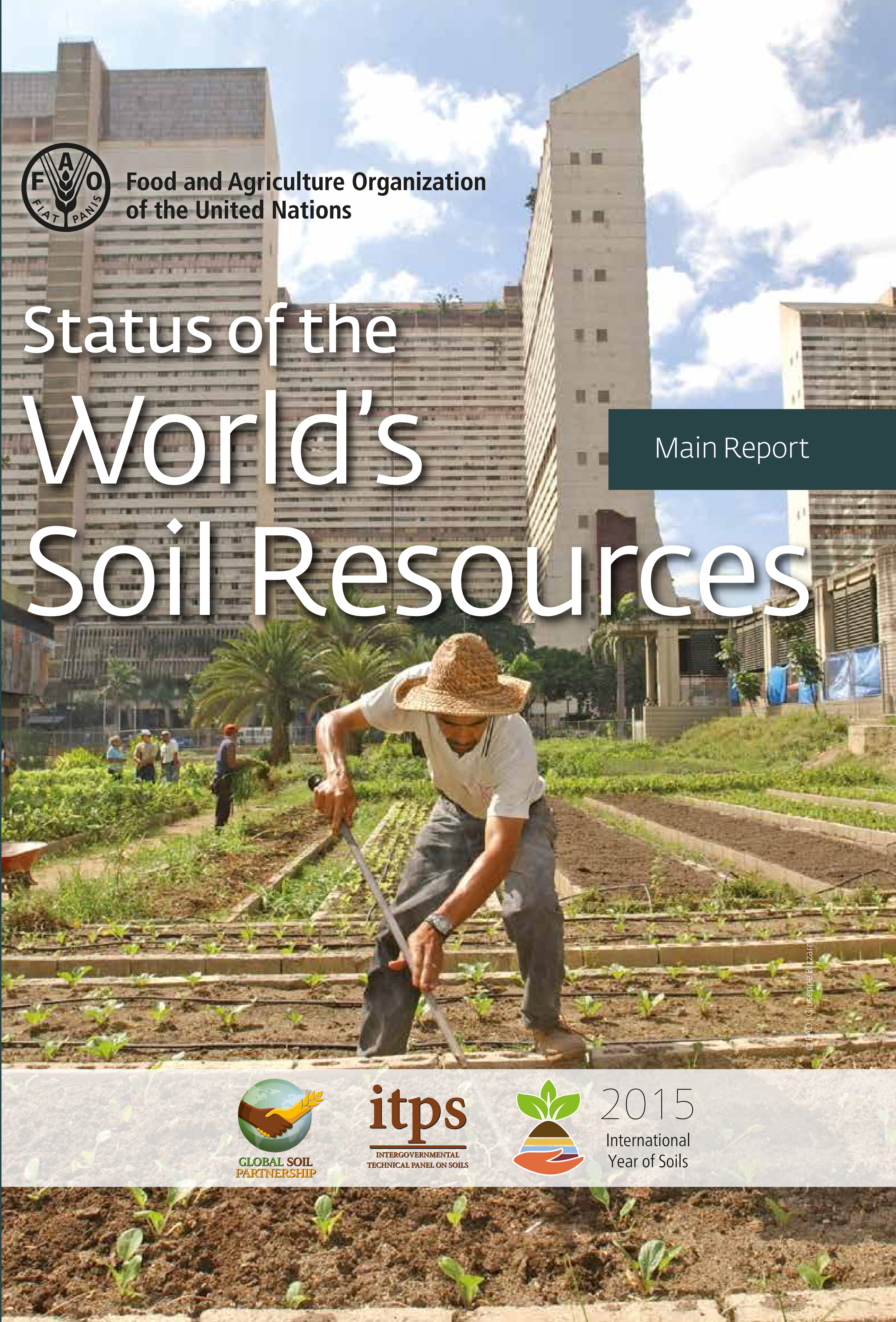
Food and Agriculture Organization of the United Nations

# Status of the World's Soil Resources

Main Report



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# 12 | Regional assessment of soil changes in Latin America and the Caribbean

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## 12.1 | Introduction

This chapter discusses the status of soil resources in Latin America and the Caribbean (LAC). The LAC region, as defined by FAO, includes the following countries: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Lucia, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay and Venezuela. The emphasis will be on human-induced 'anthropogenic' changes, and not on natural causes, although it is not always easy to separate them.

The LAC region extends from Mexico at latitude 32 degrees north to Tierra del Fuego at 55 degrees south. It also includes the Caribbean islands. The presence of 12 out of 14 terrestrial biomes (Olson *et al.*, 2001), the rugged relief in Central America and along the western side of South America, and the large lowlands in central South America that also include interior wetlands, all combine to make LAC the most bio-diverse region in the world. In fact, eight of the 17 mega-diverse countries of the world are located in Latin America: Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Mexico, Peru, and Venezuela.

In terms of natural resources, Latin America is one of the richest regions of the world. With only 8 percent of the population, it has 23 percent of the world's potential cropland, 12 percent of the actually cultivated land, 46 percent of the globe's tropical forest and 31 percent of the planet's fresh water (Garret, 1997). The region could provide a further 800 million ha of land for agriculture (Laegreid, Bockman and Kaarstad, 1999). However, most of these potential areas are under tropical rainforest and clearing would cause severe environmental changes with dramatic effects on many ecosystem functions. Agricultural conversion of natural ecosystems (grass-shrub-savannas and forest) as a percentage in LAC is of the order of 30 percent, representing slightly over 600 million ha of agro ecosystems, a figure similar to Africa but smaller than Europe and much smaller than Asia. Compared to other regions of the world, these converted agro-ecosystems had a medium to low intensity use of fertilizers and irrigation for much of the $20^{th}$ century (UNDP, 2000). However, use of fertilizer and irrigation increased dramatically in recent decades as agriculture expanded onto the temperate and subtropical plains (Grau and Aide, 2008; Viglizzo and Jobbagy, 2010).

Another important characteristic of this region is that agriculture started in the mountains, mainly because of the presence of serious diseases in the lowlands, notably malaria. Consequently, the sloping lands of the Andes and the Central America Mountains have been cultivated the longest, starting with the Incas and Mayas. Mountainous areas in LAC still have high populations that practice both intensive agriculture like horticulture and more extensive land uses like pasture and coffee growing. Exploitation of the flatter lowlands such as the Pampas and Cerrados, with tropical, subtropical and temperate climates, started only more recently. This is where most of the present intensive farming takes place, including the use of fertilizers and machinery in the production of cereals, legumes and other crops (Viglizzo and Jobbagy, 2010).

The main soil threats are related to natural features of physiography and to the type of vegetation cover. Anthropic and cultural features also play an important role, especially inappropriate agricultural practices which are a consequence of inequitable and insecure land tenure, insufficient research and lack of extension services.

Water erosion and landslides are prominent threats in the sloping lands of the mountains, especially when the slopes have been burned and overgrazed. Loss of soil carbon mostly occurs after deforestation and change of land use to permanent grassland. In semiarid and arid areas where irrigation is applied, salinity and sodicity are important threats. In areas with more intense land use and the employment of heavy farm machinery, compaction occurs. Also in these areas, the use of amendments, fertilizers and other agrochemicals bring the threats of nutrient imbalance, acidification, contamination and loss of biodiversity. In addition to induced flooding on rice fields, waterlogging and flooding are on the rise in the region as a consequence of the combination of higher rainfall promoted by the phenomenon of ENSO (the El Niño Southern Oscillation), and by land use changes which decrease ground cover by perennial vegetation. Acidification also occurs, mostly in deltas where the drainage of marine clays produces acid sulphate soils.

Overall, the most important ecosystems services affected in LAC are: (1) climate regulation, through the carbon and nitrogen cycles, especially due to the immense deforestation rate up to 2004 of the humid tropical forests, mostly in the Amazon Basin; (2) water regulation, through changes in quantity and quality of water production in the mountains, which is also due to deforestation of sloping lands accompanied by strong water erosion and landslides; and (3) loss of biodiversity, another ecosystem service threatened by deforestation and change in land use/land cover (Viglizzo and  Frank, 2006; Gardi *et al.*, 2014).

## 12.2 | Biomes, ecoregions and general soil threats in the region.

In order to give information on soil, land use and ecosystem services affected by soil threats, this chapter uses the 'Biomes' (environmental zones with similar climate, fauna and flora) outlined in the Soil Atlas of Latin America and the Caribbean (Gardi *et al.*, 2014, Figure 12.1). The boundaries of the Biomes correlate with major soil-landscapes. We will describe and discuss the Biomes in sequence starting from the most extensive. However, this sequence does not necessarily follow the significance and gravity of soil threats.


Figure 12.1 | Biomes in Latin America and the Caribbean.
Source: Olson et al., 2001.

**Tropical and Subtropical Moist Broadleaf Forest** is by far the most extensive Biome in LAC. Essentially it is a permanent very humid, high temperature forest. The landscape goes from flat plains to rolling slopes. The soils are dominated by medium to highly weathered Acrisols, Ferralsols and Plinthosols, which are in general acid and unfertile. This Biome has the greatest biodiversity of plant and animals and also shows little resilience to human intervention. It spreads from the eastern coasts of Mexico and Central America, through part of the Caribbean islands, the Pacific Coast of Colombia and the Atlantic coast of Guyana and Venezuela, down to most of the Amazon basin in Ecuador, Peru and Brazil, and finally to the western and southern coast of Brazil.

Because this Biome has had the largest deforestation rate in LAC (FAO, 2005, 2010) and because this practice removes a large and continuous addition of organic matter to the soil, the loss of land cover and soil organic carbon is clearly the most important threat to ecosystem function. Another threat in deforested areas is water erosion, which occurs when heavy rains fall on bare soil, resulting in major erosion problems on the widespread gentle and moderate slopes. As most of the nutrients in these soils are contained in the organic matter of the topsoil, its removal and rapid decomposition affects soil biodiversity, and in the long run nutrient imbalances may appear. Other ecosystem services affected include: the carbon and nitrogen cycles and their contribution to climate regulation; water quality and quantity; and landscape stability.

**Tropical and Subtropical Grasslands, Savannahs and Shrub lands** are the second largest Biome in LAC. The climate is characterized by alternating wet and dry periods and by high temperatures. The vegetation consists predominantly of grasses with different densities of trees. In general, the topography is flat to gently undulating. For the most part, and especially in Brazil (Cerrados), eastern Venezuela and Colombia, the dominant soils are acid lowfertility Acrisols, Ferralsols and Arenosols, while in the younger surfaces, the dominant soils are more fertile Luvisols, Phaeozems and Vertisols.

In these areas, the principal crops are annuals such as corn, soybean, sorghum, beans, cassava and cotton, grasses like Brachiarias, and legumes like Stylosanthes. In recent years, sugarcane and other biofuel crops have also been planted (Miyake *et al.*, 2012). Brazil, with the largest area of savannahs in LAC (around 200 million ha), has 55 million ha of introduced pastures and 22 million ha under annual crops (Sousa, 2011). In general, the soils in this Biome are low in organic matter, very infertile, and acid throughout. Counteracting the acidity and infertility of these soil conditions requires the use of amendments including gypsum and limestone, fertilizers such as rock phosphate, and inoculants. Erosion has been the main threat, but following major research and extension programmes, conservation tillage is increasing and is having an impact on the problem. Another threat has been compaction, not only by farm machinery but also by overgrazing. In grasslands where minimal fertilizer is used, a problem of nutrient imbalance has been reported (Guimarães, 2013). In agricultural land too, there is a growing imbalance of nutrients, especially in recent years with the intensification of agriculture, where fertilizer use has fallen well short of the demand of the crops (Urquiaga *et al.*, 2014). This is a threat throughout LAC. However, inputs of fertilizer have increased in recent years.

