | | | | | | | | |
| A | 3 | 5.9—7.2 | 4.9—6.7 | 30±16 | 20±3 | 50±10 | 26±14 | 2.8±0.4 | 14.0±3.0 | 17.1±3.8 | 79±12 | 0±0 | 1.77±0.07 |
| B | 3 | 5.8—6.3 | 5.0—6.1 | 30±10 | 11±3 | 59±8 | 1±1 | 0.6±0.1 | 4.8±0.3 | 7.1±1.1 | 70±8 | 2±2 | 1.65±0.25 |
| DUSKY RED LATOSOL dystrophic clayey forest | | | | | | | | | | | | | |
| A | 6 | 5.3—6.2 | 4.5—5.6 | 21±3 | 19±1 | 60±3 | 32±7 | 3.0±0.2 | 9.6±1.4 | 16.2±1.6 | 58±5 | 1±1 | 1.57±0.22 |
| B | 6 | 4.9—6.1 | 4.1—5.9 | 17±3 | 13±1 | 70±3 | 0±0 | 0.0±0.0 | 1.1±0.2 | 5.2±0.6 | 24±5 | 35±16 | 1.47±0.19 |
| IDEM dystrophic clayey *cerrado* | | | | | | | | | | | | | |
| A | 3 | 4.9—5.2 | 3.9—4.6 | 26±7 | 15±4 | 59±4 | 33±8 | 1.5±0.1 | 1.5±0.5 | 8.1±1.3 | 17±5 | 46±4 | 1.43±0.32 |
| B | 3 | 5.3—5.9 | 4.0—5.5 | 23±6 | 14±4 | 63±3 | 0±0 | 0.5±0.1 | 0.4±0.1 | 3.8±0.7 | 10±1 | 50±23 | 1.37±0.35 |

TABLE 1.—(Continued).

