CLIMATES, SOILS, AND AGRICULTURE IN THE TROPICAL REGION

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ABSTRACT: The tropical region can be geographically defined, using latitudinal delimitation, as that part of the earth located between the Tropic of Cancer and the Tropic of Capricorn, comprising 38% of the Earth's land surface. A total of 124 countries and territories are entirely or for the most part in the tropical region. On the other hand, the boundaries of the tropics are defined by climatologists commonly based on surface temperature and precipitation patterns. Hence, the estimated boundaries of the tropics can extend further from the equator than the latitudinal delimitation and the tropical zone spreads across the less well-defined subtropical zone. In this chapter, descriptions of the main climates and soils and a summary of the agricultural activities in the tropical region are presented in an integrated way, taken into consideration that the geographical delimitation is inexact at the boundaries. A global perspective is adopted and climate change is considered.

KEYWORDS: tropics, environment, soil properties, meteorological conditions, climate change.

CLIMAS, SOLOS E AGRICULTURA NA REGIÃO TROPICAL

RESUMO: A região tropical pode ser definida geograficamente, utilizando a delimitação latitudinal, como a parte da terra situada entre o Trópico de Câncer e o Trópico de Capricórnio, compreendendo 38% da superfície terrestre. Um total de 124 países e territórios estão inteiramente ou na sua maior parte na região tropical. Por outro lado, os limites dos trópicos são definidos pelos climatologistas geralmente com base em padrões de temperatura da superfície e de precipitação. Assim, os limites estimados dos trópicos podem estender-se mais longe do equador do que a delimitação latitudinal, e a zona tropical estende-se através da zona subtropical menos bem definida. Neste capítulo, descrições dos principais

climas e solos e um resumo das atividades agrícolas predominantes na região tropical são apresentados de maneira integrada, levando em consideração que a delimitação geográfica é inexata nos limites. Uma perspectiva global é adotada e as mudanças climáticas são consideradas.

PALAVRAS-CHAVE: trópicos, ambiente, propriedades do solo, condições meteorológicas, mudança do clima.

1 I INTRODUCTION

The tropical region can be geographically defined as that part of the earth located between 23°28' north and south of the equator, representing the region between the Tropic of Cancer and the Tropic of Capricorn – **Figure 1**.

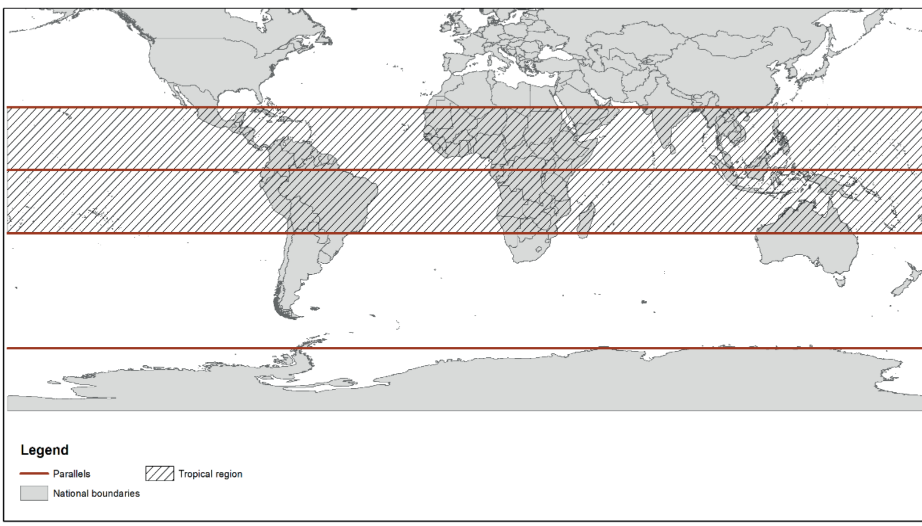

Figure 1 – Tropical geographic region (latitudinal delimitation). Data source: National Boundaries from GADM (2018). Prepared by the authors.

According to this latitudinal delimitation, the tropical region comprise 38% of the Earth's land surface, approximately 5 billion hectares, and 50% of the world's population, about 3.6 billion people in 2013. The tropical geographic region (latitudinal delimitation) encompasses the entire region of Southeast Asia, Central America, the islands in the South Pacific, the Caribbean Basin, a major part of Africa, most of South America, a large portion of the Indian subcontinent, and a small part of northern Australia. About half of the tropics are in Africa, 35% in Latin America, and 16% in Asia and Oceania. A total of 124 countries and territories are entirely or for the most part in the tropical region. Countries with considerable land area in the tropics are listed in **Table 1**.