Ecosystem services are affected both positively and negatively in this Biome. The rise in food production is the main positive effect. However, there are significant negative effects too: the carbon and nitrogen cycles are affected by the higher rate of organic matter decomposition; there is loss of water quality due to erosion and sediment movement; and there are biodiversity losses (Viglizzo and Frank, 2006; Viglizzo and Jobbagy, 2010).

**Deserts and Xeric Shrublands** occupy the third place amongst LAC Biomes in terms of area. They are characterized by low precipitation, high evaporation and quite windy conditions. The temperatures are variable: in the tropics, for example in northern Brazil, the coastal area of Peru and the Caribbean coast of Venezuela and Colombia, temperatures are quite warm; in northern and central Mexico and Chile, by contrast, a cold period occurs. In all cases, vegetation is dominated by cactuses and thorny shrubs that are very sparse and resistant to drought. The most typical soils are calcareous or gypsiferous, shallow, saline or sodic and reflect the very limited amount of leaching. Calcisols, Gypsisols, Arenosols, Regosols and Solonchaks are common soil groups.

Because of its aridity, this Biome requires irrigation for most forms of agricultural development. Irrigation requires not only a source of water, but also water of good quality and a good drainage system to leach the soluble salts common in this Biome. Preventing salinization is difficult but restoring salinized soils is even harder. The use of waste water from cities may bring additional problems, particularly contamination with heavy metals. Due to the sparse vegetation coverage and the presence of strong winds, it is common for wind erosion to increase after human intervention.

The principal ecosystem service that may be affected is the productivity of the soils due to salinization. Water quality may worsen for the same reason.

**Temperate Grasslands, Savannahs and Shrublands** have been widely studied and documented by various authors (Paruelo, Guerschman and Verón, 2005; Satorre, 2005; Viglizzo and Frank, 2006; Álvarez *et al.*, 2009; Lavado and Taboada, 2009; Viglizzo and Jobbágy, 2010). This Biome is predominantly located in the Argentinian Pampas. Its central plains are dominated by grasses on flat to gently sloping lands, with a temperate climate, and rains ranging from 1 500 mm in the northeast to 400 mm in the southwest. These areas have some of the most fertile soils of the world, the Phaeozems, although more than 13 million ha with natural saline-sodic soils (e.g. Solonetzs) also appear in this Biome.

Despite the wide adoption of no-tillage, intensive annual cultivation (largely of soybean) and the lack of rotation with other crops or pastures have resulted in soil degradation by wind and water erosion, waterlogging, compaction, sealing/capping, and soil fertility depletion (Satorre, 2005; Lavado and Taboada, 2009; Alvarez *et al.*, 2009; Sainz Rozas *et al.*, 2011; Viglizzo and Jobbagy, 2010). Clearing of forested lowlands to produce annual crops (soybean, cotton etc.) has also led to salinization or sodification in areas where the groundwater table has risen (Paruelo, Guerschman and Verón, 2005; Viglizzo and Jobbagy, 2010).

**Dry Tropical and Subtropical Broadleaf Forest** occurs in many different zones in LAC. These zones share common characteristics: they are all situated below 1 000 m elevation, all experience high temperatures, and all have at least one dry season when the trees lose their leaves. These forests are more common in hilly and mountainous landscapes with soils of medium fertility such as Luvisols, and Cambisols. Large populations live in these areas and deforestation and annual burning are common. These forests occur in western Mexico, Costa Rica, Cuba, the north of Venezuela and Colombia, the coasts of Ecuador and Peru, and central and the north east of Brazil.

This Biome is very attractive for agricultural development. The soils are fertile and the climatic conditions are favourable for human habitation and for the growth of many crops, including corn, beans, potatoes, sugarcane, fruits and coffee. Large areas of grassland are used for extensive pasturing. Deforestation is the major threat, and is in practice irreversible as the dry period makes it difficult for natural regrowth to occur. As the accumulation of organic matter in these soils is medium or low, deforestation also brings the threat of organic carbon loss, and the increase of soil temperature in bare soils accelerates decomposition. Steeper slopes are hard to cultivate and here the most common land use after deforestation is extensive pasture. After a few years, soil compaction develops, particularly along the small terraces where the animals pass. This compaction also reduces rainfall infiltration and consequently increases water erosion.

Ecosystem services affected are principally the carbon and nitrogen cycles and climate regulation due to the decrease in organic matter. Water production and quality may also decrease due to compaction by overgrazing and farm machinery which increases erosion. As erosion reaches high levels in many slopes, landscape stability can also be affected.

**Montane Grasslands and Shrublands** are present at high altitudes throughout the Andes, but mostly in Peru and Bolivia. Locally they are called Punas or Paramos. They occur above 3 000 m or even higher, and are dominated by grasses and small shrubs. Temperatures during the day may be quite high but frosts can occur at night. In general these area are quite dry. The topography may be mountainous or large mesas or high plains. Soils are generally rich in organic matter, but rather shallow. Predominant groups are Regosols, Leptosols and, in the drier zones, Solonchaks.

Most of the land remains bare or is used for extensive pastures. Most of the pastures are natural, but some have been introduced and have adapted to the conditions. In some parts of LAC, especially in northern South America, some areas are also used for intensive horticultural crops, including potatoes, carrots and quinoa. In these cases, conservation practices, irrigation and high inputs of organic and inorganic fertilizers are used throughout the year (Comerma, Larralde and Soriano, 1971). Although there are no data on impacts, it is suspected that contamination of soils and water from excessive use of fertilizers and other agrochemicals may be occurring. This can also affect soil biodiversity, which may be very important given the unique vegetation and fauna of this Biome.

This Biome is of high importance for certain ecosystem services, notably water production. It is located at the top of many watersheds and is a continuous source of pristine water, in many cases related to the process of thawing. Many soils in the Biome are rich in organic matter in the topsoil. Careful attention has to be paid to C and N cycles because of the services provided. The soil gene population, due to its unique nature, should also be studied and protected.

**Tropical and Subtropical Coniferous Forests** occur at high and medium altitudes, mostly in Mexico and south to Nicaragua. Small patches also exist in the Dominican Republic, southern Brazil and along the Chile-Argentine border. These forests occur mostly in mountainous landscapes and on many different geologic materials, including volcanic ashes. Most of the soils are Umbrisols, Luvisols, Leptosols and Andosols. The vegetation is dominated by many types of conifer with a diverse understory.

Deforestation for the establishment of pastures and wood harvesting are major land uses. In many cases these land uses are accompanied by burning. Deforestation and burning create the threats of reduced organic carbon and of water erosion. The main ecosystem services affected are water production/ regulation, C and N cycling, and landscape stability.

Temperate Broadleaf and Mixed Forest is confined to a temperate permanent forest in southern Chile. The forest occurs mainly in valleys and on the slopes of high mountains. The climate is very humid, cold and with few variations during the year. Soils are shallow and mostly Alisols, Andosols, Cambisols, and Histosols.

Because of the low temperatures and the rough relief, the land is largely a protected area, and only a few valleys are used for pasture. As human intervention is very low, threats and impacts for ecosystem services are very limited.

**Flooded Grasslands and Savannahs** in LAC occur in tropical alluvial plains, mostly in Brazil, Bolivia and Paraguay. The Pantanal, which stretches across all three countries, is the world's largest tropical wetland, and is a highly productive environment. The area is recognized by UNESCO as a World Natural Heritage Site and Biosphere Reserve. Other important areas occur in Venezuela and Colombia on flat alluvial plains. They all have in common the predominance of native pastures adapted to flooding, few trees at higher elevations, and a seasonal period of flooding alternating with a dry season. The predominant soils are Gleysols, Stagnosols, Vertisols, Plinthosols and Histosols. The most widespread use of this biome in LAC is as pasture for bovine and, more recently, bubaline cattle. Its strategic importance in the production system is in the supply of green pastures for the dry season.

Economic development in the Pantanal region, especially on the plateau of the Rio Taquari Basin, has intensified the input of sediments to the Pantanal lowlands, causing serious social, economic and environmental impacts on the region (Galdino, Vieira and Pellegrin, 2006).

The main ecosystem service is the provision of food and fiber, interacting with the service of water regulation. The ecosystem is unique and rich in flora and fauna. Soil biodiversity is of prime importance and should be investigated and protected.

Mediterranean Forest and Shrubs occupy a small strip of Chile near the coast. The Biome has a warm temperate climate, dry during the warm period and rainy in the winter time. The vegetation, relief and soils are very heterogeneous, as they represent a transition between tropics and temperate, and between dry and humid. The most common soil groups are Regosols, Leptosols and Andisols. The degree of human intervention is so complete that there are few remnants of the original vegetation.

Because of its Mediterranean climate, the natural productivity of the area is very high. This has been utilized by Chileans to create very important agricultural development areas, especially in the valleys. Irrigation, tillage and large quantities of fertilizers and other agrochemicals are used to obtain high yields. Deforestation has resulted in significant erosion threats; high levels of input use have led to contamination; and in the drier zones salinization is a threat due to the quality of irrigation water.

The ecosystem service positively affected is the provision of food. Negative effects are on water quality and possibly on human health, and loss of biodiversity related to contamination.

**Mangroves** are the smallest Biome in LAC in terms of area. They occur along the coastlines of all LAC countries and are particularly associated with the deltas of important rivers like the Amazon and the Orinoco. They are located where there is the mixture of fresh and saline water. Mangroves provide many ecological services and are considered very fragile as disturbances can produce irreversible consequences. Soils are mostly Histosols, Gleysols and Acid Sulphate soils.

Mangrove areas are mostly protected because they are hard to drain and the soils are poor, with predominance of reduced or organic soils. In cases where development projects have been implemented, the main land uses are pasture, rice, or plantation crops such as oil palm or bananas. Especially when mangroves are underlain by marine sediments, it is very common that after drainage, oxidation of Iron Sulphide (pyrite) will occur, producing extreme acidification and the formation of acid sulphate soils. This is an extreme case of the threat of acidification and reclamation is extremely difficult. After drainage, organic carbon is lost and the land surface subsides.

The ecosystem service principally affected is the reduction of productivity, especially if acid sulphate soils are formed. The Carbon and Nitrogen cycles and water quality will also be affected. Cultural heritage will also be affected, as local tribes – for example, the Waraos in the Orinoco Delta – have been living on the natural products extracted from this ecosystem for more than 4000 years.

## 12.3. General soil threats in the region

In recent years, the onset of climate changes, notably more intense and concentrated rainfall events and higher evaporation, has begun to bring change in the pace and intensity of threats such as erosion, flooding and desertification (IPCC, 2014). At the same time, other threats to soils and ecosystem services have also increased, including threats to organic carbon, biodiversity, crop production, and water quantity and quality.