| Horiz.[1] | Nº of Sites[2] | pH H₂O | pH 1N KCl (range) | Sand % | Silt % | Clay Total % | Clay Water Disp. % | Organic Carbon % | Exch. Bases[3] me/100 g | CEC[4] me/100 g | Base Sat. % | Al Sat. % | $SiO_2$[5] / $Al_2O_3$ (Ki) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DUSKY RED LATOSOL dystrophic clayey *cerrado*, pH < $H_2O$ 1N KCl | | | | | | | | | | | | | |
| A | 3 | 4.6—5.2 | 4.3—4.5 | 31±4 | 18±2 | 51±2 | 17±7 | 1.9±0.2 | 0.7±0.1 | 8.4±0.8 | 8±1 | 49±1 | 0.35±0.04 |
| B | 3 | 5.4—5.9 | 5.7—6.1 | 24±1 | 16±1 | 60±1 | 10±9 | 0.6±0.2 | 0.6±0.1 | 2.8±0.4 | 22±8 | 0±0 | 0.35±0.05 |
| IDEM eutrophic clayey forest | | | | | | | | | | | | | |
| A | 5 | 5.2—6.7 | 5.0—6.1 | 19±3 | 21±2 | 60±3 | 28±9 | 3.0±0.3 | 15.3±1.8 | 18.7±1.4 | 81±5 | 0±0 | 1.79±0.24 |
| B | 5 | 5.2—6.8 | 4.5—6.3 | 15±2 | 15±2 | 70±4 | 0±0 | 0.5±0.0 | 4.8±0.7 | 7.1±0.6 | 66±9 | 6±4 | 1.60±0.22 |
| RED-YELLOW LATOSOL dystrophic clayey forest | | | | | | | | | | | | | |
| A | 1 | 4.4 | 3.7 | 51 | 9 | 40 | 17 | 2.0 | 0.7 | 4.6 | 8 | 58 | 1.23 |
| B | 1 | 5.3 | 4.8 | 34 | 17 | 49 | 0 | 0.5 | 0.3 | 2.4 | 14 | 40 | 1.20 |
| IDEM dystrophic clayey *cerrado* | | | | | | | | | | | | | |
| A | 5 | 4.3—5.5 | 3.5—4.4 | 46±7 | 9±3 | 45±5 | 17±4 | 1.8±0.2 | 0.7±0.2 | 7.8±1.7 | 10±3 | 62±3 | 1.24±0.18 |
| B | 5 | 5.2—6.2 | 3.9—5.5 | 38±6 | 9±2 | 53±4 | 0±0 | 0.5±0.1 | 0.4±0.1 | 2.7±0.4 | 13±0 | 42±9 | 1.18±0.18 |
| IDEM dystrophic clayey *cerrado*, pH $H_2O$ < 1N KCl | | | | | | | | | | | | | |
| A | 1 | 4.7 | 4.1 | 19 | 9 | 72 | 13 | 2.6 | 0.8 | 9.5 | 8 | 86 | 0.38 |
| B | 1 | 5.1 | 5.4 | 14 | 13 | 73 | 0 | 1.1 | 0.4 | 4.6 | 10 | 0 | 0.33 |
| IDEM dystrophic loamy *cerrado* | | | | | | | | | | | | | |
| A | 3 | 4.9—5.2 | 4.1—4.2 | 71±1 | 7±3 | 22±2 | 7±3 | 1.0±0.2 | 0.5±0.1 | 4.5±0.3 | 10±3 | 58±12 | 0.65±0.07 |
| B | 3 | 5.0—5.9 | 4.5—5.3 | 64±2 | 7±2 | 26±1 | 2±2 | 0.4±0.1 | 0.3±0.1 | 2.0±0.3 | 16±2 | 42±8 | 0.64±0.06 |
| IDEM dystrophic loamy *cerrado*, pH $H_2O$ < 1N KCl | | | | | | | | | | | | | |
| A | 1 | 4.6 | 4.6 | 67 | 6 | 27 | 6 | 0.8 | 0.4 | 3.3 | 12 | 47 | 0.49 |
| B | 1 | 4.9 | 5.7 | 60 | 5 | 35 | 10 | 0.5 | 0.4 | 1.6 | 28 | 0 | 0.42 |
| LITHOLIC SOILS dystrophic *cerrado* | | | | | | | | | | | | | |
| A | 10 | 4.4—5.7 | 3.7—4.8 | 50±7 | 27±4 | 23±3 | 9±2 | 1.3±0.4 | 1.4±0.3 | 6.7±0.5 | 19±3 | 47±1 | 1.74±0.23 |
| LITHOLIC SOILS eutrophic forest | | | | | | | | | | | | | |
| A | 8 | 5.6—7.0 | 4.6—6.0 | 37±6 | 31±3 | 33±3 | 22±2 | 3.2±0.5 | 16.8±3.7 | 20.9±2.1 | 74±7 | 1±1 | 2.78±0.36 |
| QUARTZ SANDS dystrophic *cerrado* | | | | | | | | | | | | | |
| A | 7 | 4.0—5.4 | 3.9—4.3 | 87±1 | 5±0 | 8±1 | 3±1 | 0.8±0.2 | 0.6±0.2 | 4.7±0.9 | 13±3 | 59±5 | 1.32±0.25 |
| B | 7 | 5.1—5.9 | 4.2—4.7 | 85±1 | 4±1 | 11±1 | 5±1 | 0.2±0.0 | 0.2±0.0 | 1.7±0.2 | 14±2 | 60±3 | 1.38±0.28 |

85-2418/68 EK/mh

# SOILS OF NORTHEASTERN BRASIL SEMI-ARID REGION

by E. Klamt

## Introduction

In northeastern Brasil, due to semi-arid climatic conditions (Figures 1 and 2), with short periods of heavey precipitation on surfaces with low vegetation coverage, erosional processes are remarkable, such that soils are closely related to geomorphic surfaces and parent material. Direct climate influence is expressed by presence of soils with sodic and saline properties (evaporation) and high base saturation (low leaching of elements).