Tropical Africa	Tropical America	Tropical Asia and Oceania
Angola	Bolivia	Australia (Northern)
Cameroon	Brazil	Bangladesh (Southern)
Central African Republic	Colombia	Cambodia
Congo	Costa Rica	China (Guangzhou, Southern)
Ethiopia	Cuba	Indonesia
Ghana	Dominican Republic	Malaysia
Ivory Coast	Ecuador	Myanmar
Kenya	Guatemala	Oman
Mali	Honduras	Papua New Guinea
Mozambique	Jamaica	Philippines
Nigeria	Mexico (Southern)	Saudi Arabia
Somalia	Nicaragua	Sri Lanka
Sudan	Panama	Thailand
Tanzania	Paraguay (Northern)	Vietnam
Zambia	Peru	Yemen
Zimbabwe	Puerto Rico	
	Venezuela	

Adapted from Racke et al. (1997).

Table 1 – Countries with considerable land area in the tropical region.

Climatologists use different indicators to define the boundaries of the tropics, commonly based on surface temperature and precipitation patterns (SEIDEL and RANGEL, 2007) and the estimated boundaries of the tropics can extend further from the equator than the latitudinal delimitation. The tropical zone extends across the less well-defined subtropical zone, which is the climatic region found adjacent to the tropics, usually between latitudes 20^0 and 35^0 in both hemispheres, but occasionally found at slightly higher latitudes (ISAAC and TURTON, 2014).

The geographical delimitation is inexact at the boundaries because changes in climate conditions and soil types are gradual. Thus, there is no true dividing line between tropical and temperate zones, and intermediate areas are often referred to as subtropical. Geographically, the subtropical regions cover the latitudes between 23°26′11.6″ and approximately 35° in the northern hemisphere and in the southern hemisphere. Hence, parts of southern Brazil, southern Australia, southern South Africa, northern India, northern Bangladesh, and northern Mexico, outside of the tropical geographic region, are included.

Knowing the environment is fundamental for sustainable development. Hence, in this chapter, descriptions of the distinguished climates and soils in the tropical region, as well as aspects of the agricultural activities in the region, are summarized and integrated. A global perspective is adopted and climate change is considered.

2 I CLIMATES IN THE TROPICS

Climate and natural vegetation in the tropical region are closely related and the main classification systems of climates in the region employ vegetation names for the different climatic zones. Natural tropical vegetation can be grouped into the five general categories: savannas (43% of the area), moist tropical forests (30%), deciduous and thorn forests (22%), desert shrubs and scattered grasses (7%), and no vegetation (5%). Thus, most of the tropics are not covered by rainforests, as commonly assumed. Savannas are the most extensive type of tropical vegetation. It is worth mentioning that, as for climate, natural vegetation zones do not end abruptly. There is usually a transition, a combination of vegetation types and, in many instances, they form complex mosaics in the landscape (SCHOLES and WALKER, 1993).

Climate regimes in the tropical region typically present much less seasonal temperature variation. Hence, in the tropics, the mean monthly surface air temperature variation is 6°C or less between the average of the summer (3 warmest months) and the winter (3 coldest months). The daily variation is also generally within this range (SANCHEZ, 2019). This includes the hot lowlands as well as the cold highlands in the tropical region. Distributions of annual temperature and annual precipitation in the world are presented, respectively, in **Figure 2** and **Figure 3**.

