Chapter 1

Soil Ecoregions in Latin America

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INTRODUCTION

Large soil units generally reflect bioclimatic environments (the concept of zonal soils). Soil maps thus represent summary documents that integrate all environmental factors involved. The characteristics of soils represent the environmental factors that control the dynamics of soil organic matter (SOM) and determine both their accumulation and degradation. Soil maps thus represent a basis for quantitative studies on the accumulation processes of soil organic carbon (SOC) in soils in different spatial scales. From this point of view, however, and in particular if one is interested in general scales (large semicontinental regions), soil maps have several disadvantages.

First, most soil maps take into account the intrinsic factors of the soils, thus the end results of the formation processes, rather than the processes themselves. These processes are the factors that are directly related to environmental conditions, whereas the characteristics of the soils can be inherited (paleosols and paleoalterations) and might no longer be in equilibrium with the present environment.

Second, soils seldom are homogenous spatial entities. The soil cover is in reality a juxtaposition of several distinct soils that might differ to various degrees (from similar to highly contrasted), and might be either genetically linked or entirely disconnected. This spatial heterogeneity reflects the conditions in which the soils were formed and is expressed differently according to the substrates and the topography. The heterogeneity also depends on the duration of evolution of soils and the geomorphologic history, either regional or local, as well as on climatic gradients, which are particularly obvious in mountain areas. The heterogeneity is visually expressed in detailed maps and is implicit in medium-scale maps, as it is often taken into account in the definition of cartographic units. However, it is commonly masked in

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general maps, which might group territories with dissimilar characteristics within the same clusters. Thus, parameters that are linked to the environment and that could affect the dynamic of the SOM might not be apparent in soil maps.

It is thus necessary to consider the soils and the biophysical environment simultaneously and to supplement the data given by soil maps with information on the biophysical environment (climate, vegetation, landscape).

For this purpose it seems convenient to work with soil synthetic geographical entities that must be defined as a given combination of soil, climate, and vegetation within a specified physiographic (geologic, topographic, and geomorphologic) context.

An elementary landscape with its specific soils may repeat itself regularly, forming a large regular unit, as occurs in some wet tropical plains. But normally it changes because of the variation in the biophysical environment. The changes generate a definite spatial frame of the soils (Fridland, 1974). At a regional scale this frame is described in terms of soil macrostructure. Zonal macrostructures, horizontal in plains or vertical in mountains, result from gradual changes in the bioclimatic (climate and vegetation) environment. More complex spatial macrostructures are found when different types of landscapes are spatially ordered, as in hydrographic basins, or appear spatially disordered when they are strongly controlled by the lithology, for example.

On the basis of the study of soil associations and the soil spatial macroorganizations, using available soil maps and assessing the general biophysical characteristics of Latin America, there are a limited number of distinct soil regions, or "soil ecoregions."

This regionalization can facilitate the delineation of the soil C storage and help in the selection of representative sites for the study of the mechanisms of this storage.

CONTINENTAL PARAMETERS

Latin America represents more than one-eighth of the earth's land surface. It encompasses a great latitudinal span, with its broadest expanse within the tropical zone. It sprawls across 83 degrees of longitude, from 35°W at the northeastern coast of Brazil to 118°W at the California-Mexico border (Figure 1.1). Its latitudinal extent is 90 degrees, from 34°N at the California-Mexico border to 56°S at Cape Horn into the sub-Antarctic. The land area is about 20,000,000 km^2, under the jurisdiction of more than 45 countries (Figure 1.2). The region's 2000 population was estimated at 400 million people.

FIGURE 1.1. Geographic location of Latin America.

THE BIOPHYSICAL OR NATURAL ENVIRONMENT

Pattern of Landforms

A comprehensive description of the natural environment, especially the landforms and the geological history, together with an extended bibliography, can be found in SI-WWF-IUCN (2001). Only the most relevant issues will be presented here.

Latin America includes the South American continental plate, the southern portion of the North American plate, and the independent Caribbean plate. South America and North America were widely separated through most of their geological histories, and they became connected via the Isthmus of Panama during the Pleistocene period. The Antillean plate with its collection of islands formed only during the Cenozoic period.

The outstanding geological feature of South America is the Andes, which extends in a nearly straight line over 7,000 km from the north to the southern tip of the continent. The southern Andes are the oldest, with signif-

FIGURE 1.2. Countries of Latin America.

icant uplift already present in early Cenozoic times, prior to the Oligocene period. Most of the uplift of the central Andes was in the Miocene period or later, whereas most of the uplift of the northern portion of the cordillera occurred in the Plio-Pleistocene period. To the north the Andes become more complex, breaking into three separate cordilleras on the Ecuador-Colombia border.

Much of the rest of the South American continent consists of two great crystalline shields. The northeastern portion of the continent constitutes the Guayana shield, whereas much of Brazil south of Amazonia is underlain by the Brazilian shield. They consist of Precambrian igneous basement rocks overlain by ancient and much-eroded Precambrian sediments (Figure 1.3).

The Guayana region has been the most heavily eroded, with basement elevations mostly below 500 m interrupted by massive table mountains, rising to 2,000 or 2,500 m. The peak of the highest of these, Pico da Neblina on the Venezuela-Brazil border, reaches an altitude of 3,015 m and is the high-

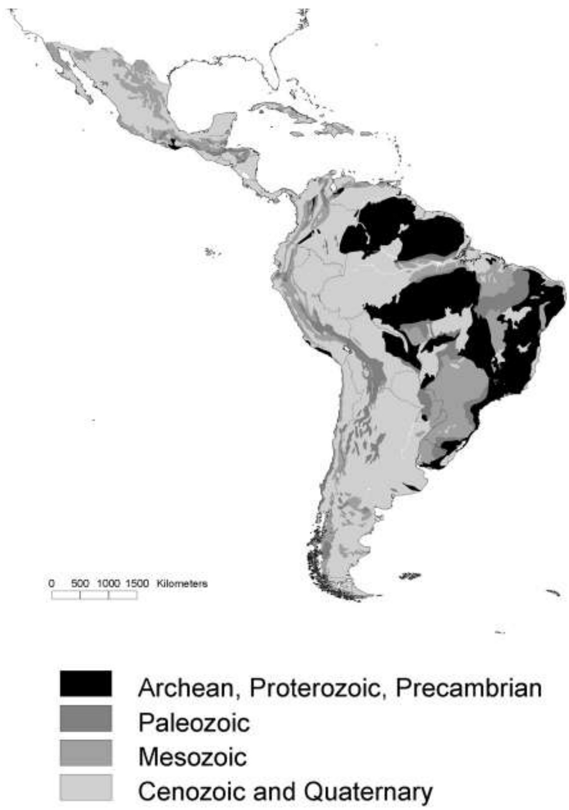

FIGURE 1.3. Geology of Latin America: General stratigraphy. (*Source:* Created from data compiled from CGMW-UNESCO, 2000.)

est point in South America outside the Andes. The Brazilian shield is generally higher and less dissected, with much of central Brazil having an elevation of 800 to 1,000 m.

In contrast to these ancient shields, the central Amazonian basin is low and geologically young. Prior to the Miocene period, most of Amazonia constituted a large inland sea opening to the Pacific. With uplift of the central Andes, this sea became a giant lake that gradually filled with Andean sediments. The region remains low and flat, such that Iquitos, Peru, is only 110 m above sea level and most of Amazonian Ecuador, Peru, and Bolivia are below 200 m in elevation.

Like Amazonia, some other distinctive geological features of the South American continent are relatively low, flat, and geologically young, such as the Chaco/Pantanal/Pampa region to the south, the Venezuelan-Colombian llanos to the north, and the trans-Andean Chocó region of Colombia and Ecuador to the west. Large portions of all of these regions are seasonally inundated.