## SOIL-LANDSCAPE-PARENT MATERIAL RELATIONSHIPS

The Northeast Highlands extends from the northeast coast to the Maranhão sedimentary basin and the northern part of the São Francisco river valley (Figure 3). It comprises three geomorphic sub-units, the Borborema "plateau", the low interland (locally called "Sertão") and remnants of plateau areas ("chapedas"). The Borborema "plateau" is an eastern highland strip, no more than 250 km wide with various small old surface remnants, ranging in altitude from 800 to 1,000 m, mostly on the Pre-Cambrian shield. The "Sertão" is an extensive low relief surface with scattered inselbergs, originated by post-Cretaceous denudation and pediplanation on the Pre-Cambrian shield, located between the Borborema and the western scarpments of the plateau remnants ("chapadas"). These tablelands are formed on Cretaceus sediments which once covered more extensivelly the crystalline shield. The dominant climate is semi-arid ("BSh" of Koeppen). A thornshrub decidous vegetation (locally called "caatinga") is characteristic of the "Sertão", the remaining area have various kind of semidecidous vegetation.

This region differs considerably from Central Brazil mainly because of the dominant current semi-arid climatic conditions. The tablelands, remnants of the SA-SUL-AMERICANA planation surface, are less extensive. The most prominent one is the "Chapada do Araripe". Other smaller, isolated residual tablelands (north of transect, not presented in Figure 3) are the "Cuité", "Sant'Ana", "Alto da Serra dos Martins" and Chapada Grande (Figure 4). They are covered by Red-Yellow Latosols (Oxisols) or Ferralsols that, like those of the Central Plateau, are very deep, dystrophic and highly westhered but the clay fraction is dominated by Kaolinite. Differences in organic matter contens seems to be related to climate: the drier the environment the lesser the amount. A good example of this is on the top of the Araripe plateau, where the higher rainfall eastern side, has Latosols with thicker A horizons (Humox), than the drier western side. A sequence of soil profiles at Chapada Grande is shown on Figure 5. On the borders of the Chapada, petroferric outcrops are common, which protect the surface against erosional degradation.

Adjacent to the SA surfaces, lower areas of succeeding erosion cycles, including the very recent stream incisions, have different soils from those of their counterparts in the Brasilian Central Highlands. The two main low relief areas: the "Soledade" and "Sertaneja" peneplains (Figure 3) frequently have eutrophic soils with high CEC clays, such as Non-Calcic Brown soils (Alfisols), Regosols (Arents) and Lithosols (Entisols), along with Solodized-Solonetz (Natrargids) and Vertisols, which are more extensive on the Soledade surface, to the west of the Araripe Plateau near the Jaicós locality, possibly on one of the few northeastern area were the drift mantle remains, deep sandy soils such as Dystrophic Regosols, Quartzitic Sands (Arents) and some Latosols (Torrox) may be found. Slightly undulating to hilly areas with AW' climate have mainly eutrophic Podzolic Soils (Alfisols) with high activity clays or Regosols. On areas with hilly or mountaineous relief rock outcrops and Lithosolic soils with high bases status are very common.

## GENERAL CHARACTERISTICS OF MOST IMPORTANT SOILS

Table 1 summarizes the classification of the main soils of northeastern Brasil Semi-arid region, which distribution is shown on Figure 3. The classification according to the Brazilian system and correlation with FAO-UNESCO and SOIL TAXONOMY is also presented. The general characteristics of these soils are:

FERRALSOLS (LV) - Deep soils with yellow (XANTHIC) to yellow red (ORTHIC) colours, mostly clayey texture and with no clay increase with depth, weak subangular blocky to crumb like structure; low concentration of bases and low cation exchange capacity, presenting an oxic subsurface horizon.

ACRISOLS (PV) - Moderately deep soils with a light colour, medium texture A horizon (OCHRIC) over a yellow red to red, clayey, moderate to strong subangular to angular blocky structure, with clay skins argillic B horizon, presenting low base saturation and low cation exchange capacity.

LUVISOLS (PE) - Similar to the Acrisols but presenting high base saturation and mostly high cation exchange capacity.

LUVISOLS (NC) - Similar to the former but less developed and found on more unstable surfaces, mostly on short and steep slopes.

SOLONETZ (SS) - Moderately deep soils with a light colour, medium texture A horizon (OCHRIC) over a clayey, strong and coarse columnar structured Natric B horizon.

REGOSOLS (RE) - Moderately deep, light in colour, coarse texture, single grain to weakly coherent structured soils.

VERTISOLS (V) - Shallow to moderately deep, heavy clay soils with open cracks when dry and slickensides.

LITHOSOLS (RE) - Shallow soils over consolidated rocks, mostly eutrophic because of low leaching conditions.