### 12.3.1 | Erosion by water and wind

This threat is considered one of the most important in the region, because it has an impact on very large populations, particularly those concentrated in the mountainous regions of the Andes, Central America, Mexico and the Caribbean. Water erosion and landslides occur mainly on steep slopes that have been deforested or in dry mountain areas which are used as pastures and which have been overgrazed. Water erosion also occurs on the gentler slopes of the cerrados as well as in parts of the pampas subject to intensive cultivation. Erosion and landslides remove fertile topsoil, affecting crop productivity, making tillage more difficult, and producing sediments that affect fields and infrastructure downstream and cause flooding in flat areas. The threat is considered in more detail in Section 12.4.1.

### 12.3.2 | Soil organic carbon change

Changes in organic carbon occur mostly if carbon supplied by vegetation decreases, as happens with deforestation, or if mineralization is increased as happens with ploughing (Sánchez, 1981). LAC contains about half of the world's tropical forest, and until recently, it had the highest rate of deforestation, which drastically reduced organic inputs to soils. The region also has some of the best soils in the world, for example in the Pampas. These soils are rich in organic matter content and very fertile, but continuous cropping has increased mineralization and reduced organic carbon. In both cases, soils are becoming less productive, limiting their ecological services (Lavado and Taboada, 2009; Viglizzo and Jobbagy, 2010; Gardi *et al.*, 2014). A recent study (D'Accunto, Semmartin and Ghersa, 2014) found that uncropped agricultural borders are highly effective in the mitigation of soil organic carbon losses. The details of changes in SOC are outlined in Section 12.4.2.

### 12.3.3 | Salinization and sodification

Natural or primary salinization and sodification are quite common in the arid and semiarid regions of LAC, including in Mexico, Cuba, northern South America, Peru, Northeast Brazil and southern Argentine. Human-induced threats are also present in these regions because irrigation is common and the quality of the water used and the lack of drainage induce salinization. Even though it may not occupy large areas, salt accumulation is an important threat because it severely reduces crop productivity. It is very difficult to prevent and even more difficult to reclaim soils once salinized. It has been estimated (AQUASTAT, 1997) that 18.4 million ha in LAC are affected by salinization caused by irrigation. The problem also appears in humid climates, where topsoil in large plains with high and saline groundwater and sodic soils (e.g. Solonetzes) may be salinized by upward soluble salt rises promoted by land clearing and overgrazing (Taboada, Rubio and Chaneton, 2011, Bandera, 2013, Di Bella *et al.*, 2015). A country-by-country analysis is provided in Section 12.4.3.

### 12.3.4 | Nutrient imbalance

The largest proportion of soils in LAC are acid and have naturally low fertility. As a result, amendments and fertilizers are required for sustainable production. These inputs also serve to boost productivity where areas for agriculture and animal production are already limited and expansion of production requires intensification. In recent years, contrasting cases of nutrient imbalance have emerged as a result of the high levels of N-fertilizers (ammonia) applied in high-input production systems (Espinosa and Molina, 1999). These N-fertilizers increase the acid ion sources in the soils, even in very fertile soils. Nutrient impoverishment has been documented in coffee and sugar cane plantations on Andisols, reducing yields (Bertsch *et al.*, 2002). Nutrient imbalance could also appear in the highly fertile Pampas region, where farmers have historically applied low amount of fertilizers (Lavado and Taboada, 2009). The imbalance could be greater were it not for the significant contribution of biological nitrogen fixation (BNF) in agriculture and livestock production of the region (Urquiaga *et al.*, 2012; Franzluebbers, Sawchika and Taboada, 2014). The contribution of BNF is particularly important for soybean in the Pampas and for legume pastures in the Southern Cone (Alves, Boddey and Urquiaga, 2003; Campillo *et al.*, 2003, 2005).

### 12.3.5 | Loss of soil biodiversity

In LAC, conservation areas can provide a bank of original soil biodiversity (Alegre, Pashansi and Lavelle, 1996, White *et al.*, 2005; Urquiaga *et al.*, 2014). One study (Ferraro and Ghersa, 2007) found that the community of microarthopods was highly sensitive to crop management and resulting soil conditions. Microbiological indices and enzymatic activity are useful new indicators and have been used in different studies in the region (Balotta *et al.*, 2004; Sicardi, Garcìa-Préchac and Frioni, 2004; Nogueira *et al.*, 2006; Green *et al.*, 2007; Franchini *et al.*, 2007; de Moraes Sa and Lal, 2009; Romaniuk *et al.*, 2012; Henríquez *et al.*, 2014).

## 12.3.6 | Compaction

In LAC there are two main causes of compaction: livestock production and machinery transit. Overgrazing by cattle and sheep causes degradation of pastures and increased erosion as found in mountainous regions, the Cerrado, coffee plantations and the arid Patagonia (Bertiller, Ares and Bisigato, 2002; Henríquez *et al.*, 2011; Taboada, Rubio and Chaneton, 2011; Pais *et al.*, 2013). The widespread use of farm machinery, especially in the Cerrados and the Pampas has caused shallow soil compaction and poor structural conditions in topsoil, especially associated with soybean mono-cropping and long winter fallow periods (Taboada *et al.*, 1998; Botta, Tolon-Becerra and Melcon, 2009; Botta *et al.*, 2010; Alvarez *et al.*, 2014; Franzluebbers *et al.*, 2014).

## 12.3.7 | Waterlogging

Many flat areas are affected by episodic human-induced waterlogging and ponding. This can result from poor topsoil structural and drainage conditions which limit infiltration rates. It may also be associated with extreme rainfall events linked to the periodic climate phenomena of 'El Niño'. Waterlogging has been documented in both agricultural and pasture soils throughout the region. There are increasing problems of catastrophic flooding, landslides and sedimentation (Pla, 2003, 1996a, 2011; Restrepo *et al.*, 2006).

## 12.3.8 | Soil acidification

Natural acidification is a common process in the soils of LAC and is very intense in tropical areas of the region, because of the high rainfall. Acidic soil parent materials are also widespread (Kämpf, Curi and Marques, 2009; Fassbender and Bornemisza, 1987). As industrialization is not intensive and widespread in the region, soil pollution from industrial sources is not common. Anthropogenic acidification in soil could also appear where there is excessive N-fertilization on crops like banana, vegetables and oil palm and under intensive coffee systems (Sánchez, 1981; Espinosa and Molina, 1999).

## 12.3.9 | Soil contamination

Different human activities may result in the pollution of soils and adjoining water bodies caused by fertilizers and agrochemicals used in high-input agriculture, and from mining and oil spills (Nriaugu, 1994; Malm, 1998; Mol *et al.*, 2001). Residues of herbicides such as glyphosate have been observed in soils and groundwater in fields devoted to no-till farming (Ometo *et al.*, 2000; Christoffoleti *et al.*, 2008; Cerdeira *et al.*, 2011; Aparicio *et al.*, 2013).

The use of mercury compounds in mining activities and the use of huge amounts of water for shale oil exploitation are causing downstream pollution in soils and waters (Nriaugu, 1994; Malm, 1998; Mol *et al.*, 2001). The increasing use of agricultural by-products and sludges increase N concentrations in groundwater and cause eutrophication of lagoons (Torri and Lavado, 2008).

## 12.3.10 | Sealing

According to the United Nations[1] , the population of Latin America is currently 630 million, 8.6 percent of the world's population. This figure is expected to increase by 25 percent by 2050. Most Latin American countries are experiencing relatively low death rates and declining birth rates, resulting in slower population growth over time.

Today 79.8 percent of the population of Latin America live in urban areas, and they account for 12.7 percent of the world's urban population. Forecasts for 2050 indicate a further increase of the share of the urbanized population in LAC to 86.2 percent. The degree of urbanization is well above the global average of 54.0 percent. Figure 12.2 illustrates the extent of urban areas and of urbanization for LAC countries. In relation to population, Brazil, Argentina and Mexico have the largest urban areas, while the highest rates of urbanization are associated with small states with high population densities.

1 http://www.un.org/en/development/desa/population/events/ot her/10/index.shtml

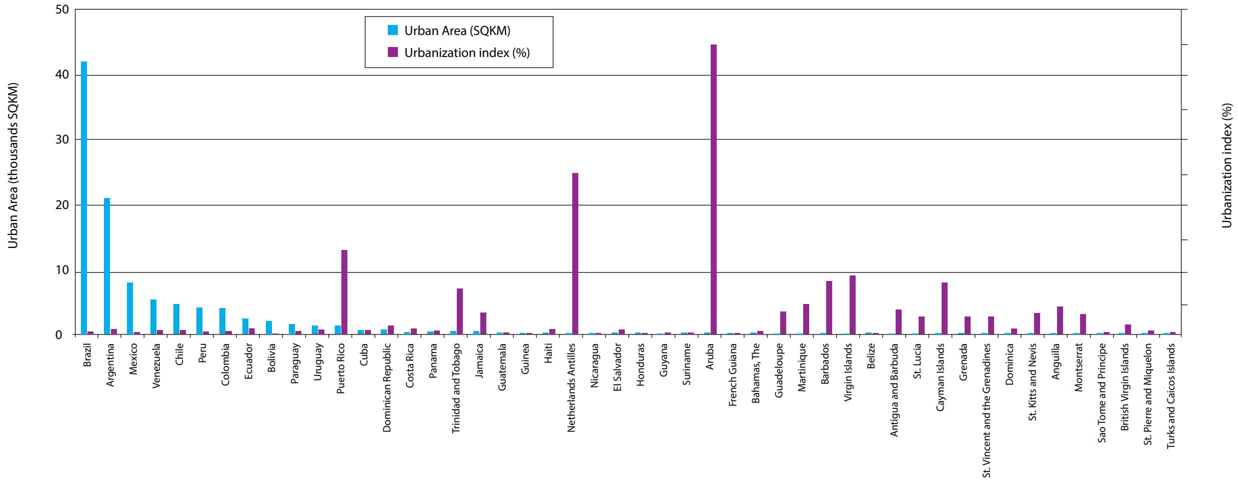



**Figure 12.2 | Extent of the urban area and the urbanization index for Latin American and Caribbean countries.**

## 12.4 | Major threats to soils

Among the general threats to soil that occur in the region, the three most important ones in LAC will be discussed here in more detail.

### 12.4.1 | Soil erosion

Soil erosion by water is the main soil degradation process worldwide and in LAC as well. Wind erosion is also prevalent in specific areas with arid and semiarid climates (rainfall lower than 600 mm).

A high proportion of the land in LAC is on steep slopes, and the main limitation for its agricultural use is water erosion (Alegre, Felipe-Morales and La Torre, 1990; Pla, 1993, 1996a; Duvert *et al.*, 2010; PNUMA-CEPAL, 2010). However, the problems of accelerated water erosion are not confined to steep slopes, but are also widespread in agricultural areas with more gentle slopes. In general, the increasing trend of erosion in LAC is mainly due to the fast growth of the human population and to pressures put on the land by deforestation and over-grazing, and by inappropriate agricultural practices in both subsistence and large-scale high-input commercial agriculture (Pla, 1996a).

Erosion in LAC is mostly caused by water. Some estimates suggest that 42 percent of flood events contribute to 70 percent of sediment export (Duvert *et al.*, 2010). In drier areas of Mexico and Argentina on the other hand, wind erosion prevails. Estimations of areas affected by erosion in the region vary, but a conservative figure is around 15 percent for South America and 26 percent for Central America (Oldeman, 1991b).

