SOILS OF THE HUMID AND SUB-HUMID TROPICS

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Summary

This contribution deals with the soils of the humid and sub-humid tropics, i.e. the inter-tropical belt with a dry season of maximum 3 months. Soil formation and weathering in this environment are intense. Physical and physicochemical processes lead to deep weathering zones, high clay contents, and the destruction of primary mineral lattice structures. Biological activity may homogenize the soil material and make soil boundaries more diffuse.

The soil which is in equilibrium with the current soil forming conditions in the humid tropics is an Oxisol, characterized by a deep ABC profile with an oxic horizon and/or the presence of plinthite. The soil is completely devoid of primary weatherable minerals and the clay fraction is dominated by kaolinite, iron and aluminum oxides and

hydroxides (goethite-hematite and gibbsite); the latter give the soil a deep red matrix color. Soils which for one reason or another have not reached the ultimate development stage are Ultisols, characterized by a clay illuviation, low base saturation and little or no plinthite. Other soils of importance in the tropics are Vertisols and Acid Sulfate Soils.

An overview is given of the classification of tropical soils in the 3 major world classification systems. This is followed by a short summary of their land use and production potential.

1. Introduction

The tropics correspond to the area of the world between the Tropic of Cancer and the Tropic of Capricorn (23^{o}27’ North and South); they cover some 2 thousand million hectares (38 % of the world land surface). The subtropics are the regions north and south of the tropics up to about 35^o latitude. Their boundaries with the Mediterranean and temperate areas are not well defined. Soil formation and soil properties in the tropics differ as a function of the rainfall pattern. The soils of the humid tropics are deep and strongly weathered; they are developed under an aggressive, warm and moist climate; or they are in the process towards such a weathering stage. This means that soil and air temperatures are high, with monthly means above 22 °C, and that soils are moist throughout the year. They are found under an Af climate in Köppen’s classification, and are covered by a dense tropical rainforest or man-made savanna. Due to the continuous high temperature and moisture which enhance also bio-chemical soil processes these soils are affected by a *ferrallitic* and *allitic* weathering (see: *Land Cover and Land Use Change*).

Soils of the sub-humid (or somewhat dry) tropics have a dry season of maximum 3 months. They occur generally under As, Am or Aw climates in Köppen’s classification and are covered by an open forest and savanna vegetation. During the dry period the weathering intensity is reduced and is then characterized as *ferrallitic* to *fersiallitic*. The soils in the tropics and subtropics developed under a dry pedo-climate have been discussed in the sections on *Soils of Arid and Semi-Arid Areas* and *Mediterranean Soils.*

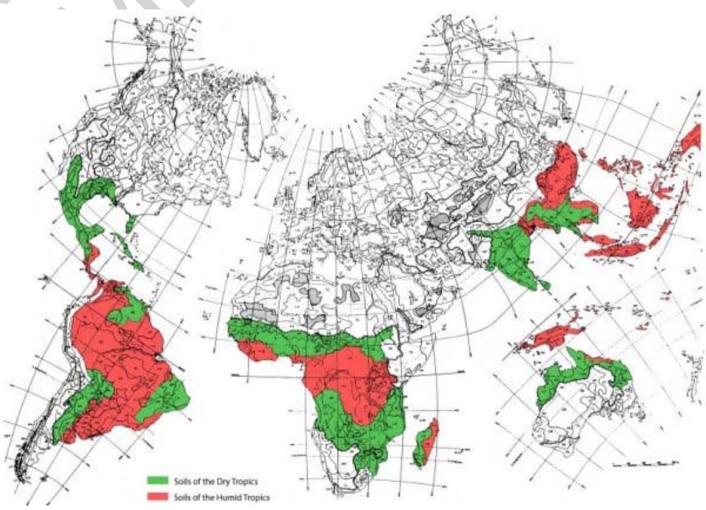

Figure1. Extension of tropical soils (after FAO, 1991)

Tropical soils occur over large areas in Africa, Central and South America and Southeast Asia, but are not extensive in Australia (Fig. 1). Isolated patches of soils with tropical properties outside the inter-tropical belt, as is the case in South Portugal and in the Sahara, are paleo-formations which reflect a change in the environmental conditions since the time they were formed.

2. Soil Forming Factors

The factors of soil formation in the tropics do not much differ from those in other areas of the world, but they act with a higher intensity than in temperate and arid regions. This is because the climate is more aggressive and physical, chemical and biological weathering processes act over almost the whole year. In tropical regions with a dry season these processes are temporarily interrupted or reduced. In tropical mountain areas temperatures are lower and soil formation takes the characteristics of temperate or even boreal climates.

2.1. Climate

Rainfall in the humid tropics is high (1800-2000 mm per year, or more) and evenly distributed over the year, most of which (60-80 %) enters the soil and participates in soil formation. When a climate is characterized as sub-humid this does not mean that it has less rain than a humid climate, but it holds some dry months during which little or no active water is available in the soil.

Tropical rains occur usually in the form of short, intensive storms with peak intensities up to 100 mm/h or more. Large raindrops beat and destroy soil aggregates, disperse fine particles, fill surface voids and reduce water intake. Under a dense forest cover, however, the kinetic energy of the raindrops is broken and most rain infiltrates the profile where it enhances the leaching of bases and soluble weathering products, increases the H^+ and Al^{3+} ion concentration, and creates an acidic environment for chemical reactions in the soil.

Air temperatures in the tropics are in the order of 22 to 28 °C. They depend in the first place on radiation, but because of the consistent cloud cover in the humid tropics they show little variation. In the dry season with fewer clouds both daily and seasonal variations are higher.