ARENOSOL (AQ) - Moderately deep to deep light colour, coarse texture, single grain soils with weak horizonation.

## LIMITATION FOR RURAL DEVELOPMENT

Besides the low availability of water due to climatic limitations and low water holding capacity of some soils (Arenosols, Lithosols), shallow depth (Lithosols, Luvisols-NC), high susceptibility to erosion (Lithosols, Solonetz, Luvisols-NC), sticky when wet and very hard when dry (Vertisols) and low availability of nutrients (Ferralsols, Acrisols, Arenosols), are the main limitations of the soils of these region for rural development.

Irrigation has been the alternative mostly used to achieve agricultural development of these region. Great amounts of capital has been invested in projects, but even so poverty has increased and many soils in irrigated areas became salinized due to deficient drainage and low amounts of water applied.

Efforts should be concentrated in studying and educate farmers on how take advantage of the natural environmental conditions. Enough humidity is available in the rainy season to obtain one reasonable crop production without irrigation. The excess of grains obtained by this procedure can feed the people and the excess of grass transformed in hay and stored in hay stacks to feed animals in the dry season. Wells can be open or small dams of low cost built on farms to supply water to animals and men.

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Brasil, Ministerio da Agricultura, Convenio ma/contap/usaid/Brasil. Levantamento exploratório-reconhecimento de solos do estrado da Paraiba (Boletim Técnica, 15-1972), Bahia (B.T. no. 52-1979), Ceará (B.T. no. 28, 1973), Pernambuco (B.T. no. 26, 1973), Rio Grande do norte (B.T. no. 21, 1971) and Alagoas (B.T. no. 35, 1975). Rio de Janeira.

TABLE 1. Classification of the soils found in the northeastern Brasil tropical semi-arid region according to the Brasilian, FAO-UNESCO and Soil Taxonomy systems and represented on Figure 3.

| SOIL SYMBOLS ON TRANSECT | CLASSIFICATION ACCORDING TO THE SYSTEMS | | |
|---|---|---|---|
| | BRASILIAN | FAO-UNESCO | SOIL TAXONOMY |
| LV | Yellow and Yellow Red Latosols | Xanthic and Orthic Ferralsols | Umbriorthox, Haplustox |
| PV | Red Yellow Podzolic, Dystrophic | Ferric/Dystric Acrisols | USTULTS |
| PE | Red Yellow Podzolic, Eutrophic | Ferric/Eutric Luvisols | USTALFS |
| NC | Non Calcic Brown Soils | Orthic Luvisols | USTALFS |
| SS | Solodized Solonetz | Orthic Solonetz | Natrustalfs Natrargids |
| RE | Regosols, Eutrophic | Eutric Regosols | PSAMMENTS |
| V | Vertisols | Vertisols | Vertisols |
| Re | Lithosols, Eutrophic | Eutric Lithosols | Entisols |
| AQ | Quartzic Sands | Ferralic/Albic Arenosols | QUARTZISPAMMENT |
| Ar | Rock outcrops | | |