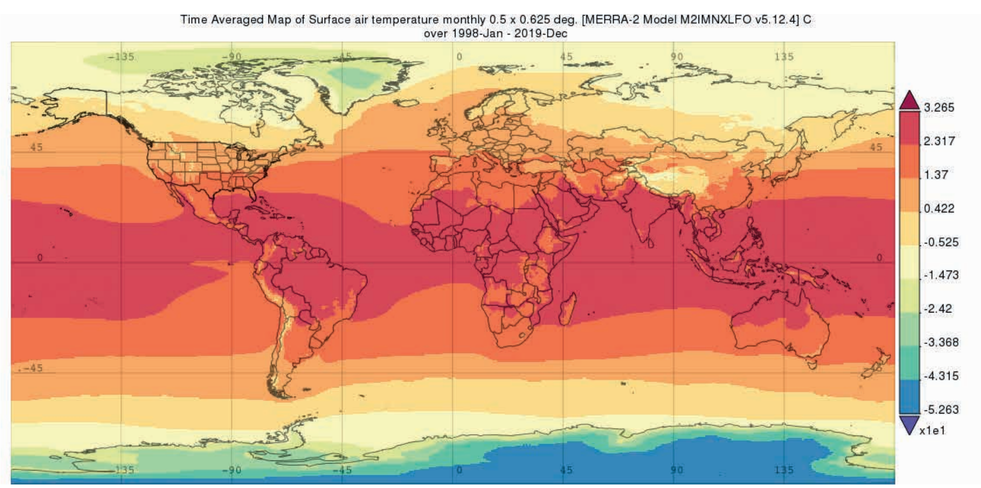

Figure 2 – Annual average temperature distribution in the world. Data source: TRMM (2011). Prepared by the authors.

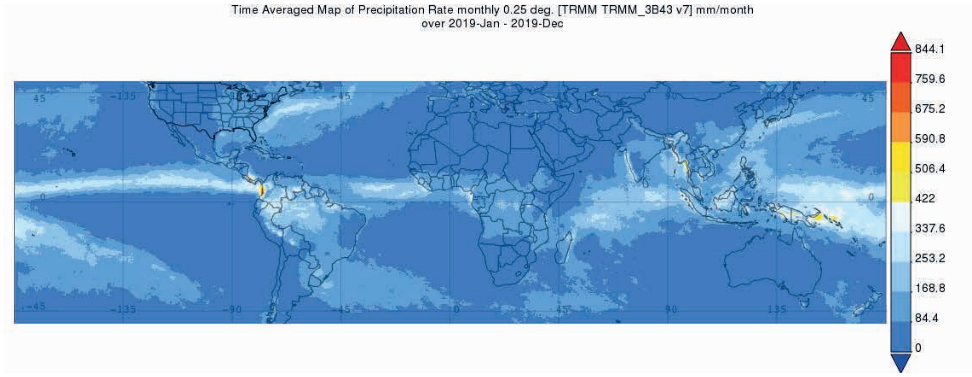

Figure 3 – Annual average precipitation distribution in the world. Data source: GMAO (2015). Prepared by the authors.

The least temperature variation occurs in latitudes within 6 degrees of the equator. As latitude increases, diurnal and seasonal air temperature variations also increase, reaching maximum values in the desert areas near the tropic of Cancer. The widest temperature variation is found in inland areas with the least rainfall in those areas (SANCHEZ, 2019).

Mean air temperatures generally decrease by 0.6°C for every 100-meter increase in elevation in the tropics. According to Juo and Franzluebbers (2003), mean annual temperature at sea level in the tropical region is about 26°C and can be even below 20°C in tropical highlands (altitude above 900 m).

As temperature is relatively uniform, rainfall distribution is the main criterion used to classify tropical climates. Rainfall in the tropics is driven by complex circulation patterns and weather disturbances. The main pattern is the movement of the Intertropical Convergence Zone (ITCZ) and the main disturbances are the El Niño Southern Oscillation and tropical cyclones (SANCHEZ, 2019).

Rainfall in the tropical region also varies with altitude and with the distance from the coast (JUO and FRANZLUEBBERS, 2003). The rainfall amount has a range from 1,500 to 10,000 mm per year, and the net recharge, also known as leaching rainfall, can reach 3,000 mm per year (KAUFFMAN et al, 1998; JUO and FRANZLUEBBERS, 2003; GMAO, 2015).

Based on elevation, the tropics may be further divided into: (1) lowland tropics – areas below 600 m, (2) midaltitude tropics – areas between 600 m and 900 m, and (3) high-altitude tropics or tropical highlands – areas above 900 m (JUO and FRANZLUEBBERS, 2003). Local variation in topography, rainfall, wind direction, and other factors change these relationships.

Approximately 77% of the land mass can be classified as lowland and midaltitude tropics, with elevations below 900 m. Climates in the lowland and midaltitude tropics generally share three common features: a year-round warm temperature, rainfall of high intensity (large volume and short duration), and a high rate of evaporation.

Tropical highlands account for 23% of the tropics. In 20% of the tropics, altitudes range from 900 m to 1800 m, whereas about 3% of elevations in the tropics exceed 1800 m, which can be found in the Andes of Central and South America, the East African Highlands, and parts of Southeast Asia. In tropical highlands, mild temperatures occur throughout the year, with a mean annual temperature of 20°C or lower. Rainfall on tropical highlands can be extremely variable within a short distance. Because of the year-round comfortable temperature, areas of tropical highlands with favorable rainfall and fertile soils are usually densely populated and hence intensively cultivated (JUO and FRANZLUEBBERS, 2003).