Although there is clear evidence that large and increasing areas of land are being affected by different processes of soil erosion, most of the existing evaluations of the type, extent and intensity of soil erosion at country or regional level are not very precise or objective. Mass and landslide erosion processes are usually not differentiated from surface erosion problems (Hincapié and Ramirez, 2010), leading to an often faulty identification of the origin of erosion processes (Pla, 1992, 1993, 2011). The magnitude of the soil erosion problems is highly variable, with estimated values for average soil losses in the Andes and Central America ranging between 5 and 50 percent of the area or from 100 to 1 000 Mg km$^{-2}$ yr$^{-1}$. Probably almost half of agricultural lands are negatively affected by surface soil erosion at different levels, with 15-25 percent, depending on the region, strongly affected (Oldeman *et al.*, 1991a, b).

New regional information has been generated largely through indirect or remote sensing, usually without sufficient ground-truthing (Bai *et al.*, 2008; Nachtergaele, Petri and Biancalani, 2011). Some indirect recent evaluations based only on soil cover and slope show a reduction in the area with risks of soil erosion to only 5 percent (EC, 2013). In those evaluations, the processes of mass erosion have not received any attention or have been confused with the very different processes of surface erosion (Pla, 2011).

The control of soil erosion and of the derived effects depend on appropriate land use and management planning supported by appropriate soil governance (FAO, 2012). In many LAC countries, the application of conservation measures is limited by lack of integration between conservation and development, the lack of legislation or ways to implement it, and the shortage of basic local information, trained personnel and financial resources (Pla, 1996b). With few isolated exceptions, there have not been policies and well-targeted subsidies or incentives through marketing prices and credits to induce sustainable land management. In addition, agricultural research has been oriented towards increasing productivity through the use of inputs rather than to sustainable land use. This has contributed indirectly to growing environmental problems, including soil erosion.

A main objective of research on soil erosion in LAC must therefore now be to collect and evaluate data to generate technology for prediction and control of soil erosion. An understanding of the basic erosion processes in each particular situation is required in order to select an effective technology and transfer it to farmers (Pla, 2003). Some empirical models to predict erosion (USLE, RUSLE) are currently used indiscriminately, without scientific evidence of their applicability to a particular situation. The uncritical use of results from these models has led to gross errors in planning land use and management (Pla, 2011). However, the RUSLE equation has been successfully adopted as a basis for soil use regulations in some countries (Alegre, Felipe-Morales and La Torre, 1990).

One key area for research is the study of existing indigenous practices. An understanding of the biophysical and human factors behind these practices might indicate how they can be adopted or adapted to the present socio-economic situation.

Finally, institutional support is essential for developing and assuring continuity of the required research in soil erosion and conservation practices in LAC countries (Pla, 2003).

### 12.4.2 | Soil organic carbon change

Soil organic carbon is the main component of humus. It is an organic compound with a stable C:N ratio which varies between 10 and 13 in most soils of LAC and of the world as a whole (Palm and Sanchez, 1990; Sisti *et al.*, 2004; Jantalia *et al.*, 2007). It is therefore only possible to increase the SOC content if the N content also increases to maintain the relationship (Boddey *et al.*, 2012 a, b, 2014). The reverse is also true: increasing one unit of soil N availability due to the mineralization of soil organic nitrogen will release between 10 and 13 units of C, equivalent to around 40 kg of $CO_2$.

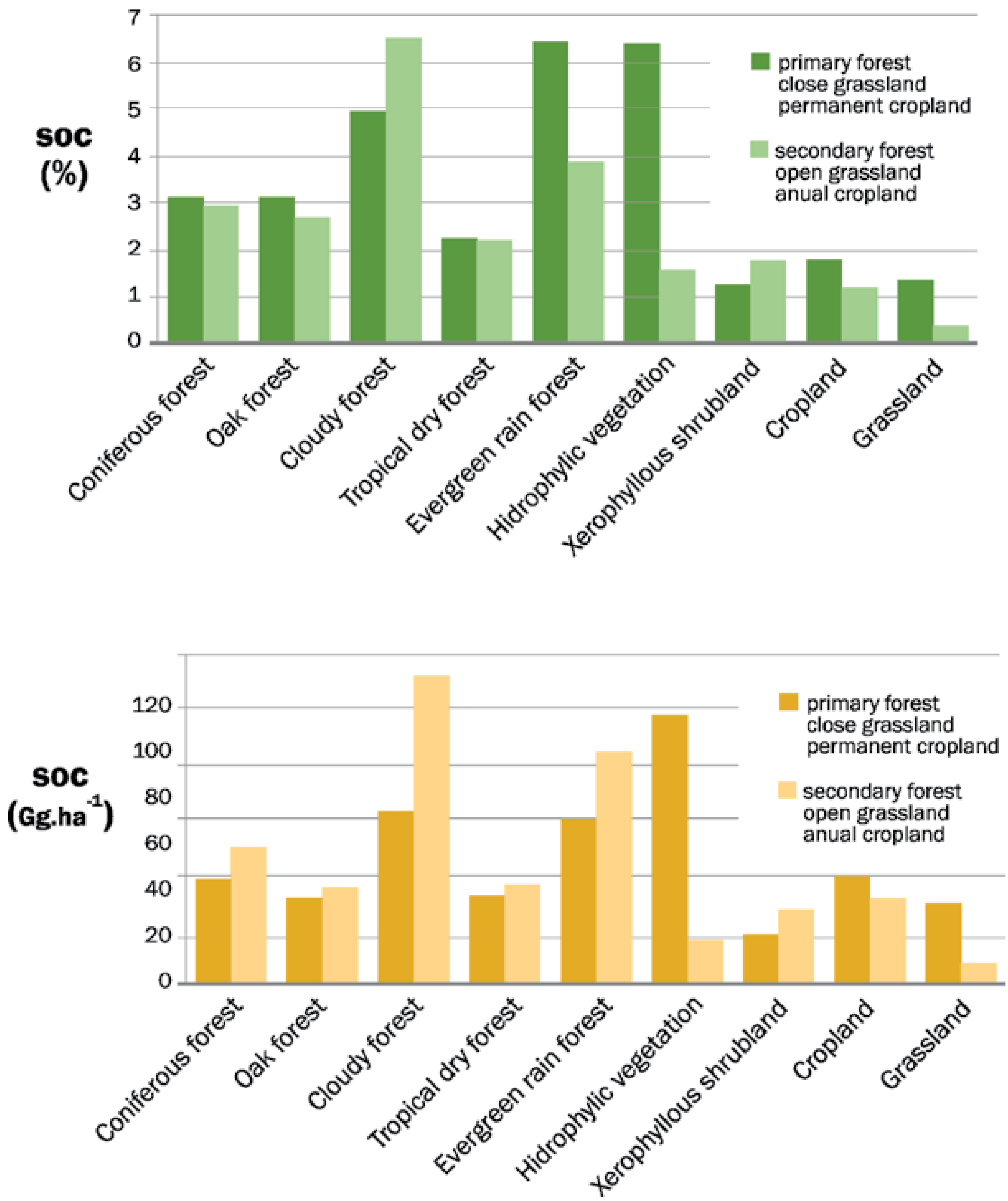



**Figure 12.3 | shows soil organic carbon contents and stocks (taking into account soil bulk density) in different Mexican ecosystems.**

*Carbon concentrations (left) and carbon stocks (right) in the main ecosystems of Mexico. In both cases the bars with the strongest tone indicate a primary forest, closed pasture or permanent agriculture. Bars with the softer tone indicate a secondary forest, open pasture or annual agriculture. Source: Cruz-Gaistardo, 2014.*

Primary forests have higher carbon concentration (in percentage) than secondary forests. However, the latter are better sinks because they have a greater capacity for conversion of $CO_2$ to biomass since they are in a more active phase of growth (Vargas *et al.*, 2008). About 185 Pg of organic carbon is stored at 1 m depth in LAC soils (16 percent of the world's soil carbon reserve). Half (95 Pg) of this amount is stored in the soils of the Amazon region, and about 52 percent of this carbon pool is held in the top 0.3 m of the soil profile (Batjes and Dijkshoorm, 1998).

LAC biomes where there is high risk of carbon losses – and also biodiversity losses – are the Amazon and the Atlantic Forest of Brazil, the Pampas of Argentina, the west coast of Colombia and the core of the Sierra Madre del Sur and Sierra Madre Oriental areas in Mexico (Hansen *et al.*, 2013). Satellite images reveal that more than half a million square kilometers of Amazon rainforest was destroyed between 1984 and 2005 and replaced by agriculture and the introduction of more than 240 million head of cattle (Gardi *et al.*, 2014).

The richest organic carbon soils in LAC, with stocks higher than 250 tonnes per hectare, are located in the sedimentary region of the Carso Huasteco and the Peninsula of Yucatán in Mexico, the tropical forests of Guatemala and Costa Rica, the region of Cauca and Magdalena in Colombia, the Orinoco delta in Venezuela, in the eastern Amazon, the Uruguayan savannas, the Valdivia forests in Chile, and the wet grasslands and steppes of Patagonia in Argentina (Gardi *et al.*, 2014). In these regions the highest proportion of Histosols, Andosols and Gleysols with high concentrations of soil carbon is found. The lowest soil carbon stocks are found in arid regions of LAC (the deserts of Mexico, Peru and Chile, as well as the drier regions of Brazil and Argentina). In these arid regions, it is essential to preserve the scarce carbon (less than 20 tonnes $ha^{-1}$) due to the fragility of the ecosystems found there (Figure 12.4).