Middle America is more complex geologically than South America. Toward south to central Nicaragua, Central America is an integral part of the North American continent. The region from southern Nicaragua to the Isthmus of Darién in Panama is geologically young and presents recent volcanism, uplift, and associated sedimentation.

Like South America, Middle America has a mountainous spine that breaks into separate cordilleras in the north. In general, the Middle American cordilleras are highest to the north in Mexico, and lowest in Panama to the southeast. In Mexico, the geology is complicated by a band of volcanoes that bisects the continent from east to west at the latitude of Mexico City.

In southern Central America, volcanism has been most intensive mainly in central Costa Rica and western Panama. The Yucatán Peninsula area of Mexico and Guatemala is a flat limestone formation more like the Greater Antilles than the mountainous terrain and volcanic soil of most of Middle America.

The Antillean islands constitute the third geologic unit of Latin America. The Antilles have a complex geological history. Some parts of the Greater Antilles island (Jamaica) are connected to Central America. Most of the Greater Antilles (Cuba, Hispaniola, Puerto Rico) has significant areas of serpentine and other ultra basic rocks. The Antilles have extensive areas of limestone. The Lesser Antilles are actively volcanic.

Major Physiographic Regions

Several major physiographic regions can be defined on the basis of terrain features, geological structure, hypsography, and watershed organization.

One broad region is composed of the Western steep-sided mountain ranges. It comprises Middle America, Central America, and the Andean cordilleras and includes the Middle America and Andean intermountain high plateaus (Figure 1.4).

Just to the east of the mountain ridge, much of the South American continent is a vast area of gentle relief. It can be divided into Guyana, central and eastern Brazilian and Patagonian uplands, and Orenoque, Amazon, and Paraná-Uruguay (or Plata) basin plains (Figure 1.5). Eastward, Central America and the Caribbean and Antillean islands constitute the last region.

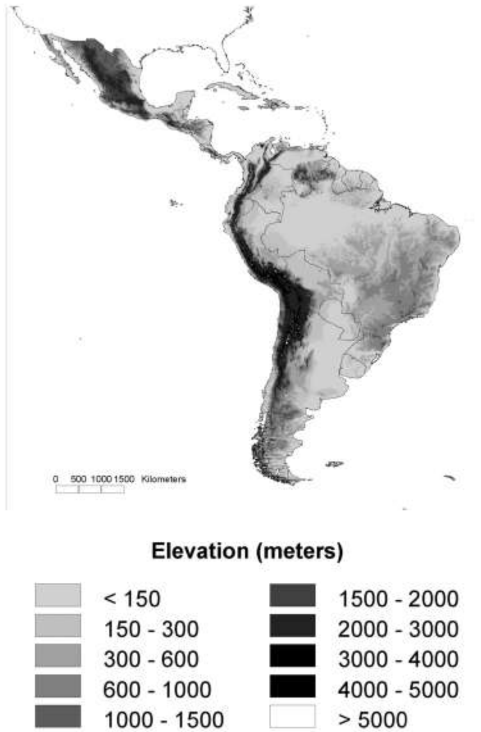

FIGURE 1.4. Hypsometry of Latin America. (*Source:* Created from data extracted from USGS, 1996.)

Glaciation

Pleistocene-Quaternary glaciations have affected only the southernmost part of the continent (Clapperton, 1993). Glacial, fluvio-glacial, and loess deposits, remains of the last glacial period, can be found on the foot slopes of the hills, the plateaus, and the low plains of the eastern side of the southern Andes (Figure 1.6).

Paleosoils

The South American inner lowlands and highlands, which have not undergone any quaternary glacial processes, exhibit a thick mantle of strongly weathered materials elaborated during the Cenozoic and Early Quaternary wet tropical climate periods (Tardy, 1997).

FIGURE 1.5. Hydrographic features of Latin America. (*Source:* Created from data extracted from ESRI, 1996, ArcAtlas database.)

The successive global long warm periods of the Cretaceous period and the warm and wet conditions of the Cenozoic period were periods of intense weathering. They produced thick saprolites and simultaneously strongly leveled the topography. Furthermore, periods of arid climate alternated with periods of wet climate. Consequently, episodes of erosion, transport, and deposition of the weathered materials followed periods of intense weathering and deepening of the profiles. The landscape resulting from such cyclic geomorphic evolution is typically a stepped landscape composed of ordered sequences of leveled land surfaces developed as well on residual saprolites as on transported continental sediments (Thomas, 1994).

FIGURE 1.6. Quaternary glacial and recent volcanic deposits. (*Source:* Created from data compiled from ESRI, 1996, ArcAtlas database.)

Two main features characterize the central and eastern parts of the South American continent: (1) remnants of the mid-Cenozoic summit surface, the South American surface (King, 1962), scattered throughout the whole zone and forming the highest plateaus, and (2) the "Barreiras formation" the Late Cenozoic-Pleistocene continental deposit that is the foundation of many coastal and inner low plateaus.

All the plateaus are uniformly covered by typical Ferralsols (or Latosol according Brazilian soil classification). The map of Ferralsols in Latin America (Figure 1.7) gives a good indication of the extent of the South American ancient landscape.

Climate

The climate of Latin America is controlled by two main factors: the latitude and the topographic patterns. North-south trends in climatic zones

FIGURE 1.7. Ferralsols in Latin America. (*Source:* Created from data compiled from FAO, 2001, SOTERLAC database.)

reflect the fundamental impact of the latitude. The Tropic of Cancer in Mexico and the Tropic of Capricorn define major thermal demarcations. Tropical climatic regimes span nearly the entirety of Latin America. Only in the southern part of South America is the climate cold. Temperatures decrease with increasing elevation, such that the tropical climate of the lowlands and lower slopes changes to subtropical and temperate climates at intermediate elevations of the Andes and the interior uplands, and finally to cold climate at the top of the mountain ridges. The barrier effect of the western cordilleras oriented N-S and ocean currents are other climatic controls with great regional importance, mainly on the annual rainfall amount and rainfall seasonal distribution (Figure 1.8).

The Köppen Climate Classification System is the most widely used system for classifying the world's climates. Its categories are based on the an-

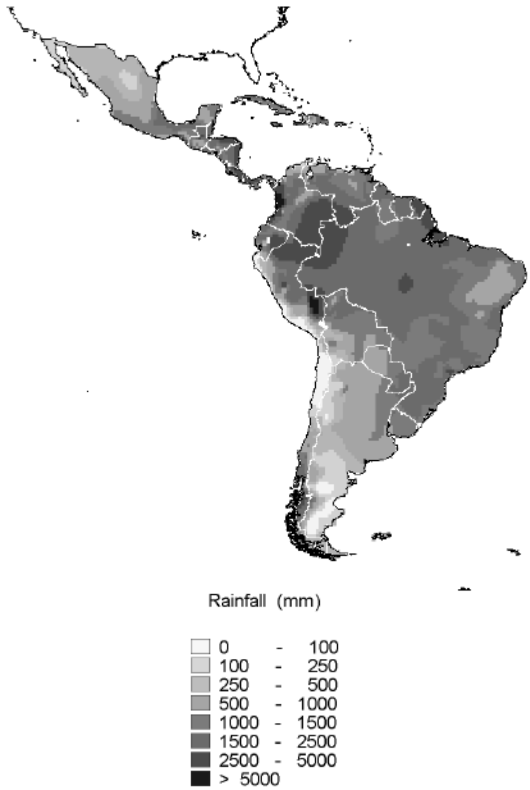

FIGURE 1.8. Annual rainfall in Latin America. (*Source:* Created from data extracted from FAO-SDRN, 1997.)

nual and monthly averages of temperature and precipitation. Each type is designated by a capital letter. Four major climatic types of the Köppen system are recognized in Latin America: (1) tropical moist climates (A) where all months have average temperatures above 18°C, (2) dry climates (B) with deficient precipitation during most of the year, (3) temperate (midlatitude) climates (C), and (4) polar climates (E) (Figure 1.9). A fifth category, the cold climate (D), has no significant area (FAO-SDRN, 1997).