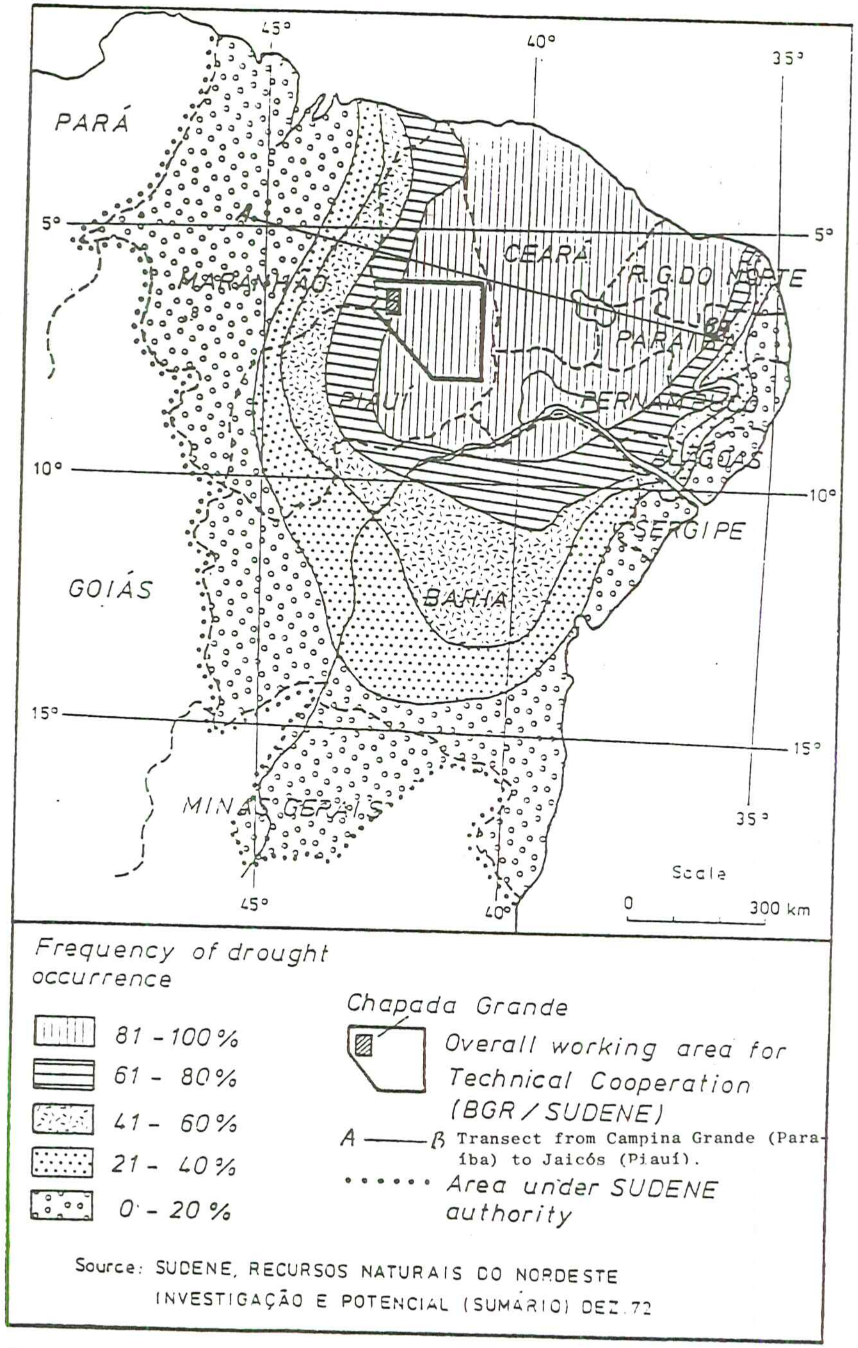



Fig. 1: Drought regions of northeastern Brazil

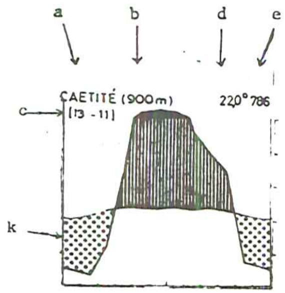



Fig. 2a Climatic data of Caeteté station, northeastern Brasil tropical semi-arid region.

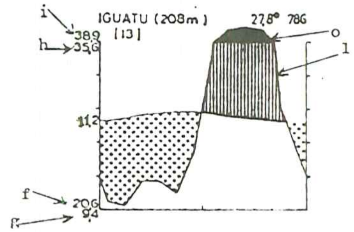



Fig. 2b. Climatic data of Iguatu Station, northeastern Brazil. tropical semi-arid region.

Legend:

a) Name of station.

b) Altitude

c) Number of years of observation

d) Mean annual temperature (°C)

e) Mean annual precipitation

f) Mean temperature of coldest month

g) Absolute minimum temperature

h) Mean of hottest month

i) Absolute maximum temperatur

k) Mean temperatur

l) Mean precipitation

o) Precipitation above 100 mm.