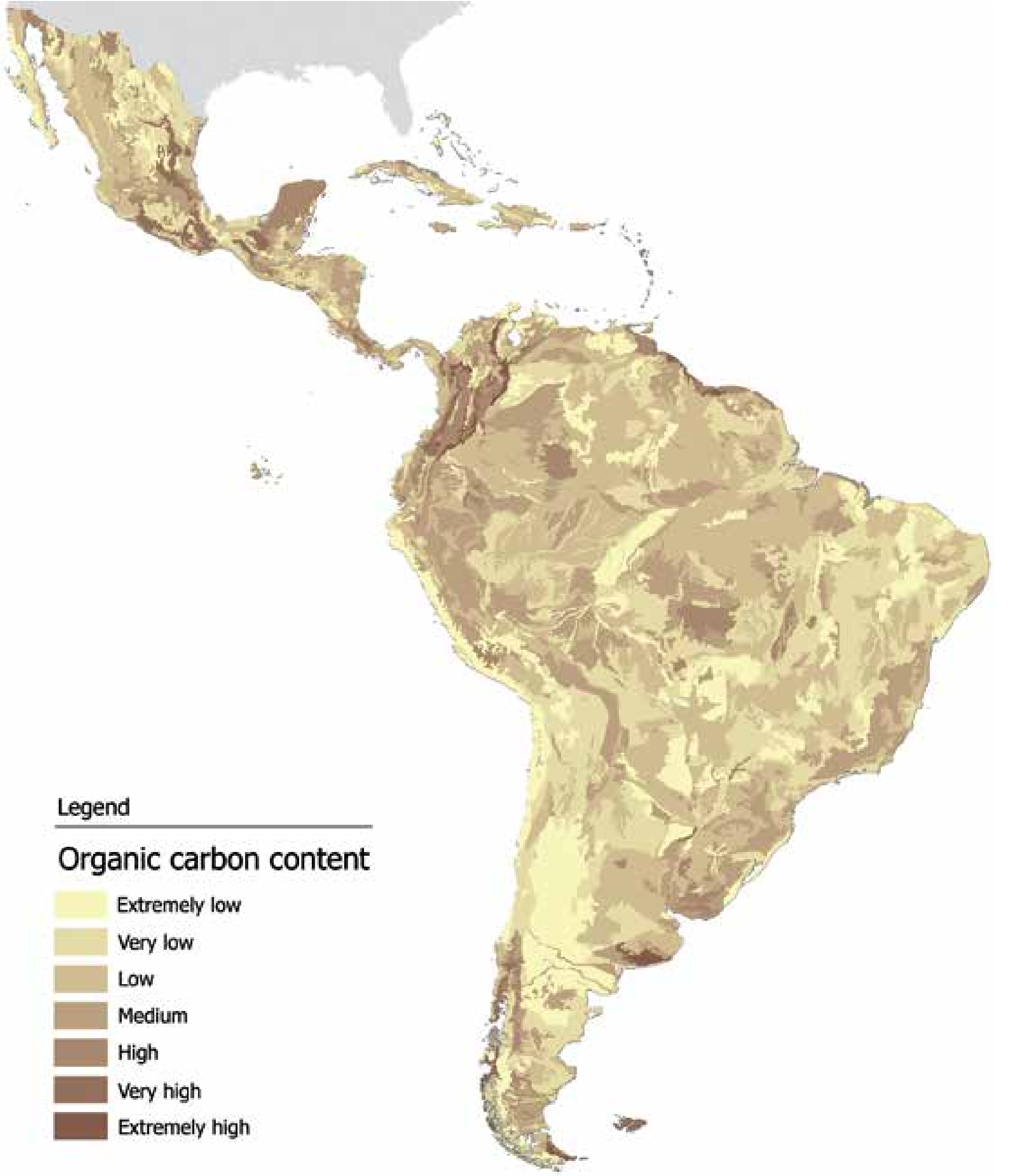
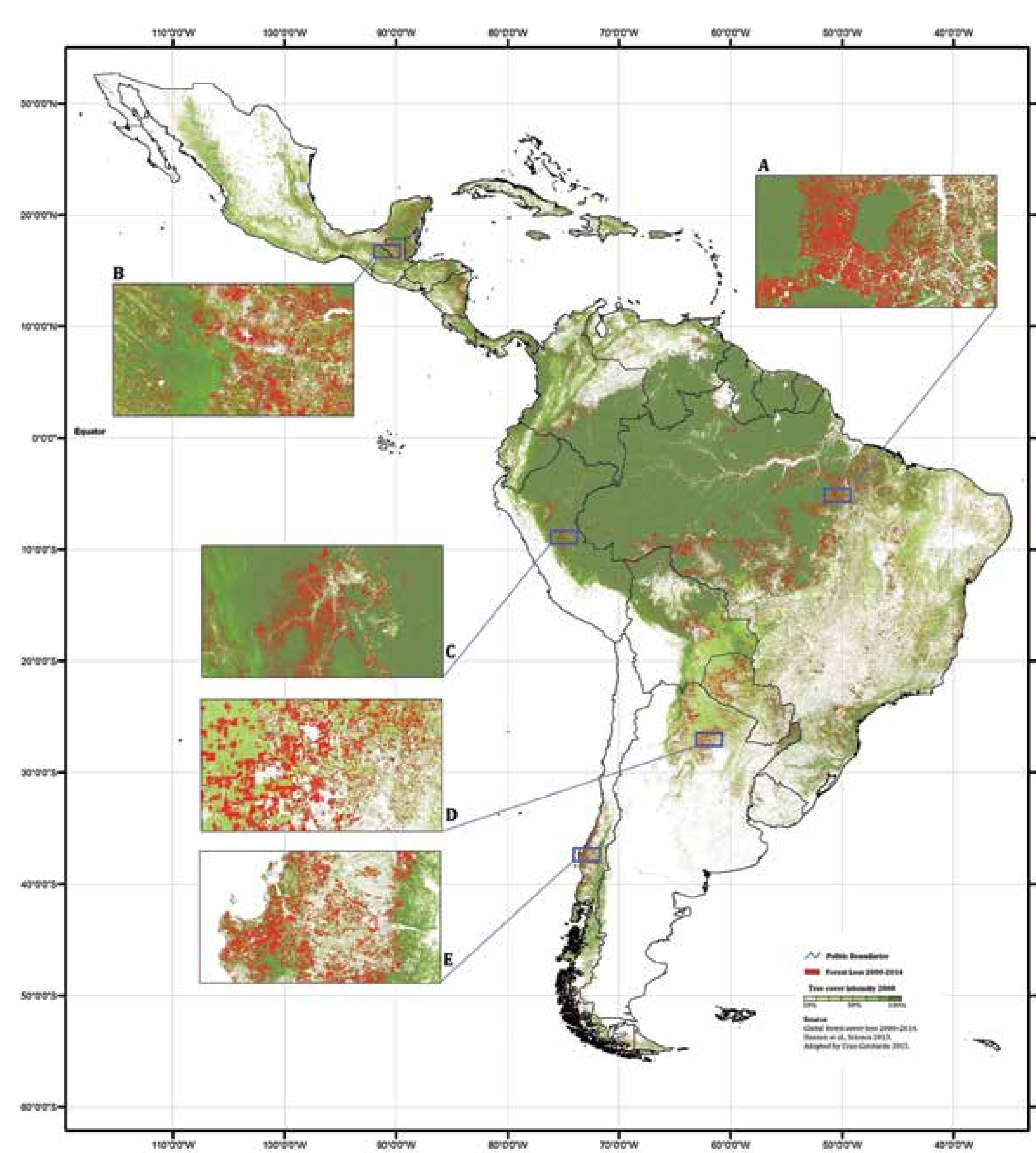



**Figure 12.4 | Organic carbon stock (or density) in soils of Latin America and the Caribbean, expressed in Gigagrams per hectare. Source: Gardi et al., 2014.**

Land use changes from forestry to urban or livestock use cause the greatest loss of soil carbon in LAC (Lal, 2005, 2006; van der Werf *et al.*, 2010; INPE, 2010). The loss of ground cover due to deforestation exposes the soil to direct precipitation that could cause erosion and compaction of the soil surface microstructure in addition to carbon loss. Deforestation of tropical forests prevents the return to the soil of about 15 tonnes of organic inputs per ha each year. Agricultural soils return on average only 2 tonnes of residues per ha each year (Hughes, Kauffman and Jaramillo, 1999).

Forest cover loss in the global tropical rainforest biome accounts for about one third (32 percent) of all global forest cover loss, and nearly half of this loss of tropical rainforest occurs in South American rainforests. Several studies have been carried out and information is documented in the region related to deforestation and reforestation (CIAT, 2014; Gardi *et al.*, 2014). The tropical dry forests of South America had the highest rate of tropical forest loss, due to deforestation dynamics in the Chaco woodlands of Argentina, Paraguay and Bolivia (Grau and Aide, 2008; Viglizzo and Jobbagy, 2010). Brazil is a global exception in terms of forest policy change, with a dramatic policy-driven reduction of deforestation in the Amazon Basin (INPE, 2010, 2013; Spavorek, 2012) (Figure 12.5).




Prepared by C. Cruz-Gaistardo

Figure 12.5 | Tree cover in the tonne  2000 and forest loss in the period 2000-2014. (A) Brazil, centered at 5.3°S, 50.2°W; (B) Mexico and Guatemala, centered at 16.3°N, 90.8°W and (C) Perú, centered at 8.7°S, 74.9°W; (D) Argentina, centered at 27.0°S, 62.3°W and (E) Chile, centered at 72.5°S, 37.4°W. Source: Hansen et al., 2013.

The litter on the ground also influences carbon fluxes to the mineral soil. A conserved forest can accumulate up to 10 tonnes of litter per hectare; however, when this forest is degrading its accumulation rate drops to 2 tonnes per ha (Cruz-Gaistardo, Díaz and Martínez, 2010). In an extreme case of erosion, litter would completely disappear. The loss of soil carbon results in the loss of natural fertility and of the existing biodiversity. These factors lead to extreme soil degradation, and could affect the local and regional economy (Smith *et al.*, 2007).

In the temperate Pampas of Argentina and Uruguay, conversion of grassland and pastures to agriculture caused soil organic carbon stocks to decrease from 27 Mg $ha^{-1}$ to 19-20 Mg $ha^{-1}$ in the first 20 cm of soil profile (Alvarez *et al.*, 2009).

Across LAC, there are initiatives to improve soil health and the environment. The large cities in LAC, such as Mexico City, Lima, Buenos Aires, São Paulo, Rio de Janeiro, Santiago and Bogota, manage their urban wastes, which are rich in organic carbon, in order to reduce pollution, especially in the surrounding rural areas which typically receive the waste (Da Silva and Donini, 2008). In the region of Santiago de Chile, for example, about 200 Gg of urban sludge and muds are produced each day by the seven million inhabitants (CEPAL, 2010). These wastes are currently being evaluated as possible fertilizers for farmland. However, this type of sludge may need up to three years to be mineralized, dissolved and available to plants. There is a risk that the concentration of metals (mainly zinc and copper) may increase in the soil (González, 2008). In Brazil, there are initiatives to grow rice without flooding the soils (so reducing methane emissions) and to cut sugar cane without resorting to direct burning. In Colombia and Cuba the use of organic fertilizers is widely promoted (Willer and Lukas, 2009).

International policy initiatives such as the United Nations Framework Convention on Climate Change (UNCCCD) and the programme for Reducing Emissions from Deforestation and Forest Degradation (REDD) often lack the institutional, investment and scientific capacity to begin implementation. In effect, policy is sometimes ahead of operational capabilities, even when the necessary information is available. By contrast, Brazil's use of Landsat data in documenting trends in deforestation was crucial to its policy formulation and implementation. To date, only Brazil produces and shares spatially explicit information on annual forest extent and change (UNFCCC, 2013; INPE, 2010, 2013).

Most soil sampling sites in LAC have been selected to address questions related to fertility or taxonomy. They were not selected to specifically quantify carbon in different pools (above- and below-ground). Consequently, they cannot be used for payment for environmental services. To overcome this, Mexico and Brazil are currently conducting national soil surveys designed to quantify soil carbon, increasing the number of sites within a systematic grid and using state-of-the-art instrumentation. The surveys are employing field spectrophotometers and micrometeorological towers to measure carbon fluxes between the land and atmosphere (Vargas *et al.*, 2013). In the case of Mexico, there are currently 11 000 sites with systematic information on all carbon reservoirs and coordinated programs for re-sampling and continuous monitoring.

### 12.4.3 | Soil salinization

Salt-affected soils are found mainly in the arid and semi-arid regions. Salinization caused by irrigation affects 18.4 million ha in LAC, particularly in Argentina, Brazil, Chile, Mexico and Peru (AQUASTAT, 1997). Many of the large plains of the continent are affected by natural salinization, but land use changes and overgrazing have also caused topsoil salinization (Taboada *et al.*, 2011; Bandera, 2013; Di Bella *et al.*, 2015).