Most approaches that have been used to classify climates in the tropics are based on the original classification of Köppen and Geiger (1936), updated by Rodenwaldt and Jusatz (1963) and Kotteck et al. (2006). Four main tropical climates, based on the length of the rainy seasons, namely, rainy climates (Af, Am), seasonal climates (Aw), dry climates (Bsh), and deserts (BW), are presented in **Table 2** and **Table 3**.

Climate	Köppen-Geiger Classification	Natural Vegetation	Area in the Tropics	
			Mha	%
Humid tropics	Rainy climates (Af, Am)	Humid tropical forests	1191	24
Subhumid tropics	Seasonal climates (Aw)	Savannas, deciduous forest or woodlands	2430	49
Semiarid tropics	Dry climates (BSh)	Shrubs and trees with discontinuous grass cover	771	16
Arid tropics	Desert (BW)	Deserts	558	11

Table 2 – Distribution of major climates in the tropics and relationships with natural vegetation.

Adapted by Sanchez (2019) from Köppen and Geiger (1936) and Rodenwaldt and Jusatz (1963). Mha stands for million hectares.

Such climates occur at almost all elevations in the tropics and their associated natural vegetation types are indicated in **Table 2**. The geographical distribution of these climates is shown in **Figure 4**.

Climate	Tropical Africa		Tropical America		Tropical Asia and Oceania	
	Area (Mha)	Main Areas	Area (Mha)	Main Areas	Area (Mha)	Main Areas
Humid tropics	197	Congo forest, New Guinea, parts of coastal West Africa, eastern Madagascar	646	Amazon Basin, Atlantic coast of Central America, Atlantic coast of Brazil, Pacific coast of Colombia	348	Most of Indonesia, Malaysia, many Pacific islands, Philippines
Subhumid or wet-dry tropics	1144	Most of the continent south of Sahel and north of Kalahari Desert (except the humid Congo Basin)	802	Cerrado of Brazil, Llanos of Colombia and Venezuela, eastern Amazonia, Pacific coast of Central America and Mexico, most of Cuba	484	Most of India, mainland Southeast Asia, a belt in Northern Australia
Semiarid tropics	486	Part of Sahel, parts of East, Southern Africa	84	Much of Mexico, Northeast Brazil	201	Parts of India, most of Northern Australia
Arid tropics	304	Kalahari Desert, Horn of Africa, parts of Sahara Desert, narrow coastal area in Namibia	25	Narrow coastal desert in Peru	229	Arabian Peninsula, Australian Desert
Tropical highlands[1]	N[A]2	Highlands are found in East Africa (Ethiopia, Kenya, Uganda, Rwanda, Burundi)	NA[2]	In the Andean region of South America (Peru and Bolivia) and the highlands of Central America (Mexico)	NA[2]	NA[2]

Table 3 – Main areas in different climates in the tropics.

Adapted from Sanchez (2019) and Juo and Franzluebbers (2003). [1]Elevation higher than 900 m above sea level.[2]Data or information not available. Mha stands for million hectares.