Tropical moist climates (A) are controlled by equatorial and tropical air masses. They extend northward and southward from the equator to about 15 to 25° of latitude. All months have average temperatures greater than 18°C. Annual precipitation is greater than 1,500 mm. Three minor Köppen climate types exist in the A group, and their designation is based on seasonal distribution of rainfall.

FIGURE 1.9. Climates of Latin America (Koeppen types). (*Source:* Created from data extracted from FAO-SDRN, 1997.)

The tropical wet (Af) is a tropical climate where precipitation occurs all year round and total rainfall is 2,000 mm or greater. The monthly temperature averages vary from 24 to 30°C. It is the typical Amazonian climate (Figure 1.10a).

The tropical wet and dry climate (Aw) has a distinct dry season, with at least one month with precipitation <60 mm. The total rainfall is normally lower than in the Af type. It is the climate of the southwestern side of the Amazonian basin.

The tropical monsoon climate (Am) has an annual rainfall lower, equal to, or greater than Af. Most of the precipitation falls over seven to nine months. The seasonal pattern of moisture is due to the migration of the intertropical convergence zone. The wet season is synchronous with the high sun and the presence of the convergence zone. During the rainy season, the climate is warm and humid, similar to the tropical wet climate. During

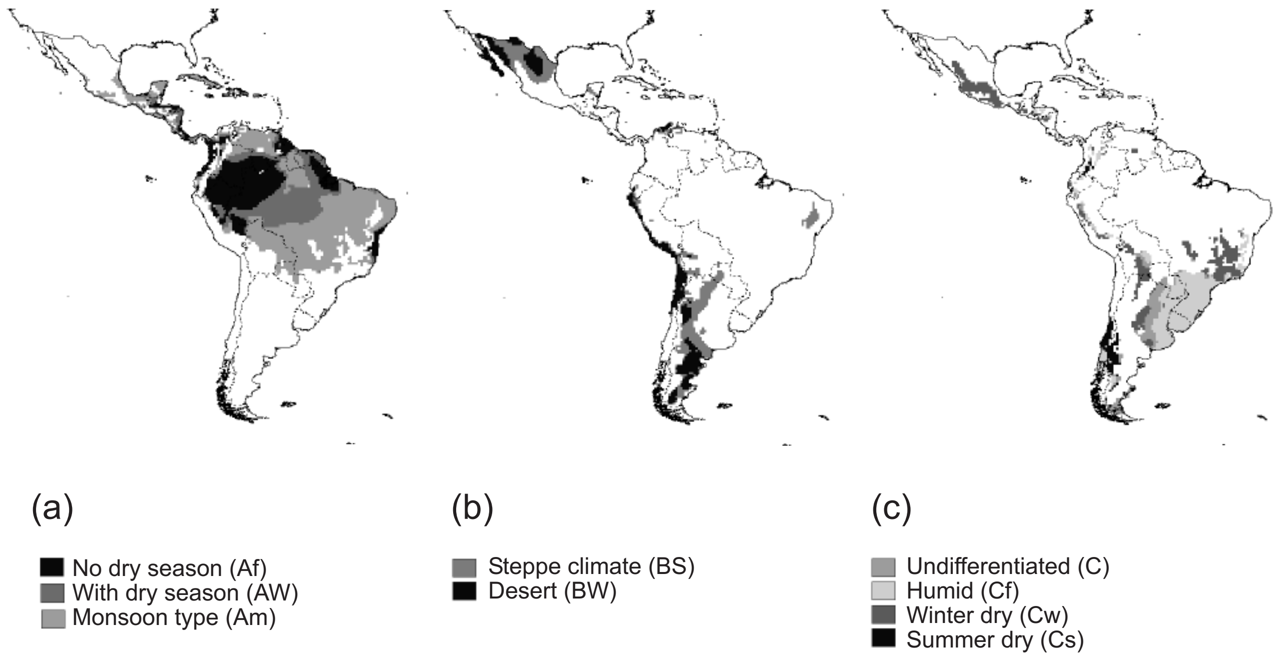

FIGURE 1.10. Climate subtypes: (a) tropical climate subtypes, (b) dry climate subtypes, (c) temperate climate subtypes. (*Source:* Created from data extracted from FAO-SDRN, 1997.)

the dry season very little rainfall occurs. It is the climate of central Brazil, northeastern Brazil, the coast of Venezuela, and central Mexico.

The dry climates (B) extend north and south of the equator and in large continental regions of the subtropics and midlatitudes. The most obvious feature of these climates is that annual evaporation exceeds annual precipitation. The two main subtypes are the dry semiarid climates (BS) and the dry arid climates (BW).

The dry semiarid climate (BS) is characterized by steppe vegetation. It receives more precipitation than the BW. With less rain, the steppe would be classified as an arid desert. With more rain, it would be classified as a tall-grass prairie. The semiarid steppe climates cover considerable parts of northern and western Mexico and western Argentina (Figure 1.10b).

The dry arid (BW) is a true desert climate. It is dominated by xerophytic vegetation. The dry tropical desert climate predominates in low-latitude deserts approximately between 18 to 28° in both hemispheres. It has major expanses in the east of the Andes and in narrow regions in southern South America (between 20°S and 30°S from the coastal desert of Atacama to the Argentine Chaco and Patagonia) and in northern Mexico where aridity is universal except at higher elevations.

The temperate climates (C) are mainly found between 30 to 50° latitude. They have a seasonal regime characterized by a cold or mild winter and a warm summer. The average temperature of the coldest month is <18°C and that of the warmest month is >10°C. They are generally moist climates with mean annual rainfall ranging from 500 to 5,000 mm, and have warm and humid summers with mild winters.

In the Cs type (Mediterranean climate) the summer is a dry season. Aridity may extend for up to five months. It rains primarily during the winter season. Locations in Latin America are California, central Chile, and central-western Argentina (Figure 1.10c).

In the Cw type winter is a dry season with at least ten times less precipitation in the driest month of winter than in the wettest month of summer. This climate type is centered on the tropics of Cancer and Capricorn. It coincides with the intermediate elevations of the highlands of central Mexico and central-eastern Brazil. It also occurs in central and northeastern Argentina.

The humid Cf type (humid subtropical climate) is characterized by at least 30 mm precipitation in the driest month, and the difference between the wettest and driest months is less than between Cw and Cs. It occurs mainly on the eastern border of the continent. The humid subtropical climate has hot humid summers and mild winters. It is located in southeastern Brazil-Uruguay-northeastern Argentina with annual precipitation ranging from 2,000 mm in Brazil to less than 1,000 mm in northern Argentina. It occasionally occurs in Central Mexico.

The polar climate (E), or subboreal, is the climate of the southeastern tip of the continent. The average temperature of the warmest month is greater than 10°C, while the coldest month is less than –30°C. It extends northward from southern Chile through most of the Andean highlands of Chile, Peru, and Colombia. On the southern part of South America it is wet, temperate-cold, and very cold at high elevations. Northward in mountains and Andean highlands, the general mean annual temperatures are between 3°C in the south and 6°C in the north, and mean annual precipitation varies, decreasing from west to east.