Around 85 million ha are affected by excess of salts and sodium in **Argentina**, including arid and semi-arid zones (Szabolcs, 1979). Information provided by Bandera (2013) indicates that Argentina has approximately 600 000 ha of irrigated soils affected by salinity, which is the third largest area in a single country after Russia and Australia. In Argentina there are also areas of soils affected by salts in humid and sub humid climates, where salts come from groundwater. This is the case of the Pampa Deprimida (Depressed), the Buenos Aires East-Center (9 million ha), Buenos Aires Northwest (2.5 million ha), and the Submeridional Lowlands of Chaco and Santa Fe provinces (3 million ha).

The irrigated agricultural area of the northeast region of **Brazil** is around 500 thousand ha, and 25–30 percent is in the process of salinization (Heinze, 2002). Irrigation-induced salinization is an important land degradation process that affects crop yield in the Brazilian semi-arid region. Gypsum has been used as a corrective measure for saline soils in these areas (Moreira *et al.*, 2014). The addition of gypsum to irrigation water improves soil physical and chemical properties and can be considered as an alternative for the reclamation of saline-sodic and sodic alluvial soils in Northeast Brazil (Silveira *et al.*, 2008).

The salinity of soils on the cultivated land in the coastal valleys in northern **Chile** (Azapa and Lluta valleys) is generated by the salinity of irrigation water.

In **Colombia**, soils susceptible to salinization cover approximately 86 592 $km^2$, of which 90 percent are located in dry regions (Casierra-Posada, Pachón and Niño-Medina, 2007). Areas susceptible to salinization are located in the Caribbean region and inter-Andean valleys and highlands.

In **Cuba**, the soils with primary salinity only occupy restricted areas, often near to sea coasts. Secondary salinity, however, affects the majority of Cuban soils. The main causes of secondary salinity are: increase of the level of saline groundwater, deforestation of hilly lands, and use of saline water for irrigation (Alvarez *et al.*, 2008). There are 160 000 ha under rice, of which approximately 100 000 ha have problems of salinity and/or sodicity, in varying degrees (Borroto and Castillo, 1986).

In **Ecuador**, approximately 8.1 million ha have soils suitable for agriculture, of which about a quarter are currently used for agriculture. This includes: production of short cycle crops such as rice, maize, cassava, soy, watermelon, melon, tomato, pepper; cultivation of perennial crops, including cocoa, coffee, sugarcane and banana; and, on 63 percent of the area, natural and artificial pastures. One of the most serious problems facing this ecosystem is the increase in salinity. This is caused by irrigation with waters of medium quality and by excessive use of fertilizers in fert-irrigation. Soil salinity constitutes one of the main causes of crop yield reduction, and a significant part of Ecuadorian highland soils are considered as having high-salinity. The main causes are the pyroclastic nature of the soils, the effects of erosion, and the poor use of irrigation water (Jaramillo, Arahana and Torres, 2014).

In **Mexico**, approximately 20 percent of irrigated agricultural land (6 million ha) is affected by salinity and sodicity problems. In 1964 it was estimated that, in the irrigation districts of Culiacán, Fuerte River, Río Mayo, and Rio Yaqui which have a total area of 610 701 ha, over one third (218 495 ha, 36 percent) of the area had some kind of salt problem (Palacios-Vélez, 2012).

The lack of complete feasibility studies prior to implementing irrigation projects in Peru has caused increased drainage and salinity problems on 2 500 $km^2$ in the Coastal Area. In fact, all irrigation projects on the coast have experienced drainage and salinity problems within a few years after starting to irrigate (Cornejo, 1970). More than 300 000 ha (40 percent of the cultivated land in Peru's Coastal Valleys) were affected by soil salinity in the 1970s. About 25 percent (roughly 190 000 ha) were characterized by light to extreme salinity (>4 dS $m^{-1}$), enough to have negative effects on crop productivity (World Bank, 2007). Currently, there is little interest from the government to stop degradation of land. Even up-to-date information is lacking and what there is dates back to the 1970s (Santayana, 2012).

In **Venezuela**, the existence of problems of salinity was recognized in soils in the arid and semi-arid areas of the States of Zulia, Falcón, Lara, Anzoátegui and Trujillo (Villafañe, 1995). Falcon was one of the major vegetable producing states in Venezuela until soil degradation by salts had negative effects on yields and caused the abandonment of farms in this area.

## 12.5.1 | Argentina

Argentina is the eighth largest country in the world, with an area of 2 780 400 $km^2$. Seventy percent of its territory has an arid, semiarid or dry sub-humid climate, and the remaining 30 percent has a humid or sub humid climate. Regions under humid and sub humid temperate and subtropical climates (e.g. Pampean, Chaco and Mesopotamia) concentrate on the production of cereals, oilseeds, industrial crops, forages, forest plantations, domestic livestock and dairy products (SIIA, 2015).

Agriculture in Argentina began in earnest at the end of $19^{th}$ century with the arrival of European immigrants and government colonization policies (Barski and Gelman, 2001; Viglizzo and Jobbagy, 2010). Agriculture and livestock grazing expanded until the mid-$20^{th}$ century by bringing new lands into production, largely employing low intensity production practices (Viglizzo and Jobbagy, 2010). This resulted in moderate to severe land degradation, not only in agricultural areas but also in dryland areas (SAGyP-CFA, 1995). In the second half of the $20^{th}$ century agriculture intensified, especially in the Pampean region, with the use of more productive cereal varieties, hybrids and genetically modified crops, fertilizers and no till farming (Paruelo, Guerschman and Verón, 2005; Satorre, 2005; Viglizzo and Jobbagy, 2010).

In recent years, the agricultural frontier has expanded to the north-east, the north-west and the west (Figure 12.6), moving into areas with drier climates and/or less fertile soils (Paruelo, Guerschman and Verón, 2005; Viglizzo and Jobbagy, 2010). As a result, the cultivated area increased from about 15 to 32 million ha from 1988 to 2010, and bulk grain production shot up from about 20 to nearly 100 million tonnes in the same period (SIIA, 2015). At the same time, the ratio of crops produced changed. In 1990, the mix was: 37 percent wheat, 30 percent soybean and 13 percent maize. Twenty four years later (in 2014), production was 61 percent soybean, 19 percent maize and only 11 percent wheat (SIIA, 2015). This shift was driven by export demand for oil and biofuel soybean (Gobierno Argentino, 2014). Although a success in terms of fuel saving and adoption by farmers, this move towards a soybean monoculture appears to have driven many smaller farmers out of business (Pengue, 2005).

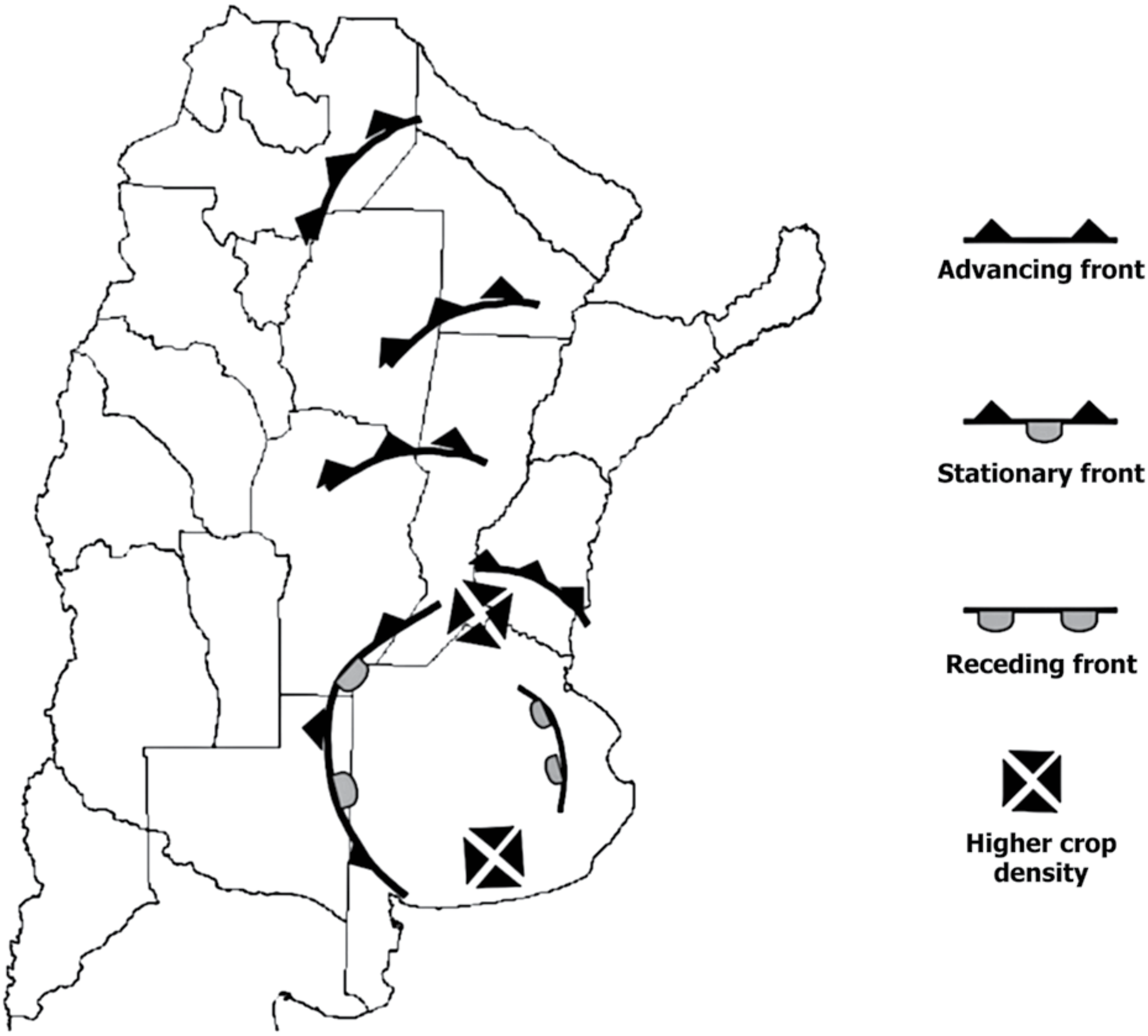



Figure 12.6 | Expansion of the agricultural frontier under rainfed conditions in the north of Argentina.
Source: Viglizzo & Jobbagy, 2010.

It has been estimated that agriculture in Argentina during the 20th century decreased soil carbon stocks by 27-50 percent. The causes included the turning over of grasslands and prairie soils rich in organic C with mould board and disc ploughs, and the loss of crop diversity (Studdert, Echeverría and Casanovas, 1997; Viglizzo and Jobbagy, 2010; Sainz Rozas, Echeverria and Angelini, 2011; Caride, Piñeiro and Paruelo, 2012; Milesi Delaye *et al.*, 2013). The potential of no-till farming to increase soil organic C stocks is still under discussion. In a review of 42 no-till vs plough till data sets from field experiments conducted in the Pampean region, Steinbach and Álvarez (2006) concluded that a 2.76 Mg $ha^{-1}$ organic C increase was observed in no-till systems compared with tilled systems, with a relatively higher increase of organic C in areas of low organic matter level. However, Álvarez *et al.* (2009) observed no significant change in topsoil organic C content after adoption of continuous no-till in previously conventionally tilled loam, silty loam, and silty clay loam soils in well-managed farms of the region.