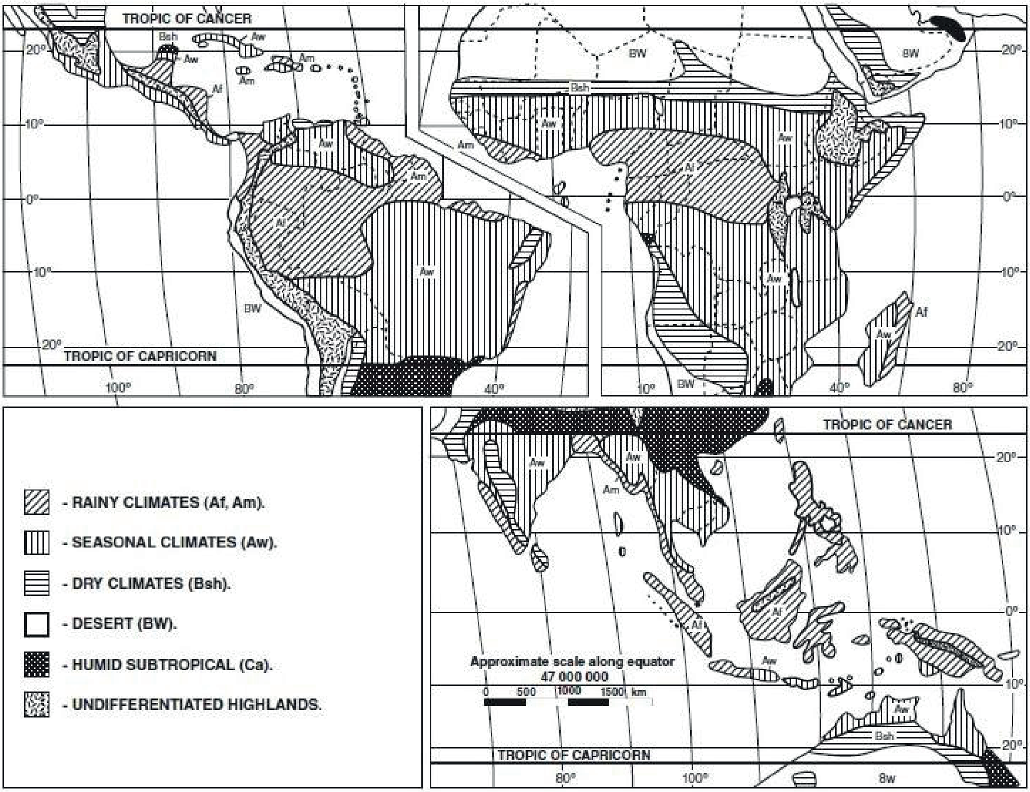

Figure 4 – Geographical distribution of climates in the tropical region. Adapted by Sanchez (2019) from Rodenwaldt and Jusatz (1963).

Simplified definitions of soil moisture regimes applied to the tropics, based on the moisture control section (SOIL SURVEY STAFF, 1999; 2014), and related climate are presented in **Table 4**. According to Sanchez (2019), the moisture control section roughly corresponds to depths of 10–30 cm for fine loamy, silty and clayey soils, 20–60 cm for coarse loamy soils, and 30–90 cm for sandy soils. The term 'dry' refers to soil moisture tensions at or above the wilting point of most plants.

Soil Moisture Regime	Consecutive Months per Year with Dry Soil Control Section	Related Climate
Udic	< 3	Humid tropics
Ustic	3 – 9	
Typic tropustic	3 – 6	Subhumid tropics
Aridic tropustic	6 – 9	Semiarid tropics
Aridic	> 9	Arid tropics
Aquic	Saturated with water long enough to cause oxygen depletion	

Table 4 – Simplified definitions of soil moisture regimes in the Soil Taxonomy system, as applied to the tropics*, with subdivisions, and related climate.

Adapted by Sanchez (2019) from Soil Survey Staff (1999, 2014), van Wambeke (1981, 1982, 1987) and van Wambeke and Newhall (1985). * 'iso' temperature regimes.

Rainy climates are the most common near the equator, in the low-pressure zone, with a short or none dry season in the humid tropics. They are characterized by large amounts of rainfall almost evenly distributed throughout the year, exceeding the potential evapotranspiration in most of the months. Rainy climates occur roughly in one-fourth of the tropics. As consequence of a misleading perception, the lowland humid tropics, typically hot and wet, are considered the tropical climate.

Moving away from the equator, the amount of rain tends to decrease, characterized by seasonality in rainfall distribution, with one or two distinct dry periods per year. Areas with classic monsoon climates are in this zone. The subhumid climate covers about half of the tropics. At latitudes higher than 5 degrees the subhumid tropics have one long dry season and one long rainy season. The subhumid tropics include the most agriculturally productive tropical areas of Latin America, Asia, and West Africa.

The semiarid tropics are characterized as drylands with one short, intense rainy season and a long-duration dry season. They cover about 16% of the tropics. In the semiarid tropics, flash floods occur, normally during heavy rains at the beginning of the rainy season when raindrops hit partially bare and often surface-sealed soils (SANCHEZ, 2019).

The tropical deserts, defined as those areas with sporadic rainfall, having two rainy months or less, cover about 11% of the tropics. When irrigated, many of the loamy or clayey soils are extremely productive.

The tropical highlands, because of its cool annual temperature and low rate of evaporation, are considered in a special climatic zone of the tropics (JUO and FRANZLUEBBERS, 2003). In highlands, there are considerable areas with humid tropical climates. Even near the equator, climates are pleasantly cool at 1000–2000 meters of altitude, where low but constant temperatures are typical (SANCHEZ, 2019).