The Pattern of Natural Vegetation

Broad vegetation classes according Fedorova et al. (1993) and JRC (2000) were extracted from ArcAtlas data (ESRI, 1996). At the very broadest level the lowland vegetation types of South America may be summarized as follows:

I. Forest vegetation (Figure 1.11)
   A. *Evergreen forest* (or evergreen rain forest) in Amazonia, the coastal region of Brazil (from Bahia to Serra do Mar), the Choco and the lower Magdalena Valley, and along the Atlantic coast of Central America to Mexico;
   B. *Semideciduous forest* (or semievergreen rain forest) close to the same regions, mainly the Guayana shield in the Amazon region, and also along the Pacific side of Mexico and Central America. The semideciduous forest also comprises the Brazilian Atlantic forest ("Mata Atlantica") and the central Brazilian Forest ("Cerradão").
   C. *Deciduous forest* (or dry forest) extends in a discontinuous strip from northwestern Argentina to northeastern Brazil, encompassing Chaco, eastern Bolivia and Caatinga, northern Colombia and Venezuela, coastal Ecuador and adjacent Peru, central and western Mexico, with scattered smaller patches elsewhere (also the Mediterranean climate region of central Chile);

II. Nonforest vegetation (Figure 1.12)
   D. *Wet savanna* of the cerrado in central Brazil, the Llanos de Mojos and adjacent Pantanal of Bolivia and Brazil, the llanos of Colombia and Venezuela, and the Grand Sabana and Sipaliowini savanna in the Guyana region;

E. *Grassland* in the Pampas region of northeastern Argentina and adjacent Uruguay and southernmost Brazil;
F. *Desert and xeric shrubland* on northern Mexico, the dry Sechura and Atacama regions along the western coast of South America, and the Monte and Patagonian steppes of southeastern South America.

Montane formations occur along the Mexican-Central American cordillera system with subtropical coniferous and mixed forests, tropical and equatorial montane forests, and the Andean Cordillera with tropical and equatorial montane forests, subboreal forest in southern Chile, montane

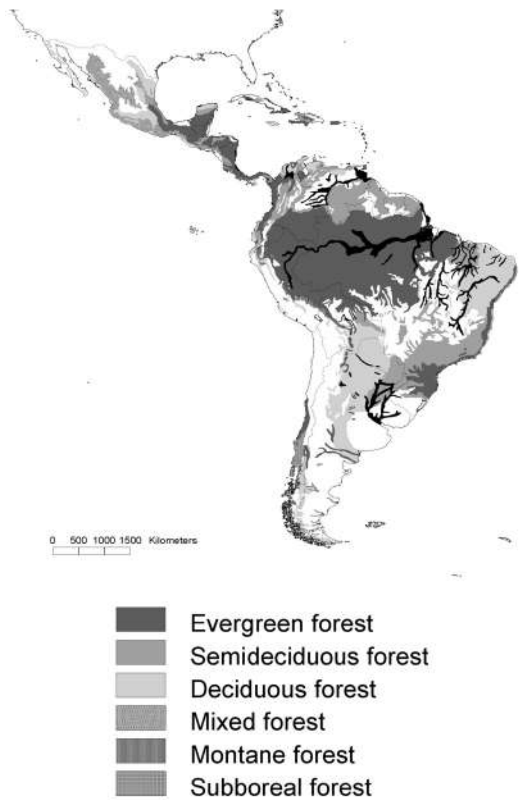

FIGURE 1.11. Forest vegetation in Latin America. (*Source:* Created from data compiled from ESRI, 1996, ArcAtlas database.)

FIGURE 1.12. Nonforest vegetation in Latin America. (*Source:* Created from data compiled from ESRI, 1996, ArcAtlas database.)

grasslands (Puna, Paramos), and in the tepuis of the Guayana highland region.

Detailed descriptions of these vegetal formations can be found in NSG-WWF-ESRI (2001).

Pattern of Soil

The sources of information are the published large-scale soil maps (1:1,000,000 to 1:5,000,000) synthesized on the SOTERLAC map (FAO, 2001). This map applies the Revised Legend FAO (FAO, 1990) founded on observable soil characteristics (diagnostic soil horizons). For the purpose of a broad generalization on the scale of the whole of Latin America, we have integrated the original soil units in larger units using genetic criteria (soil-forming conditions and processes) instead of diagnostic horizons as in the former soil classifications (Marbut, 1928; Baldwin et al., 1938; Aubert and

Duchaufour, 1956). The resulting distribution pattern is easier to understand and reflects better environmental relationships.

Classically, soils can be grouped into two broad categories: zonal soils directly related to the regional bioclimatic environment and azonal soils determined by local factors such as topography or the parent material.

Zonal soils are directly related to the broad bioclimatic zones. Five main zonal types are found in Latin America.

Ferrallitic Soils (Kaolinic Soils)

Ferralltic soils (Robinson, 1949) group. These are the Ferralsols (or Latosols), Acrisols, Lixisols, Plinthosols, Nitosols, and part of the Cambisols. Ferrallitic soils are formed under wet tropical conditions. The wet tropical climate promotes strong chemical weathering of rocks. Feldspars and ferromagnesian minerals are substituted by clay minerals, mainly kaolinite and sesquioxides, the sand content reflecting the content of coarse quartz in the original parent rock. After long periods of chemical weathering the "saprolite" (weathered rock) may extend down to a depth of more than ten meters. Ferrallitic soils are thoroughly weathered and extensively leached soils. They are red or yellow in color, deep, finely textured, contain no more than traces of weatherable minerals, strongly leached, and have low-activity clays. They are prevalent in large parts of the eastern South American Precambrian shields, the sedimentary plains comprising the Amazon basin, and Guyana's coast in regions with wet tropical climate. But they are also largely represented in tropical regions with a pronounced dry season, as well as in regions with subtropical warm climate or with semiarid climate (Figure 1.13). Many of these last soils were most likely formed under a previously more humid climate. Ferrallitic soils are also sparsely found in the mountain folded belts of Central America and the equatorial Andes and Central America,

Ferralsols occur on old, stable geomorphic surfaces, typically in level to undulating terrain. They are particularly well represented on old erosional or depositional surfaces in the Amazon Basin and central and eastern South America (Figure 1.7). They are found in the semiarid regions in northeastern Brazil, where they must be considered as fossil soils (Volkoff, 1985).

Acrisols and Lixisols are ferrallitic soils in which clay has washed out of an eluvial horizon down to an argic subsurface horizon that has low-activity clays. Acrisols have a low base saturation level. Lixisols have a moderate to high base saturation level. Acrisols and Lixisols are found together with Ferralsols, generally with Acrisols or Lixisols on slopes. In South America Acrisols are prevalent in the humid Amazon basin and southeastern coastal

FIGURE 1.13. Ferrallitic, fersiallitic, and siallitic soils in Latin America. (*Source:* Created from data compiled from FAO, 2001, SOTERLAC database.)

regions. Lixisols occur in their subhumid periphery, extending mainly into northeastern Brazil. On a continental scale there is no apparent zonality for Ferralsols, but there is a clear climatic zonality of Acrisols and Lixisols.

Elsewhere in regions with wet tropical climates Nitosols may occur on basic rocks, and Plinthosols are frequently related to depressional areas. In these regions the typical setting of ferrallitic Cambisols is on the eroding slopes of low hills and uplands and on the steeper slopes of mountain areas.

Fersiallitic Soils

These soils are considered to be zonal soils in subtropical climates (Botelho da Costa, 1959; Volkoff, 1998). Some fersiallitic soils are neutral or eutrophic soils, for example, ferric Luvisols in northern Brazil, while others are acidic, distrophic soils. Alisols represent the fersiallitic acid soils.