No-till farming is considered to improve topsoil physical properties, especially when combined with suitable crop rotations and pastures (Álvarez *et al.*, 2014). However, the prevalence of soybean mono-cropping in the Pampean and Chaco regions promoted unfavourable topsoil physical conditions such as laminar and massive aggregation, shallow compaction and decreased infiltration rates (Sasal, Andriulo and Taboada, 2006; Álvarez and Steinbach, 2009; Álvarez *et al.*, 2009, 2014). These structural forms were found to decrease soybean yields under rainfed conditions (Bacigaluppo *et al.*, 2011).

Fertilizer use in Argentina was quite low until the mid-1990s and despite the eight-fold increase in fertilizer use in the last two decades, negative budgets of nitrogen, phosphorus and sulphur still persist in the Pampean region (Lavado and Taboada, 2009; Viglizzo and Jobbagy, 2010). Nutrient removal by grains was found to have exceeded application by 2.3-3.2, 1.4-2.0 and 2.0-2.6 times for N, P and S over a four year period, respectively. Phosphorus is a special issue, as it has decreased to 'deficient' levels in several areas (Sainz Rozas, Echeverria and Angelini, 2012).

During the 20th century, more than 1.2 million ha (32 percent of the agricultural area) were affected by moderate to severe soil water erosion, characterized by 47 to 131 Mg $ha^{-1}$ $yr^{-1}$ soil losses and by 5 to 20 cm surface horizon thickness decreases (SAGyP-CFA, 1995). According to estimations by Viglizzo and Frank (2010), the widespread adoption of no-tillage helped to control erosion losses, which was reported to have decreased to only 7 Mg $ha^{-1}$ $yr^{-1}$. However, more field data are needed to check these estimations.

Salt affected soils cover more than 70 million ha in Argentina, the third largest area in any country in the world (FAO, 1976). At least 600 000 ha of irrigated soils under arid and semiarid climates are affected by anthropogenic salinization, often related to unsuitable drainage management and/or poor water quality. In sub humid and humid regions, there are about 12 million ha of naturally salinized soils. In these areas, anthropogenic salinization was also promoted by livestock grazing (Taboada, Rubio and Chaneton, 2011), supplementary irrigation (Andriulo *et al.*, 1998) deforestation (Nosetto *et al.*, 2012) or afforestation (Jobbagy and Jackson, 2004).

A detailed evaluation of the state of land degradation in the drier areas of Argentina came to the following conclusions (FAO, 2010):

- Eighty one percent, or more than 1 240 000 $km^2$ of the evaluated systems, present some process of degradation. The degree of degradation of dry lands, defined by the intensity of the process, varies from 'non-degraded' to 'extreme'. This result is obtained after adding all degradation processes identified, including water and wind erosion, salinization and loss of vegetative cover.
- Amongst the degrading processes analyzed, 50 percent of the area is affected largely by processes of biological degradation (variation of vegetative cover, loss of habitats, and decrease of biomass). Twenty 6 percent of the area presents a strong degree of degradation. The rate of degradation is slow in 40 percent of the areas with biological degradation, while almost 20 percent of these areas present a high rate of increase.
- Fifteen percent of the land use systems analyzed presented symptoms of physical degradation of the soil (compaction, crusting, flooding). Of these 60 percent present a high degree of degradation. Thirty percent are degrading at a moderate rate.
- Five percent of the area analyzed presented symptoms of degradation of water resources (decrease of the average moisture content of the soil, changes in volume, reduction of the quality of water, reduction of the capacity to capture and retain water). Eighty percent of the area presents a strong degree of degradation, with approximately 20 percent having a moderate rate of increase.
- Forty percent of the area analyzed is affected by wind erosion, with a degree of degradation that is mostly moderate to strong with a tendency to increase. Water erosion affects 40 percent of the area analyzed (Figure 12.7), with a similar degree of severity to wind erosion, although with a lower rate of increase.

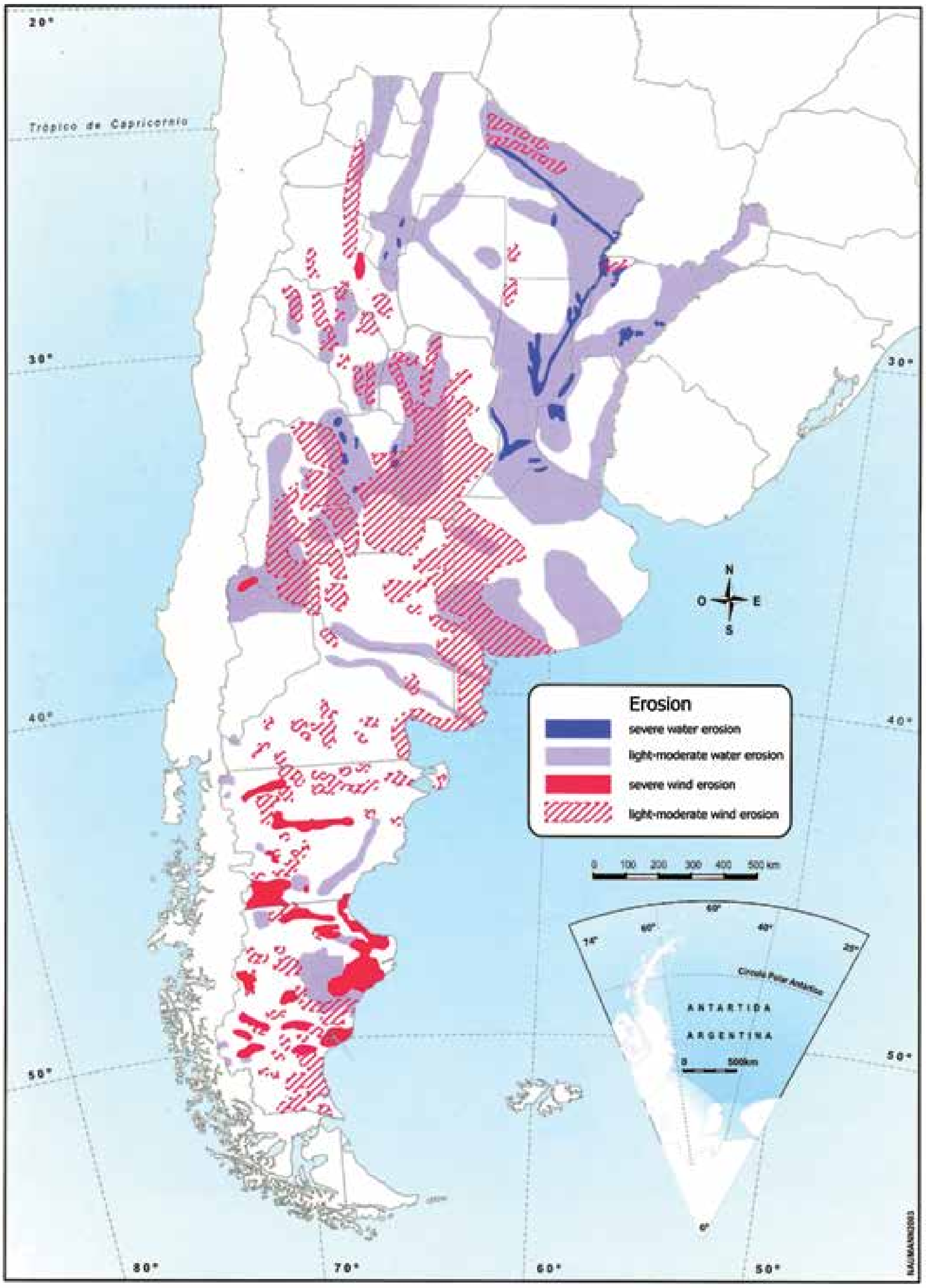



Figure 12.7 | Percentage of areas affected by wind (a) and water erosion (b) in Argentina.
Source: Prego et al., 1988.

## 12.5.2 | Cuba

The main island of Cuba is the largest island in the West Indies, with a total land area of 104 945 km². The area of the country as a whole, including the Isla de la Juventud (2 200 km²) and around 4 195 keys and small islands, is 110 860 km². The topography is mostly flat to rolling, with rugged hills and mountains in the southeast and south-central area. The Cuban mountain range system is formed by four massifs covering about 18 percent of the surface of the Cuban archipelago. The surface cover of Cuba consists of cropland and crop/natural vegetation mosaics (44 percent), shrub lands, savanna and grasslands (24 percent), forests (23 percent) and wetlands (9 percent).

Mean annual rainfall is 1 335 mm, with a pronounced seasonal variation between the driest and wettest months. Rainfall levels vary widely across the country, from 300 mm annually in the Guantánamo area of the south to more than 3 000 mm in the north. Mean annual temperature is 25°C (CUBA, 2014).

In recent decades, significant variations have been detected in the country's climatic patterns (Centella *et al.*, 1997). An overall increase in temperature has been accompanied by a reduction in annual rainfall totals of 10-20 percent and an increase in inter-annual variation in rainfall of 5-10 percent, with reduced rainfall in the rainy season and increased rainfall in the dry season (Lapinel, Rivero and Cutié, 1993; Goldenberg *et al.*, 2001). At the same time, the frequency of unseasonal droughts has increased.

The National Environment Strategy 2007/2010 is the guiding document for Cuban environmental policy. It defines the five main environmental issues in Cuba, which are: land degradation; factors affecting forest coverage; pollution; loss of biological diversity; and water scarcity. The Strategy proposes policies and instruments to tackle the five issues in order to improve environmental protection and the rational use of national resources. Land degradation is considered the most important of the five issues.

Cuba has a wide variety of soils, including those developed over sedimentary limestone (Nitisols, Ferralsols and Lixisols), and others over older rocks (Cambisols and Phaeozems). Cuba has complete soil studies and maps at cartographic scales of 1:250 000, 1:50 000 and 1:25 000 (Gardi *et al.*, 2014).

The most recent assessment of land degradation at local and national level was carried out between 2006 and 2010, using a standard methodology (Liniger *et al.*, 2011; Bunning, McDonagh and Rioux, 2011). In parallel, the sustainable land management practices applied to stop or reverse the degradation process in the country were inventoried in each land use system (AMA, 2010). A first set of 23 thematic maps at 1: 250 000 scale was produced in 2010 and these were updated in 2013 (IGT-AMA, 2014).

Fifteen different types of degradation, affecting the whole country to a lesser or more serious degree were recognized (Figures 12.8 and 12.9). The four main types of degradation in terms of extent are: (1) loss of topsoil by water erosion, which covers more than 30 000 km² and is present in all provinces; (2) the loss of vegetative cover, which has a similar extent and also occurs in every province; (3) processes of salinization and compaction, which cover between 10 000 to 20 000 thousand km² in 14 and 11 provinces respectively; and (4) loss of habitat condition and areas affected by fire, which occupy up to 5 000 km² each in nine provinces of the country. The other types of degradation such as aridity, loss of soil fertility, reduced organic matter content and reduced quality of surface and groundwater occupy areas that do not exceed 5 000 km².