The effect of soil temperature as a soil forming factor in the (sub)humid tropics is particularly important in combination with high air humidity under a dense forest canopy. Temperature affects both physical and chemical soil processes; it has moreover an impact on evapo-transpiration, organic matter decay and biotic activity. Its importance in soil formation can be related to the von 't Hoff's temperature rule that for every 10 °C rise in temperature the velocity of chemical reactions increases by a factor 2 to 3. As a result, primary rock minerals are rapidly disintegrated, and the dissolution products and individual bases eliminated, leaving behind a residual accumulation of quartz, iron and aluminum oxides, or newly formed stable secondary minerals like kaolinite, goethite-hematite and gibbsite.

Obviously, soils of the humid tropics are usually very deeply weathered, attending sometimes several meters, and they contain relatively high clay contents. Soils of the sub-humid tropics or affected by erosion are less deep and may still contain other clay minerals than kaolinite.

The predominant role of climate as a soil forming factor at regional or continental scale is at the origin of the soil zonality concept introduced by Dukouchaiev and collaborators (see also: *Soil Geography and Classification*).

2.2. Parent Material

One of the factors that can consistently modify the effect of climate in soil formation is the parent material and the way its components react to an aggressive weathering. In broad terms, basic rocks (basalt for example) weather more easily under intensive weathering than acid rocks (granite, gneiss, quartzite), apparently because the latter include much more resistant minerals. Quartz for example is especially resistant so that acidic rocks never disintegrate as completely as basic parent materials.

Soil mineral weathering has been studied for many decades, but most available information is only empirical in nature and can only be used for qualitative, not for quantitative predictions. Amongst the multitude of investigations on this topic two of the most common weathering sequences are discussed. For more details on this subject the reader is referred to Dixon and Weed (1989) and Dixon and Schulze (2002).

The mineral stability sequence of Goldisch is based on the concept that in an aqueous environment the least stable minerals (olivine-augite in the ferromagnesian group or Ca-plagioclases in the feldspar group) are the first to disappear and dissolve, while the most stable ones (muscovite, quartz) are the least to do (Table 1). In other words, the dominant presence of a mineral in the sequence reflects the relative weathering stage of the soil profile. Because the rate of dissolution depends largely on environmental properties the main drawback of this approach is that it does not consider the weathering conditions, and that no attention is paid to secondary minerals that are themselves sometimes weathering products of the preexisting primary minerals.

Ferromagnesian minerals		**Feldspar minerals**
Olivine		
↓		Calcic plagioclase
Augite		↓
↓		Calci-Alkalic plagioclase
		↓
Hornblende		Alkali-Calcic plagioclase
↓		↓
		Alkalic plagioclase
Biotite		
	↓ ↓	

	Potash feldspar	
	↓	
	Muscovite	
	↓	
	Quartz	

Table 1. Mineral stability sequence of Goldisch (in Rai and Kittrick, 1989).

The second approach refers to the weathering sequence of Jackson and Sherman. Here the relative degree of soil development is associated with the minerals present in the clay fraction (Table 2). In this approach the focus is on the relative resistance to weathering of primary minerals in a continuous leaching environment, and on the type of clay mineral that is derived from such weathering. It comprises 13 stages represented from the weakest (gypsum) to the most resistant compound (TiO_2 or anatase) in the sequence displayed in Table 2. The colloidal fraction of the soil usually consists of 3-5 minerals of the sequence, one or two of them being dominant and others being adjacent. Moreover, the percentage of minerals of the early stages of the weathering sequence decreases with increasing intensity, whereas those of succeeding members increases.

Relative degree of development	**Prominent minerals in soil clay fraction**
1	Gypsum, and other soluble salts
2	Calcite, dolomite and apatite
3	Olivine-hornblende minerals
4	Biotite, glauconite, ferromagnesian chlorite
5	Feldspars
6	Quartz
7	Muscovite-illite
8	Interstratified 2:1 layer silicates and vermiculite
9	Montmorillonite
10	Kaolinite and halloysite
11	Gibbsite and allophone
12	Hematite-goethite
13	Anatase-leucoxene

Table 2. Types of minerals as indicators for the relative degree of development (the higher the number the higher the degree of development), according to Jackson and Sherman (in Rai and Kittrick, 1989).

Though the concept of this weathering sequence seems to be sound, it has been criticized for not making a difference between primary and secondary (newly formed) minerals. In the case of calcite for example, it is of real importance to know whether this mineral occurs as an original rock building component, or as a result from secondary crystallization of $CaCO_3$. In the latter case this would mean that calcium was previously leached from primary soil forming minerals (for example calcic plagioclase), and later re-deposited by an evaporating soil solution. This objection holds also for quartz versus crystoballite and for muscovite versus illite (see also: *Soil Mineralogy*).

As a result of aggressive chemical reactions the rock material is disintegrated and weathers into a loose material, leaving the unaltered rock at several meters depth. The contact zone between the unaltered rock and the loose soil material is called the *saprolite* and has a characteristic flecked, multi-colored aspect (Photo 1). This transition layer usually includes traces of the underlying rock structure and/or partly weathered rock fragments. The nature and intensity of the flecks are variable and depend mainly on parent rock characteristics. The white colors can generally be associated with micas (or feldspars) that have been transformed into kaolinite or halloysite. The depth at which the *saprolite* occurs is a good indicator of the weathering stage of the soil.

Photo 1. Saprolite

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Biographical Sketch

Willy Verheye is an Emeritus Research Director at the National Science Foundation, Flanders, and a former Professor in the Geography Department, University of Ghent, Belgium. He holds an MSc. Degree in Physical Geography (1961), a PhD. in soil science (1970) and a Post-Doctoral Degree in soil science and land use planning (1980).

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