Neutral fersiallitic soils (ferric Luvisol) are common in warm subtropical regions with distinct dry and wet seasons (e.g., Mediterranean climate). In Latin America they occur on gently sloping young land surfaces. They are moderately weathered soils and have high-activity clay mineral (hydromica, smectite). They typically have a brown to dark brown surface horizon over brown to strongly brown or red subsurface horizon. Soft powdery lime may occur in the subsoil horizon in the drier climatic zones. They are usually associated with Cambisols. Neutral fersiallitic soils are found in central coastal Chile and northeastern Brazil.

Acid fersiallitic soils (Alisols) are formed on strongly but incompletely weathered materials, normally under moist subtropical climates. Secondary high-activity clays (vermiculite and smectite) dominate the clay complex. They are strongly acidic, red or brown-yellow in color, and they are most common in old land surfaces with a hilly or undulating topography in southeastern Brazil and on eroding steep slopes in the foothills of the Andes (Paraguay and western Amazon basin).

Siallitic Soils or Haplic Luvisols (Brown Soils)

They are soils of wet temperate climates and have a small extent. They occur in temperate central Argentina. Vertisols, commonly associated with siallitic soils, have a greater extension. They are found in Uruguay, southern Argentina, and northeastern Mexico (Figure 1.13).

Steppic Soils

Steppic soils are Phaeozem, Kastanozem, and Chernozem. They are associated with a semiarid climate and steppe vegetation, and are characterized by a thick, dark surface layer that is rich in organic matter and bases. Their agricultural potential is generally high. Phaeozems are soils of prairie regions and occur under subhumid conditions. They are dusky red soils with high base saturation. Kastanozems have a brownish surface layer and carbonate and/or gypsum accumulation at some depth. They occur in the driest parts of the steppe zone. Chernozems have a deep, very dark surface layer and carbonate enrichment in the subsoil. Steppic soils are the principal soils of Uruguay and northeastern Argentina.

Xeric Soils or Aridisols (Calcisols and Gypsisol)

These are mineral soils with low organic matter content. Redistribution of calcium carbonate and gypsum is an important mechanism of horizon differentiation in soils. They are associated primarily with arid climates. Calcisols are soils with secondary carbonate enrichment. Gypsisols are soils with a horizon of secondary gypsum enrichment. Xeric soils are extensively found in northern Mexico, central Argentina, and central Andean regions (northwestern Argentina and central Chile) (Figure 1.14).

The zonation of fersiallitic, steppic, and xeric soils is commonly north-south. It is independent of the main morphostructural units, which on a continental scale indicate the role of the climate and the vegetation in soil formation.

Azonal soils are divided in two groups: soils conditioned by the topography and those conditioned by the parent material.

Soils Conditioned by Topography

The soils conditioned by topography include (1) incompletely developed and eroded soils (Cambisols and Regosols), and (2) hydromorphic wetland

FIGURE 1.14. Arid soils in Latin America. (*Source:* Created from data compiled from FAO, 2001, SOTERLAC database.)

soils (hydromorphic soils, Solonetz, Planosols) and alluvial soils (Fluvisols). Cambisols occur predominantly at medium altitudes in hilly and mountainous regions under relatively moist climates. They are especially present in the wet tropical zone (Figure 1.15). Regosols occur in widely differing environments. They are very shallow soils over hard rock (Leptosols or Lithosols) or also deeper soils that are extremely gravelly and/or stony in unconsolidated materials and which have only surficial profile development (Regosols). They are particularly common in mountain regions and in arid regions (Figure 1.15). Fluvisols are soils developed in alluvial deposits along rivers and lakes, in deltaic areas. Hydromorphic soils (Gleysols) are soils of the wetland, of depression areas and low-landscape positions with shallow groundwater. Hydromorphic soils are associated with halomorphic soils with a high content of sodium and/or magnesium ions (Solonetz in semiarid, temperate, and subtropical regions; Solonchaks in arid and semiarid regions), and Planosols, soils with a degraded eluvial surface horizon lying abruptly over dense subsoil, mainly in subtropical and temperate

FIGURE 1.15. Cambisols and Regosols in Latin America. (*Source:* Created from data compiled from FAO, 2001, SOTERLAC database.)

and subhumid regions of southern Brazil, Paraguay, and Argentina (Figure 1.14).

Soils Conditioned by Parent Material

Arenosols are developed on sands (Figure 1.14), Andosols on weathered volcanic ash (also landscapes with fall of ash) (Figure 1.7), and Rendzina on soft limestone. Tropical Podzols, where leaching is the predominant soil-forming process, can be linked to the category of soils conditioned by sandy parent material. Some Vertisols are also directly related to sedimentary clay deposits.

SOIL REGIONS IN LATIN AMERICA

The broad geographic belts determined by climate and vegetation with specific types of genetic zonal soil are subdivided into soil regions. A soil region is defined by one or several soil associations and a distinctive spatial distribution of these soils. Soil associations and the spatial structures (macrostructures of the soil cover) are determined by the regional characteristics of the environment, including landscape, drainage pattern, and soil parent materials (bedrock, superficial sedimentary cover, present formed or inherited saprolites), and local variations of the vegetal cover.

Following Glazovskaya (1984), Latin America was divided into 13 regions (Figure 1.16).

Amazonian Region

This region constitutes the core of the South American continent. It lies on both sides of the equator, and on crystalline basement and sedimentary rocks. It matches approximately with the Amazon basin and a large part of the Orenoque basin. It is mainly a low plain. The central lowlands area is a broad sedimentary plain, composed of Cenozoic deposits, with altitudes below 200 m. The river valleys isolate a set of well-drained low plateaus. The bordering Guyana and Brazilian shields have a smooth, hilly relief. The altitude increases gradually toward the periphery of the region where, particularly in the Brazilian shield, the sloping hilly relief alternates with vestiges of perfectly leveled, old geomorphic surfaces. The only noticeable elevations are the Guyana highlands.

Within this extended area the climate ranges from wet tropical without a dry season to tropical monsoon. The evergreen forest, the Amazonian “rain forest,” covers most of the region. Wet savanna occurs in both the north and

FIGURE 1.16. Soil regions in Latin America. (*Source:* Adapted from Glazovskaya, 1984.)

the south. Colombian llanos were provisionally included in the region because of their climatic environment being similar to the Amazonian climate.

Ferrallitic soils are almost exclusive to the Amazonian region. Ferralsols are closely associated with Acrisols and predominate on the well-drained plateaus of the low plain and on the higher geomorphic surfaces. Plinthosols occur in the lower, poorly drained areas. Acrisols-Cambisols associations characterize the hilly areas.

At the scale of the total Amazonian region the distribution of the soil associations is determined by bioclimatic factors that infer a large zonal soil macrostructure. At a lower scale watershed-organized macrostructures prevail, as can be observed in the main secondary basins, for example in the Rio Negro, Tapajós, or Purús basins.

Andean Equatorial Region

It is predominantly a mountainous region following north from the equator to Colombia. The mountains rise above 5,000 m, the highest peaks being volcanoes. There are also leveled surfaces lying at 2,500 to 3,000 m. The climate is mainly wet tropical with very high annual precipitation in the northern Pacific coastal parts. The vegetation is the montane rain forest on the eastern Pacific and Caribbean-Colombian coasts, mountain semideciduous forests in the midaltitude zones, and montane grasslands ("paramo") on the high-mountain zones.

The region is mainly characterized by zonal mountain bioclimatic soil macrostructures. Specific macrostructures related to the volcanoes and to their present and past activity bring an additional soil pattern. It can be assimilated to a "volcanic macrostructure." Acrisols and ferrallic Cambisols are formed below 2,000 m, Cambisols on midaltitude zones, and Regosols and Leptosols on paramo above 3,000 to 4,000 m. Andosols are formed on the volcanic ashes that cover the steep slopes of volcanoes and some levelled high surfaces.