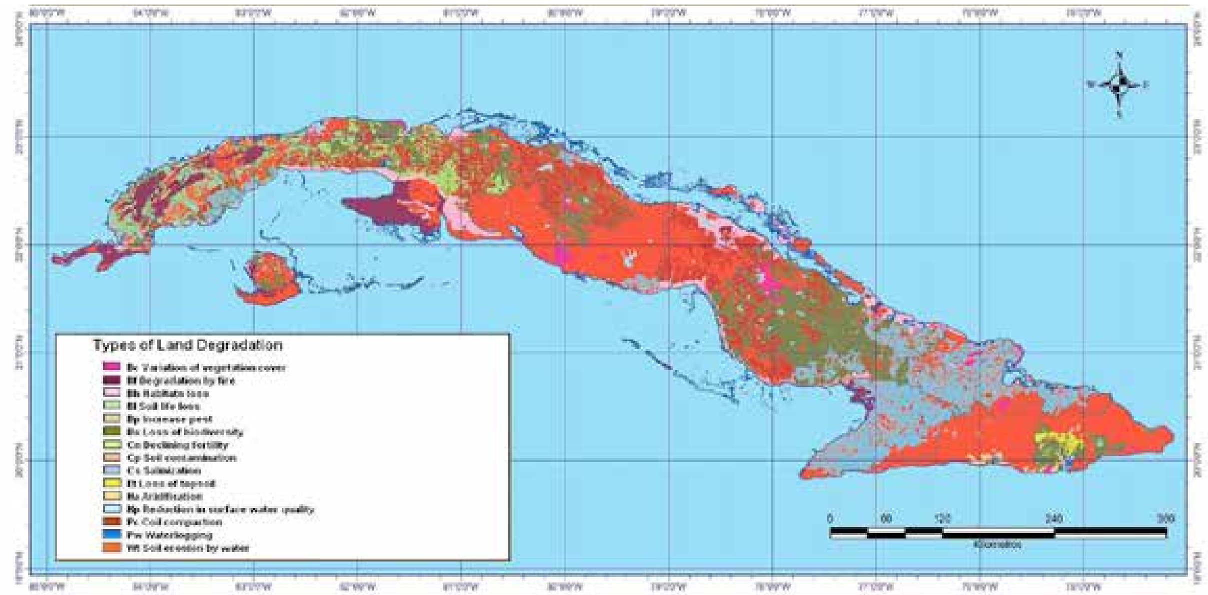



Figure 12.8 | Predominant types of land degradation in Cuba.
Source: FAO, 2010.

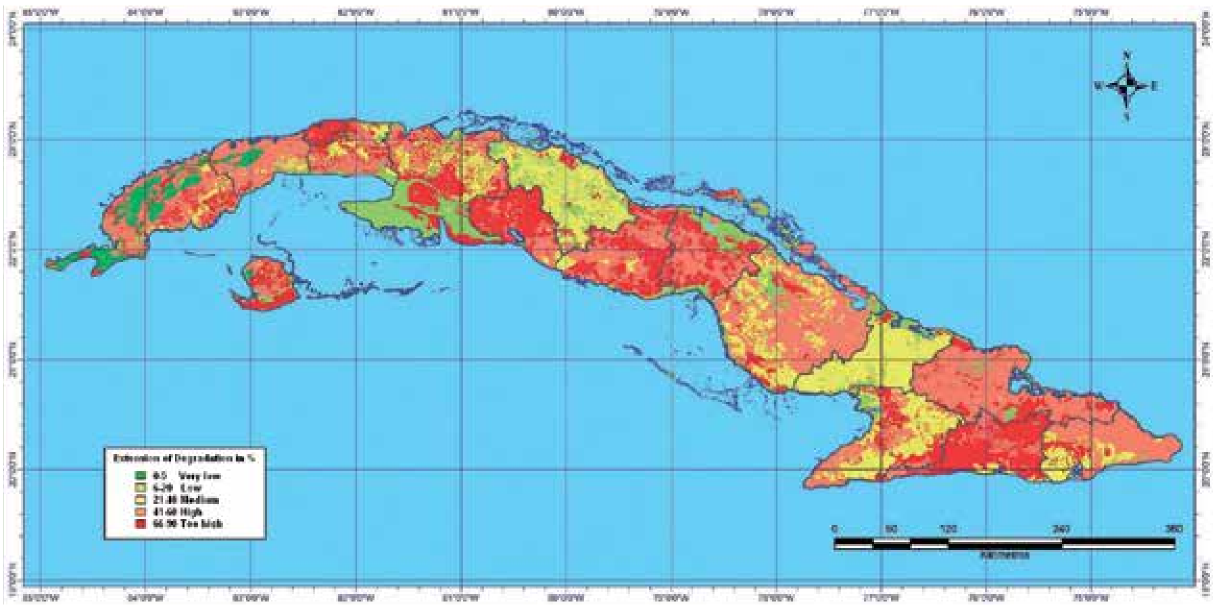


Figure 12.9 | Extent of land degradation in land use system units in Cuba.
Source: FAO, 2010.

As far as the intensity of degradation is concerned, 12 percent of Cuban territory is classified as grade 1 (slight), while 68 percent is grade 2 (slight or moderate intensity) and 19 percent is grade 3 (strong or intense degradation). The last two grades are mainly located in the central and eastern area (Figure 12.10).

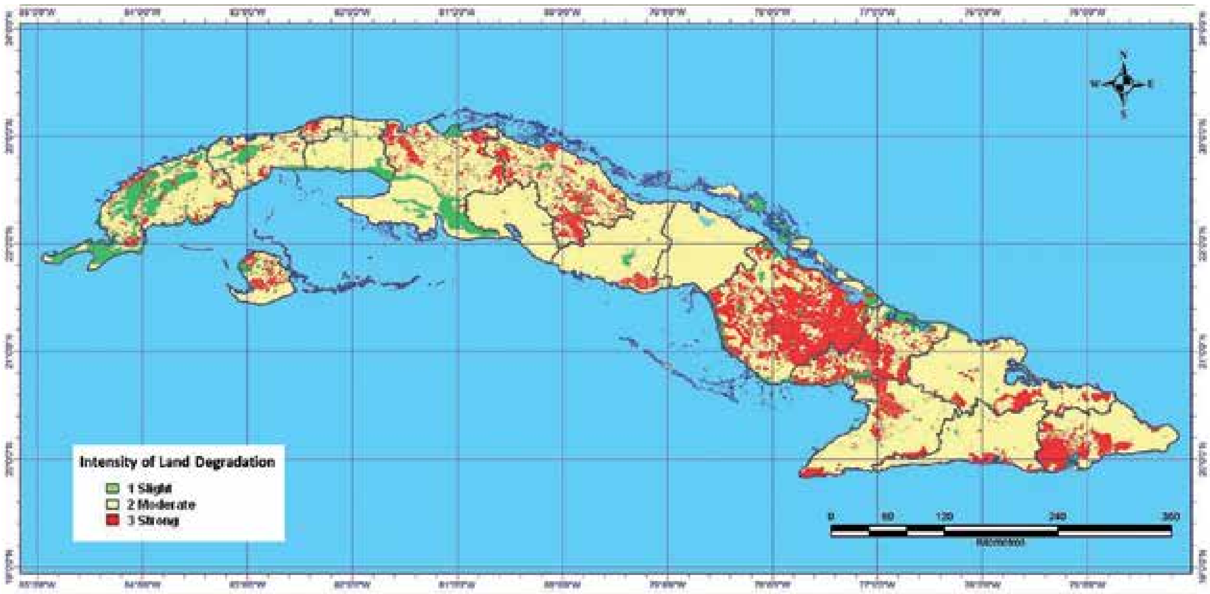



Figure 12.10: Intensity of land degradation in Cuba. Source: FAO, 2010.

A systematic local inventory of land degradation processes was carried out in the dryland areas of Cuba. The drylands occupy a total area of nearly 10 000 km$^2$, and occur mainly in the eastern region of the country, between Camagüey and Guantanamo, covering 6 provinces and 20 municipalities. Surveys were carried out in the most representative areas of Camaguey-Tunas, Granma and Guantanamo covering soil health, water quality and quantity, vegetation status and biodiversity, among others. Since 2001, the country has established different programmes and strategies based on sustainable soil management approaches in order to combat soil degradation. The most important of these is the National Program for Soil Improvement and Conservation, which is overseen by the Soil Institute. Over the last decade, at least 500 000 ha have benefited from these programs, which are financially supported by Cuban government (Instituto de Suelos, 2001).

## 12.6 | Conclusions and recommendations

LAC has a wide range of biomes and probably the largest potential area of cropland in the world. The soils of the region are subject to a number of threats, of which the three most important are: soil erosion, organic carbon losses and salinization. Other threats such as imbalance of nutrients, loss of biodiversity, compaction, waterlogging, contamination, and sealing and capping are also common (Table 12.1).

The most important ecosystem services affected in LAC are: climate regulation through the disturbance of the C and N cycles due to deforestation, and water regulation and food production on sloping lands. Deforestation and erosion caused by inappropriate land use are the initial causes of various anthropogenic threats to soil quality.

An enhanced natural resource information system is necessary in many countries of LAC, in order to perform a better diagnosis of soil conditions and their level of degradation. This will allow possible solutions to be identified, including land use planning and appropriate legislation.

A major effort is required to design and implement sustainable soil management in the region, taking into account the risks and threats assessed as well as the particular characteristics of each country. A participatory process is required if the final goal is to be reached, namely, protection of the soil resource for food security and for the production of ecosystem services for present and future human well-being.

Stable: =
Variable: ↗↙
Improving: ↗
Deteriorating: ↙
Evidence and consensus is **low**
Evidence and consensus are **limited**
**Adequate** high-quality evidence and **high level** of consensus

Table 12.1 | Summary of Soil Threats Status, trends and uncertainties in in Latin America and the Caribbean

| Threat to soil function | Summary | Condition and Trend | | | | | Confidence | |
|---|---|---|---|---|---|---|---|---|
| | | Very poor | Poor | Fair | Good | Very good | In condition | In trend |
| Soil erosion | Widespread across the region. Landslides are accelerated by land use in highland areas | | ↙ (Deteriorating) | | | | Adequate | Limited |
| Organic carbon change | Declines are caused by deforestation, intensive cultivation of grasslands and monoculture. | | ↙ (Deteriorating) | | | | Limited | Limited |
| Salinization and sodification | Caused by inadequate irrigation technology and water quality. Land use changes also promote salinization. | | ↙ (Deteriorating) | | | | Adequate | Adequate |
| Nutrient imbalance | Most countries have negative nutrient balances due to over-extraction. In some cases over fertilization also causes nutrient imbalance. | | ↙ (Deteriorating) | | | | Limited | Limited |
| Loss of soil biodiversity | Suspected to occur in deforested and over-exploited agricultural areas. | | | ↗↙ (Variable) | | | Low | Limited |
| Compaction | Caused by overgrazing and intensive agricultural traffic. | | ↙ (Deteriorating) | | | | Limited | Limited |
| Waterlogging | Due to deforestation and poor structural conditions in agricultural areas. | | | = (Stable) | | | Adequate | Adequate |
| Soil acidification | Soil acidification is limited to some areas with overuse of N fertilizers | | | ↗↙ (Variable) | | | Low | Low |
| Contamination | Industrial sources cause soil contamination in some places. Non-point soil pollution prevails in sites with intensive agriculture (e.g. herbicides residues). | | | ↗↙ (Variable) | | | Low | Limited |
| Soil sealing and land take | In some valleys and floodplains, urbanization has expanded onto fertile soils. | | | ↗↙ (Variable) | | | Limited | Limited |

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