3 I SOILS IN THE TROPICAL REGION

The two most extensively used natural soil classification systems are the World Reference Base for Soil Resources – WRB (BRIDGES et al., 1998; DECKERS et al., 1998; IUSS WORKING GROUP, 2014, 2015) and the Soil Taxonomy (SOIL SURVEY STAFF, 1999, 2014). One limitation of natural soil classification systems is that they quantify only inherent attributes, most of them located in the subsoil (SANCHEZ, 2019). Many important attributes of soil related to crop production, which occur mostly in the topsoil, are not considered in soil classification systems. In addition, agricultural practices change the soil physical, chemical and biological conditions.

The World Reference Base (WRB) was developed by an international collaboration coordinated by the IUSS Working Group. It replaced the FAO/UNESCO Legend for the Soil Map of the World as international standard and it is the international standard for soil classification system. The WRB map of world soil resources is available at 1:25.000.000 scale and the FAO/UNESCO soil map have larger cartographic scale (1:5.000.000). Cartographic scale (or map scale) is a measure of the degree of generalization and at large scales more details can be observed than at small scales.

The WRB reference groups of predominant soils in the tropical region, with main characteristics, and the approximate Soil Taxonomy equivalents are in **Table 5**. The WRB has two categories (reference groups and subgroups), that correspond to the order categories of Soil Taxonomy, but inadequately identify many suborders and great groups identified by soil moisture regimes in the Soil Taxonomy system. Most soil characteristics identified in the soil families of Soil Taxonomy are not identified by the WRB (SANCHEZ, 2019).

WRB Reference Soil Group	Main Characteristics	Approximate Soil Taxonomy Equivalents
Acrisols	Soils with a horizon of low activity clays (< 24 cmolc/kg of clay at pH 7) and base saturation of < 50 %, acid and nutrient poor.	Most Ultisols, kandic great groups
Arenosols	Deep, sandy soils featuring weak or no soil development. Mainly in the Sahel, Kalahari and Australia.	Psamments, sandy Haplustepts
Cambisols	Weakly to moderately developed soils.	Ustepts, Udepts.
Ferralsols	Deep, strongly weathered soils with chemically poor, but physically stable subsoil.	Oxisols (except Aquox)
Fluvisols	Young soils in alluvial deposits.	Fluvents
Gleysols	Soils temporarily or permanently wet near the surface.	Almost all "Aqu" suborders and subgroups
Leptosols	Very shallow soils over hard rock or gravel.	Some Orthents, Rendolls, lithic subgroups
Luvisols	Soils with subsurface accumulation of high-activity clays. Mainly in temperate zone.	Alfisols (in part)
Nitisols	Deep, dark red, clayey soils with an argillic horizon. Very fertile.	Rhodic or Eutric Ultisols and Alfisols
Regosols	Soils with very limited development.	Some Orthents
Vertisols	Heavy, cracking clayey soils.	Vertisols (all)

Table 5 – The World Reference Base (WRB) groups of predominant soils in the tropical region, with main characteristics, and the approximate Soil Taxonomy equivalents.

Assembled from Bridges et al. (1998) and Sanchez (2019). The key in IUSS Working Group on WRB (2014, 2015) and subsequent versions must be used for complete classification.

As pointed out by Driessen et al. (2001), major soils in the humid and subhumid tropics are mineral soils conditioned by wet climates (such as, Acrisols, Alisols, Ferralsols, Lixisols, Nitisols, Plinthosols). Normally clay soils are expected to present lower field capacity and lower hydraulic conductivity, but in tropical regions it is necessary to consider the influence of soil structure on the soil hydraulic properties, and not only texture data (OTTONI et al., 2019; TUREK et al., 2020).

According to Sartori et al. (2008), only texture is not enough to be adopted as criterion for hydrologic classification of some soils in the tropics. NRCS (2007) classifies clayey soils as group D or may be as group C (SARTORI et al., 2008), whereas clayey Ferralsols (or clayey Oxisols), as example, are classified into the groups A or B. Briefly, soils in the groups A and B have low to moderately runoff potential when thoroughly wet and water moves freely through the soil. On the other hand, soils in the groups C and D have moderate to high runoff potential when thoroughly wet and water movement through the soil is restricted or very restricted.

Soils present in the tropics also occur in the temperate region, but in different proportions. The most extensive soils in the tropical region, classified by Soil Taxonomy, are: Oxisols, Ultisols, Inceptisols, Entisols, Alfisols, Aridisols, and Vertisols – **Table 6**. Soils in these orders occupy around 97% of the tropical land area.