Central American Region

It comprises parts of Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. This region has a complex topography. In the north the transvolcanic belt is a large mountain range running from west to east in the central portion of Mexico. The Sierra Madre del Sur runs parallel to the Pacific coast in a northwestern direction. The Sierra Madre de Chiapas runs parallel to the Pacific coast. In southern Panama the elevation is less than 500 m. The Yucatan Peninsula is a relatively lowland region.

The climate is mainly wet tropical. In the south, rainfall ranges from about 2,500 mm per year in central Panama to over 5,000 mm per year in southern Nicaragua. In the north of the region the climate is wet temperate (subtropical). The maximum rainfall is in summer; the winter is dry. Annual precipitation is between 1,200 to 2,000 mm on the mountain slopes and 600 to 800 mm in the interior parts.

In the south and on the eastern mountains and plains the vegetation is an evergreen tropical forest. The ferrallitic soils predominate and include Acrisols and Nitosols. Regosols-Leptosols (Rendzina) are found on Yucatan limestone.

In the central, western, and northern parts, soils and vegetation vary widely both on the mountain slopes, according to their orientation, and on the intermontane plateaus and depressions. Vegetation ranges from montane evergreen forest to montane deciduous and mixed forests (pine-oak forests). Cambisols are found on the steeper slopes. Fersiallitic soils, which can be either neutral or acidic, are formed in the interior regions. Andosols are present on volcanic ashes, and basaltic lava is present on volcano slopes as well as on uplands and intermontane depressions.

The main soil spatial distribution pattern is zonal mountain bioclimatic with occurrence of volcanic macrostructures.

Brazilian Atlantic Region

This region is located between 7°S and 27°S. It covers the easternmost elevated (800 to 2,000 m) part of the Brazilian highland and its eastern slopes facing the Atlantic Ocean. The eastern slopes receive at least 1,500 mm per year of rainfall, with either a uniform precipitation distribution throughout the year or the occurrence of a short dry season.

It is divided into two subregions: the northeastern Brazilian soil subregion and the southeastern Parana soil subregion.

The northeastern Brazilian soil subregion extends from the Serra do Mar in Rio de Janeiro and Sao Paulo states to Bahia state along the Atlantic coast. The climate is typically wet tropical. The coastal forests are evergreen tropical forest. The evergreen forests are bordered westward through Minas Gerais and Bahia states, by semideciduous and deciduous forests (Bahia interior forest). The soil cover is mainly composed of Ferralsols and Acrisols.

The southeastern Parana soil subregion is located on a basalt plateau. The subregion has a humid temperate (subtropical) climate with no dry season. Plateaus are occupied by coniferous *Araucaria* forests with sparse areas of tallgrass prairie. Tropical evergreen forests are found along the river valleys. The *Araucarias* forest is bordered on the west by a semideciduous forest (Parana/Parnaiba semideciduous forest). The soil cover is composed of Alisols in association with Ferralsols on plateaus and Acrisols on the slopes.

The latitudinal zonality attributable to the climatic change from the north, tropical, to the south, and subtropical is partly masked by paleoclimatic influences. Most of the Ferralsols covering the inner and border plateaus are remnant of an ancient landscape that is probably not in equilibrium with the present bioclimatic environment. Geomorphology and lithology are the factors controlling the soil spatial patterns. Paleoclimatic and disordered lithologic soil macrostructures characterize this soil region.

Central Brazilian Region

The region represents the area of the Brazilian central plateau. The climate is typically tropical wet and dry. The dry period, which occurs from May through September or October, coincides with the coldest months of the year. The average annual rainfall varies between 1,250 and 2,000 mm, and the average annual temperature ranges between 20 and 26°C.

The Central Brazilian soil region is characterized by wet savanna vegetation (Campo cerrado) that is a woodland savanna. Areas of grassland (Campo limpo) and semideciduous forests occur within the cerrado.

Soils of this region are essentially ferrallitic soils. The main soil type is a Ferralsol that is very similar to the Ferralsol of the Amazonian region. They are strongly leached and have a stable microaggregate structure. Many soils have high contents of iron oxides, which accounts for the very low cation exchange capacity. Ferralsols are associated with Acrisols (Podzolico Vermelho Amarelo), and those of the Central Brazilian soil region have developed on old, highly weathered materials that are the result of a long weathering process probably initiated in the beginning of Cenozoic era. Ferralsols are found on extended residual plateaus, and Acrisols occupy the dissected lower areas between them. Soils associated with products of the weathering of basalts, basic rocks (dolerites), and sandstones are widespread. Dark red Ferralsols and Nitosols are found on basalts, mainly in the southern parts. Arenosols are distributed throughout the area. The soil spatial organization is controlled by geomorphology and lithology. Paleoclimatic and disordered lithologic macrostructures are characteristics of this soil region.

East Brazilian Region

This region occupies northeastern Brazil (Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Sergipe, Alagoas, Bahia, and northern Minas Gerais) on crystalline basement or on sedimentary deposits. It is a gently undulating plain whose continuity is broken by isolated plateaus, remnants of several geomorphic cyclic old surfaces.

Annual rainfall ranges from 250 to 1,000 mm, and the average annual temperature is between 24 and 26°C. The climate is tropical with five to six dry months. It is a dry climate (subarid dry climate) with 6 to 11 dry months in the interior regions.

The natural vegetation is a deciduous forest that ranges from dry tropical forest to “caatinga,” a shrubby sclerophyllous vegetation. A cerrado-like vegetation covers the residual plateaus of the region. The “agreste” is a deciduous forest along the coastal wetter areas. The soil cover is represented by several associations: fersiallitic soils, Regosols, Planosols on crystalline lowlands, ferrallitic soils (Lixisols) and Arenosols on sedimentary lowlands, and ferrallitic soils (Ferralsols and Lixisols) on residual plateaus. Soil cover pattern is characterize by paleoclimatic (Ferralsols covering the residual plateaus must be considered as Paleosols) and disordered lithologic macrostructures.

Paraguay-Preandean Region

This region extends meridionally between 15°S and 40°S and occupies mostly flat interior plains and foothills of the eastern slopes of the Andes. It encompasses the eastern lowlands of Bolivia situated at the southern limit of Amazonian forests (Chiquitano), the Pantanal located near the borders of Brazil, Bolivia, and Paraguay, the Chaco, east of the Andes in southeastern Bolivia, in the western and center of Paraguay, and northwestern and northeastern Argentina, the Córdoba Montane and "Pampa occidental," transitional vegetation to Monte in central and southern Argentina.

The annual precipitation in this region decreases from east to west and from north to south. The Chaco has a mean annual rainfall of 950 mm and is characterized by a strong dry season during the winter. The north and the east are characterized by a mean annual rainfall of 1,000 to 1,400 mm and by a strong dry season during the winter. At the southern and western boundaries the climate is dry (dry semiarid), with an annual rainfall of 350 to 650 mm, and an average temperature of 12 to 28°C.

At the limit of Amazonian forests, deciduous forest and wet savanna mark the transition to drier thorny scrub forests that extend farther south in the Chaco. In the east the vegetation is characteristic of deciduous xerophytic forests, palm groves, and grassy savannahs. In lower areas that are easily subject to flooding, there are grasslands and bogs. The Chaco vegetation consists of xerophile forests mixed with palm savannas. The forests are composed of quebracho colorado *(Schinopsis balansae)* and quebracho blanco *(Apidosperma quebracho-blanco).*

Three soil subregions can be distinguished: a northern gently undulating plain with ferrallitic soils; a central, leveled plain characterized by recent intracontinental sediments with fersiallitic and halomorphic soils; and a southern area frequently covered by loess with steppic soils.