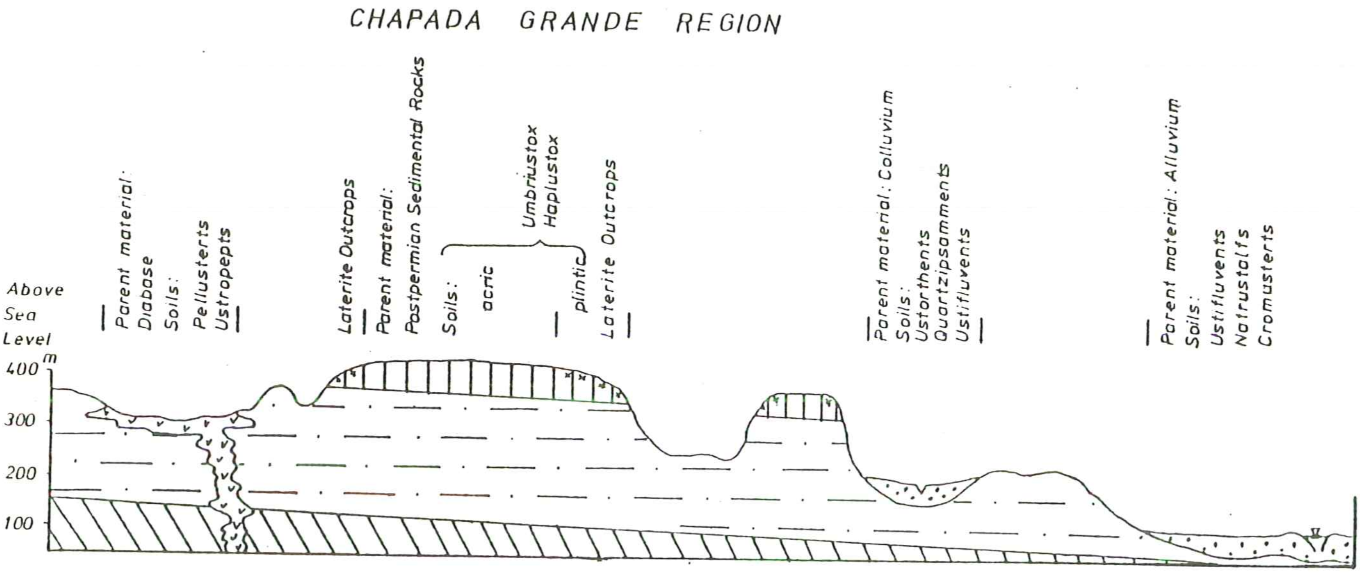



Fig. 4. Relationship between soil and geomorphology of the Chapada Grande, Piauí (After Lücken et alii, 1982).