Soil Taxonomy Order	Area in the Tropical Region		Area in the Temperate Regions	
	(Mha)	(%)	(Mha)	(%)
Oxisols	962	24.8	19	0.4
Ultisols	760	19.6	341	7.3
Inceptisols	606	15.7	537	11.5
Entisols	603	15.6	1436	30.7
Alfisols	480	12.4	487	10.4
Aridisols	186	4.8	1163	24.6
Vertisols	150	3.9	160	3.5
Other soils	119	3.2	540	11.6
Total	3866	100	4684	100

Table 6 – Distribution of the main soil orders in the tropical and temperate regions, classified by the Soil Taxonomy system.

Adapted from Buol et al. (2011) and Sanchez (2019), based on Soil Survey Staff (1999, 2014). Tropics: 0° – 23°28'; Temperate: 23°29' – 60° of latitude. Mha stands for million hectares.

Areas with Oxisols and Ultisols are remarkably larger in the tropics than in the non-tropical regions. Oxisols are the most extensive soil order in the tropical region, covering approximately 962 million hectares (close to 25%) of the tropical land area. About 98% of areas with Oxisols in the world are in the tropics – **Table 7**. Most of the Oxisols, except wet Oxisols (Aquox), correspond to the Ferralsols in the WRB system.

Soil Taxonomy Order	Area in the Tropical Region		Area in the Non-Tropical Regions		Area in the World
	(Mha)	(%)	(Mha)	(%)	(Mha)
Oxisols	962	98.1	19	1.9	981
Ultisols	760	69.0	342	31.0	1102
Inceptisols	606	47.5	669	52.5	1275
Entisols	603	28.5	1510	71.5	2113
Alfisols	480	38.0	783	62.0	1263
Aridisols	186	11.8	1392	88.2	1578
Vertisols	150	47.0	169	53.0	319
Other soils	119	4.6	2485	95.4	2604
Total	3866	34.4	7369	65.6	11235

Table 7 – Distribution of the main soil orders between the tropical and non-tropical regions, classified by the Soil Taxonomy system.

Adapted from Buol et al. (2011) and Sanchez (2019), based on Soil Survey Staff (1999, 2014). Tropics: 0°– 23°28' of latitude; Extratropical: latitudes higher than 23°29' (temperate and boreal regions).

Ultisols occupy around 760 million hectares (almost 20%) of the land area in the tropics (**Table 6**), and 69% of areas where they occur in the world are in the tropical region (**Table 7**). Many Ultisols with udic and ustic soil moisture regime are classified as Acrisols in the WRB system.

4 I TROPICAL AGRICULTURE

Over the centuries, agricultural activities, initially in fertile areas along the banks of large rivers, occupied areas with good distribution of rain and with fertile soils. With the development of irrigation systems, from the simplest, as flooding in rice growing areas, to complex systems used in fruit crops in semiarid regions, agriculture reached the current distribution, occupying a total of 1.87 billion hectares of croplands in the world, roughly 12.6% of the global terrestrial area (THENKABAIL et al., 2012; TELUGUNTLA et al., 2015).

The economies of most countries in the tropical region are based on agriculture, defined in its broad sense to encompass crops, livestock, forestry, fisheries, and resource management of agricultural landscapes (SANCHEZ, 2019). The tropical region has provided in abundance a wide range of agricultural products for the world population (JUO and FRANZLUEBBERS, 2003).

As pointed out by Juo and Franzluebbers (2003), there are many images of agriculture in the tropics: the cash and tree crop plantations on the rich volcanic soils in Latin America and the Pacific Islands, the rice paddies on the fertile alluvial soils in tropical Asia, the savanna grasslands in sub-Saharan Africa, and the slash-and-burn farming throughout the humid tropics. Thus, as noted by Sanchez (2019), agriculture in the tropical region is not homogeneous and, as illustrated by the author, "within short distances one can observe large sugar cane plantations being harvested by large machines, minute and carefully hand tended paddy rice fields, and a wide array of trees and crops growing together on steep hillsides that are cleared by slash and burn".

In most tropical region, the growing season of crops is defined by the number of humid months, when rainfall exceeds evapotranspiration, within a year, even though these climatic divisions are somewhat arbitrary in view of high variability in rainfall and evaporative demand (JUO and FRANZLUEBBERS, 2003).