The ferrallitic soils of the northern subregion are Ferralsols and Acrisols, most of which are Paleosols. The main soils of the central subregion are chromic Cambisols and chromic Luvisols grading to Phaeozems. They are associated with Solonetz and Gleysols. Soils of the southern subregion are predominantly typical Phaeozems. Regional soil cover is characterized by zonal, plain, bioclimatic macrostructure and watershed-organized macrostructure.

Caribbean Region

The region comprises a continental part, the northern plains of Venezuela, the northeastern Andes, and the islands of the Greater and Lesser Antilles.

The general climate is tropical wet and dry. The dry season, three to five months long, occurs between December and April. Total annual rainfall ranges from 1,000 to 1,600 mm. It is lower (300 to 1,000 mm per year) in the northeast Venezuelan coast, and higher on the southwestern slopes of the northeastern Andes (2,500 mm per year). The mean annual temperature is 27°C.

The natural vegetation is a complex mosaic of evergreen tropical forest, deciduous forest, and wet savanna. Xeric shrublands are found on the coastal cordillera in the northern part of Venezuela. A uniform savanna (llanos) is located along the Orinoco River. The mosaic of vegetation is even more complex in the islands. However, the evergreen tropical forest is the most significant Antillean vegetation.

The most representative soils of the continental parts are the ferrallitic soils (Acrisols) in llanos and fersiallitic soils (Luvisols and Alisols) associated with Cambisols in the drier parts of the Venezuelan coast. In the Caribbean islands (Cuba, Haiti-St. Domingue) very diversified soil mosaics occur, with the frequent occurrence of Acrisols. It has a disordered lithologic soil macrostructure

South American Meadow Region

The region extends north and south from the estuary of the La Plata River. It is relatively flat, ranging from sea level to elevations of about 500 m in some areas. The complex geology includes Precambrian, Cretaceous, and Jurassic rocks, as well as more recent sedimentary rocks (loess, sandstone, limestone). Many freshwater and saltwater lagoons are present.

The climate is humid temperate (subtropical). The annual average rainfall ranges from 1,000 to 1,600 mm. The rainfall is distributed uniformly throughout the year; summers are hot (24 to 27°C) and winters are mild (10 to 16°C).

The vegetation is comprised of a tallgrass meadow (“Pampas”). Xeric vegetation occurs in the southern part.

Soils of the Pampa plain are dominantly Phaeozems. Phaeozems are associated with fersiallitic soils (ferric Luvisols and Alisols) and Vertisols in the northern parts of the region (Uruguay and southern Brazil). A plain bioclimatic soil zonality is observed.

Mexican Region

The Western Sierra Madre separates the two principal dry zones of Mexico: the Chihuahuan Desert in the east and the Sonoran Desert in the west. The Chihuahuan Desert corresponds to the major portion of the central plateau of Mexico. Eastward, the central plateau is bounded by the Eastern Sierra Madre. The coastal gulf plain begins in the east at the base of the Eastern Sierra Madre.

In the Chihuahuan Desert and the Sonora Desert, which comprises the Sonora coastal plain and the major part of Baja California, annual precipitation averages less than 200 mm, and less than 50 mm in some areas.

In the Western Sierra Madre temperatures and rainfall fluctuate widely due to great variations in elevation. Mean annual rainfall is around 500 mm, with the western sides generally receiving more rainfall than other regions. The temperature varies between extremes of –3°C and 28°C. Summers are wet and winters are mild. Pine-oak forests grow on elevations of 1,500 to 3,500 m. The southwestern slopes on the Western Sierra Madre are covered by semideciduous tropical forests. In the Eastern Sierra Madre, the average annual rainfall ranges from 250 to 300 mm in the north, and 900 to 1,500 mm in the southern parts. The climate is temperate humid on the northeastern slope, and temperate subhumid on the western slope and highest portions. Mixed pine-oak forests cover most of the mountains.

In the eastern coastal plain, the climate is dry and hot, with precipitation levels below 500 mm per year. Precipitation levels increase gradually toward the south. The native vegetation type covering much of northeastern Mexico and parts of southern Texas is mesquite-grassland. The vegetation then grades to a deciduous forest to the south

Regosols, Leptosols, and xeric soils (Calcisols) are the dominant soils of the deserts. Vertisols occur along the coastal gulf plain, and steppic soils (Phaeozems) occur along the eastern base of the Western Sierra Madre on the Mexican central plateau. There is predominantly a mountain bioclimatic soil zonality.

Central Andes Region

This meridionally extended region includes the Pacific coast, with latitudes ranging from the equator to 38°S, and the central Andes from Colombia, Peru, and Bolivia to northern Argentina. The coastal area is an almost uninterrupted desert (the Atacama Desert and the Sechura Desert) that occupies an extended continuous strip. The average width of the coastal area is less than 100 km. Close to the border of Peru and Bolivia, the Andean mountain range is divided into two mountain systems, the Cordillera Occidental and the Cordillera Oriental, with a large plateau in between called the Altiplano.

This coastal desert is virtually rainless. The xeric conditions extend up to 1,500 m on the western drier slopes. In Andean Peru and eastern Bolivia the average precipitation in the Altiplano ranges from 500 to 700 mm per year. The average annual temperature is low, ranging from 5 to 7°C. In southwestern Peru, precipitation is lower and varies between 250 and 500 mm per year. Eastern slopes of the Andes have a wet and humid climate, and rainfall typically exceeds 2,500 mm per year.

The Pacific coast is a desert. The vegetation of the high plateaus is the "Puna." It is a xeric shrubland that grades into montane grassland in humid areas. The eastern Andean slopes are covered with evergreen or deciduous forests (southern Andean and Peruvian yungas and Bolivian montane dry forests).

Regosols (Leptosol and Lithosols) are the dominant soils of the region, and are associated with Cambisols in areas less prone to erosion. Fersiallitic soils occur in association with Cambisols. They are neutral (chromic Luvisols) under deciduous forests and acidic (Alisols) under evergreen forests. The mountain bioclimatic soil zonality is the prevailing pattern. A latitude bioclimatic zonality occurs in the coastal area.

South Argentine Region

This soil region is connected with the Central Andes region and is restricted to the pre-Andean zone of western Argentina ranging from 30º S to the Tierra del Fuego in Chile and Argentina. The region covers the piedmont plains and intermontane depressions of the first range of the Andes. The northern and central parts correspond to the "monte desert." It is a plain that lies at an altitude of 1,000 to 1,500 m, the altitude decreasing toward the east. A number of closed internal drainage basins are present. In the south, Patagonia is a stepped plateau sloping from the foothills of the Andes to the east. The maximum altitude is 2,000 m.

The climate of the monte part is dry, semiarid, and arid; rainfall is 200 to 300 mm. The climate of Patagonia is very dry and cold; the average annual precipitation normally does not exceed 200 mm. The climate of southern Patagonia is cold and humid, with 200 to 300 mm of rainfall per year and an average temperature below 8ºC.

Vegetation of the region consists of three main formations: the scrub monte desert, the Patagonian steppe, and the Patagonian Tierra del Fuego grassland. In the monte desert the dominant vegetative formation is xeric scrubland with evergreen bushes and cactus scrub. The Patagonian steppe is also xerophytic. It consists of resinous evergreen bushes and herbaceous species. In the Patagonian grasslands the dominant vegetation is a grass-steppe mixed with shrubs.

Most soils of the monte desert are Calcisols. Solonetz occur in relief depressions. In the northern and central Patagonia, soils are xeric Calcisols associated with halomorphic soils (Solonetz and Solontchak) in river valleys. Soils with steppic characteristics occur in southern Patagonia. In the Patagonian steppe zone, Kastanozems are associated with calcic and haplic Luvisols, and in the Patagonian Tierra del Fuego grassland zone, Phaeozems are associated with Cambisols. The general spatial soil pattern is zonal, bioclimatic plain-zonal.