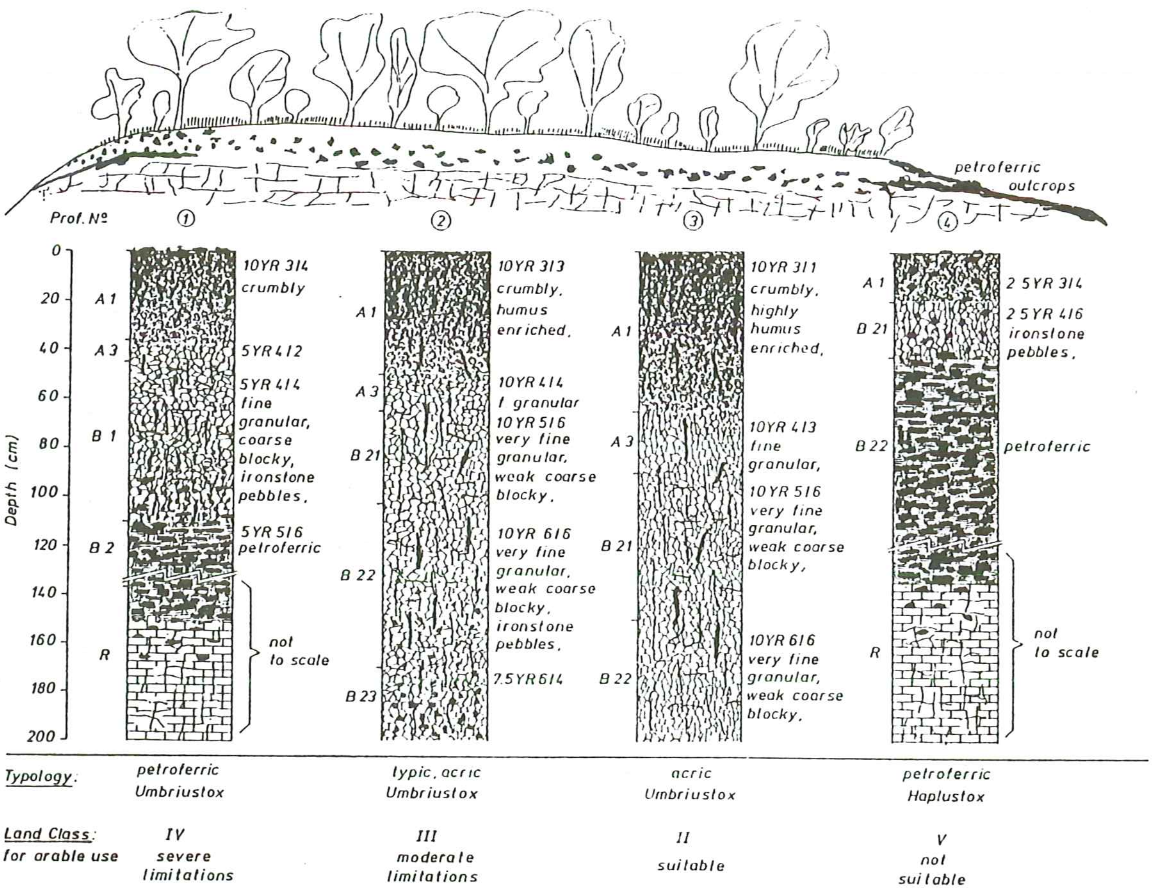



Fig. 5: Sequence of soil profiles of the Chapada Grande (After Lücken et alii, 1982).

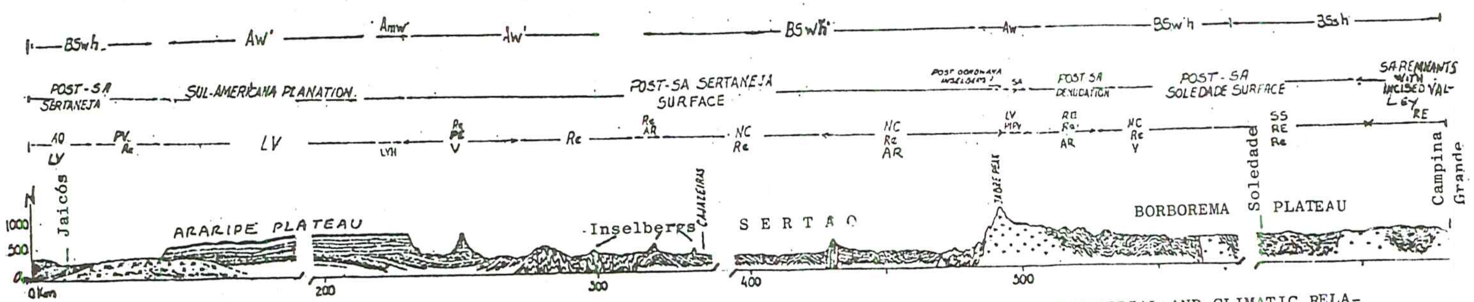
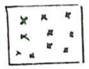
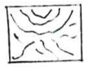
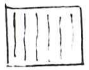
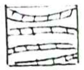


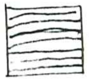

FIGURE 3. TRANSECT FROM CAMPINA GRANDE (PARAIBA) TO JAICOS (PIAUI) SHOWING SOIL-LANDSCAPE-PARENT MATERIAL AND CLIMATIC RELATIONSHIPS IN NORTHEASTERN BRASIL TROPICAL SEMI-ARID REGIONS ( AFTER LEPSCH ET ALII, 1982).

 - PLUTONIC ACID ROCKS - MAINLY GRANITE

 - PRE-CAMBRIAN SCHIST , GNEISS & MIGMATITES.

 - PRE-CAMBRIAN QUARTZITE WITH MUSCOVITE

 - POST PERMIAN SEDIMENTARY SANDSTONE, SILTSTONE & CLAYSTONE.

 - CRETACEOUS/TERTIARY SEDIMENTS (BANANEIRAS FORMATION).