Juo and Franzluebbers (2003) summarized agricultural features of climatic zones in the tropics:

- In the humid tropics, cops grown are those well adapted to the continuous hot and humid conditions and not requiring a pronounced dry season for harvesting. Common food crops include plantain or starchy banana and a variety of root crops including cassava, taros, and sweet potato. Major commercial tree crops cultivated in the humid tropics are rubber and oil palm. Rice is widely grown in irrigated lowlands with fertile soils in tropical Asia. Because of the lack of a distinct dry season and heavy insect and disease pressure, corn and beans, grown in per-humid regions, are usually harvested and consumed before reaching maturity. From both ecological and economic viewpoints, destroying large areas of tropical forests to make way for cattle ranching is perhaps the least desirable farming system in the humid tropics.

- In the subhumid tropics, there are large farms that use high technology to produce mainly soybean, wheat, and corn. Where a pronounced dry season occurs yearly, grain crops such as corn and beans are well suited to wetter areas, whereas sorghum, cotton, cowpea, peanut, and other pulse crops are better suited to drier areas. Root crops such as cassava, sweet potato, yams, and starchy banana or plantain are also commonly cultivated in the wetter areas. Cacao is a common tree crop grown on less acidic and more fertile soils in wetter areas, whereas oil palm and rubber plantations are commonly found on the more acidic soils in higher rainfall areas. Irrigated lowland rice is a common food crop grown mainly in the lowland areas of tropical Asia. In Africa and Central and South America, open grasslands with scattered trees cover large areas under the drier end of the rainfall regime. The establishment of temporary pasture is feasible as it can survive the dry season and carry some livestock through it.

- In the semiarid tropics, rainfed agriculture (that relies on rainfall for water, with no irrigation) is restricted to areas where the low total annual rainfall occurs in a monomodal pattern (with no alternation of humid and dry months within the wet season), such as the Sahel region of West Africa. Common food crops include millet, peanut, cowpea, and pigeon pea. Sorghum and cotton are cultivated in wetter areas. Nomadic cattle herding has been a prevailing farming system in the semiarid tropics of Africa.

- In the arid tropics, nomadic herding is the dominant traditional farming activity. Food crop farming is restricted to small inland valleys, where runoff water from the upper slopes is collected at the valley bottom for crop cultivation. Crops in small inland valleys are also irrigated with well water where groundwater is available.

- The tropical highlands are grouped as a special climatic region of the tropics, because of its cool annual temperature and low rate of evaporation. Tropical highlands, particularly areas with adequate rainfall and fertile volcanic soils, are among the most densely populated and intensively cultivated areas of the tropics. Potato and beans are the main food crops in the Andes highlands; whereas corn and beans are widely grown in the tropical highlands of Central America and East Africa. Highland coffee, originated in the tropical highlands of Ethiopia, is an important cash crop cultivated in this region. The cooler temperature regime is also better suited for a wide range of leafy vegetable crops.

Juo and Franzluebbers (2003) highlighted that technological advancement and economic expansion have brought many changes and the large commercial tree and cash crop plantations and cattle ranches are significant new farming systems developed in the tropics. The authors mentioned that high-input management strategies are used on large tree and cash crop plantations. As examples, large coffee plantations are found in Brazil, Colombia, El Salvador, and Kenya; sugarcane estates in Brazil, Philippines, Hawaii, and Caribbean Islands; tea plantations in India, Sri Lanka, and Kenya; banana estates in Honduras, Cameroon, and the Ivory Coast; oil palm estates in Malaysia, Indonesia, Nigeria and Ivory Coast; cacao plantations in Nigeria, Ghana, and the Ivory Coast; coconut estates in Malaysia, Indonesia, India, Sri Lanka, and Philippines; rubber estates in Malaysia, Sri Lanka, and Indonesia; and sisal estates in East Africa and Madagascar.

5 I FINAL CONSIDERATIONS

As it is in the rest of the world, the climate is changing in the tropics (IPCC, 2013), despite the less obvious changes, because of the considerable natural variability (CORLETT, 2014). It is noteworthy that there are evidences from long-term meteorological measurements that the tropical and subtropical zones are expanding poleward in both hemispheres (SEIDEL et al., 2008; IPCC, 2013; ISAAC and TURTON, 2014; LUCAS et al., 2014). As highlighted by Brevik (2012), soils are intricately linked to the atmospheric-climate system and altered climate affects soil processes and properties, and soils, in turn, have effects on climate. Agriculture is closely dependent on soil properties and weather conditions.

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