South Chilean Region

The region stretches from 35°S to 56°S, i.e., to the southern tip of Tierra del Fuego. It is a mountainous region. In its northern part, the Andean cordillera rises to 4,000 m or more, whereas in the south, altitudes do not exceed 2,000 m. In the south, glaciers fill the valleys, whereas the northern part displays several active volcanoes. Intermediate depressions and central valleys are covered by volcanic ash and glacial moraines fields.

Most of the region receives 2,000 to 5,000 mm rainfall per year. On the eastern slopes facing Patagonia, the rainfall decreases to 1,000 mm per year or less. Rainfall is distributed regularly around the year. The climate is "moist mid-latitude type with cold winters." It is a temperate, or subboreal, climate, temperate-cold in the south. The vegetation is a temperate (or subboreal) broadleaf and mixed forest: the Valdivian temperate rain forest in the north, the Magellanic subpolar forest in the south.

The mountain bioclimatic zonality of the soils is not clearly apparent because Regosols (Leptosols or Lithosols) are the predominant soil types of the region. Only slightly developed soils (Cambisols) are found on the less eroded parts of the topography. Andosols are largely represented in the north.

CONCLUSION

Three groups of soil ecoregions are found in Latin America.

1. Arid soil ecoregions where the predominant soils are undeveloped soils and slightly developed soils directly correlated to the present arid climate. They consist of the Mexican, the Central Andes, and the South Argentina regions. Within each ecoregion, variations in the soil characteristics are associated with climatic changes. A range of climatic subzones is determined by either geographic or orographic factors.
2. Mountain soil ecoregions where limited soil development is associated with the steep topography. Ecoregions in this group are differentiated according to their position in latitude, which determines the bioclimatic environment as well as the main characteristics of their soils and of their soil associations. These regions are the Central American, the Andean Equatorial, and the South Chilean. Within each ecoregion, soil characteristics vary according to the altitude (vertical bioclimatic zonation).
3. Other soil ecoregions, where wetter climates coupled with a fairly leveled topography allow soil development and conservation of an ancient soil cover. Although this is not a general rule, the boundaries of these regions can occasionally match the limits of natural physiographic units, as is the case in the Amazon basin. In general, the boundaries are gradual, thus relatively imprecise, the definition of the soil ecoregions being based on criteria that do not account for clear geographical limits, such as climate-vegetation combinations, soil associations, and soil cover macrostructures. Soil distribution rules are specific to each region. Spatial patterns are determined by geomorphologic and lithologic factors as well as by the climate-vegetation combinations. Therefore, the Amazonian region is a wet tropical forest region, with a relatively homogeneous soil cover dominantly composed of Ferralsol; the Paraguay pre-Andean region has a tropical wet and dry climate that grades to dry climate toward the south, and contains a parallel soil zonation that ranges from Acrisol to Luvisol and Phaeozem; the Eastern Pampas region has a subtropical wet (or temperate) climate and a relatively homogeneous soil cover composed of Phaeozem; the Caribbean region has tropical wet and dry climate and a complex soil cover mainly due to a heterogeneous lithology; the Central Brazilian region has a tropical wet and dry climate and a relatively homogeneous soil cover mainly composed of inherited Ferral-

sol; the East Brazilian region has a tropical wet and dry climate and a contrasted soil cover composed of Luvisol and inherited Ferralsol; the Brazilian Atlantic region has a subtropical wet (or temperate) climate with contrasted soils consisting of Alisol and Ferralsol. A number of regions, including the Paraguay pre-Andean and the Brazilian Atlantic regions, consist of two or more overlapping climatic zones and need to be further subdivided.

The major characteristics of the soil ecoregions are summarized in Tables 1.1 and 1.2.

In conclusion, organizing soil and environmental data in soil ecoregions significantly reduces the spatial variability. By working at this scale, it will be possible to assess the potential of soil C sequestration on the basis of the dominant soil types, and then to build spatial models that could be used to establish more accurate evaluations.

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TABLE 1.1. Characteristics of the soil regions: Environment.

Region name	Topography	Climate type	Climate subtype	Vegetation
Amazonian	Plain	Tropical	Af, Aw, Am	Evergreen forest and wet savanna
Andean Equatorial	Mountain	Tropical	Af, Aw, Am	Montane forest and montane grassland
Central American	Mountain	Tropical	Am, Aw	Montane and mixed forest
Brazilian Atlantic N	Plateau	Tropical	Af	Evergreen and semideciduous forest
Brazilian Atlantic S	Plateau	Temperate	Cf, Cw	Evergreen and semideciduous forest
Central Brazilian	Plateau	Tropical, temperate	Am, Cw, Cf	Wet savanna and semideciduous forest
East Brazilian	Plain and plateau	Tropical, dry	Am, BS	Deciduous forest
Paraguay Preandean N	Plain	Tropical	Am	Deciduous forest and wet savanna
Paraguay Preandean C	Plain	Dry, temperate	BS, Cw, Cf	Deciduous forest
Paraguay Preandean S	Plain	Dry	BS	Deciduous forest
Caribbean	Low mountain	Tropical	Af, Aw, Am	Wet savanna, evergreen forest, decidous forest
Eastern Pampas	Plain	Temperate	Cf, C	Grassland
Mexican	Mountain	Dry	BS, BW	Desert and xeric shrubland
Central Andes	Mountain	Dry, polar	BW, E	Desert, xeric shrubland, and montane grassland
South Argentina	Plain and plateau	Dry	BS, BW	Desert and xeric shrubland
South Chilean	Mountain	Polar	E	Subboreal forest

TABLE 1.2. Characteristics of the soil regions: Soils.

Region name	Main soils[a]	Other soils[a]	Soil macrostructure
Amazonian	Ferralsol, Acrisol	Cambisol, Plinthosol	Zonal plain bioclimatic and watershed organized
Andean Equatorial	Cambisol, Acrisol	Andosol	Zonal mountain bioclimatic
Central American	Cambisol, Luvisol	Andosol	Zonal mountain bioclimatic
Brazilian Atlantic N	Ferralsol	Acrisol	Paleoclimatic and disordered lithologic
Brazilian Atlantic S	Alisol	Ferralsol, Acrisol, Cambisol	Paleoclimatic and disordered lithologic
Central Brazilian	Ferralsol	Acrisol	Paleoclimatic and disordered lithologic
East Brazilian	Ferralsol, Regosol, Luvisol	Lixisol, Planosol	Paleoclimatic and disordered lithologic
Paraguay Preandean N	Ferralsol, Acrisol	Plinthosol, Solonetz	Zonal plain bioclimatic and watershed organized
Paraguay Preandean C	Phaezem, Solonetz	Luvisol, Gleysol	Zonal plain bioclimatic and watershed organized
Paraguay Preandean S	Phaeozem	Solonetz	Zonal plain bioclimatic and watershed organized
Caribbean	Acrisol	Luvisol, Alisol, Cambisol	Disordered lithologic
Eastern Pampas	Phaeozem	Alisol, Vertisol, Solonetz	Zonal plain bioclimatic
Mexican	Regosol, Calcisol	Leptosol, Phaeozem, Vertisol	Zonal mountain bioclimatic
Central Andes	Regosol	Cambisol, Chromic Luvisol	Zonal mountain bioclimatic
South Argentina	Calcisol, Luvisol	Solonetz, Kastanozem	Zonal plain bioclimatic
South Chilean	Regosol	Cambisol, Andosol	Zonal mountain bioclimatic

[a]Soils are named according to the Soil Map of the World legend (FAO, 1990); correlations with USDA Soil Taxonomy can be found in Deckers et al. (2003).

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