World Soils Book Series

Juan F. Gallardo *Editor*

The Soils of Spain

Springer

World Soils Book Series

Series editor

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Preface

About 3 years ago, I was approached by Springer to write a book on Spanish soils that could become part of the international book series of Prof. Alfred Hartemink, *The World Soils Book Series*. I gave it a lot of thought, as involved a lot of time and effort, especially since I was (and still do) frequently travel to Latin American countries. In order to have the most complete and interesting content possible for this book, I decided to ask other experts in Spanish soils to participate in the project. After three long years of intensive discussions, writing, revising, and rewriting, the book is finally finished.

The Soils of Spain gives a comprehensive overview of Spain's soils and, in addition, of the status quo of soil science in Spain; the book also reveals the distribution of soils in the various regions of Spain and their properties. Therefore, this book is, in essence, a basic documentation of the soils of Spain, written by soil experts and scientists with much experience in soil research—all of whom are looking for a better understanding of Spanish soil resources. All topics included are up-to-date and allow the use of the material included. In addition, an abundant bibliography is included in each chapter.

Therefore, The Soils of Spain is of interest not only to soil scientists, but also to geographers, territory planners, agronomists, food producers, foresters, and environmentalists, among others.

A regional structure was chosen in this book because Spain, in addition to being a vast country, is comprised of very dissimilar areas in which climatological and geological soil factors diverge, causing distinct effects and determining various soil units.

This book is divided into six chapters:

- An introduction to the soils of Spain.
- In the second chapter, the classification and distribution of the soils of Spain are reviewed.
- The third chapter discusses the soils of the humid northern Iberia.
- The fourth provides a picture of the soils in the arid southern and Northeastern Spain.
- In the fifth, the Mediterranean soils, dominated by red colors, are exposed, using the presence of olive trees as an indicator to distinguish whether these soils are *climax* or just *paleosols*.
- And lastly, the sixth chapter addresses the main challenges and future scenarios related to the soils of Spain for the coming years.

I hope this structure can help readers understand the diversity of soils in Spain because of the very different climatic and geological features (soil factors) found there.

This is our personal contribution to the International Year of Soil (2015).

Acknowledgments

I would like to personally thank Dr. Alfred. E. Hartemink, who proposed the publication of this volume. I also thank the various contributors for their excellent work and, last but not least, Dr. M. Isabel González, soil scientist and professor at the University of Salamanca (and my wife), for supporting me to conclude my scientific career.

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Introduction

1

Juan F. Gallardo

Spain is a large European country (about 500,000 km^2) located in the Iberian Peninsula. (Portugal is the other country, about 92,000 km^2, occupying most of the western part of the Peninsula, except in the north). In addition, some islands belong to Spain; the large ones are located in the western Mediterranean Sea (Balearic Islands) and the others off the western coast of the African Sahara (Canary Islands).

1.1 Geology and Geomorphology

Spanish territory has various environments: (1) big mountains, with west-east direction, the rough ones located in the north (Cantabrian and Pyrenees Mountains), central (Sistema Central System and the Toledo Mountains), and in the south (*Sierra Morena* and *Sierra Nevada* Mountains), and to the northwest-southeast the *Sierra de La Demanda* Mountains (or Iberian System); (2) two large tableaus or "*mesetas*" (Fig. 1.1), the northern one (*Meseta Castellano-Leonesa*) and the southern one (*Meseta Castellano-Manchega*); and (3) two elongated valleys (North Ebro River Valley and South Guadalquivir River Valley).

From the geological point of view, Spain is very complex; there is a large diversity of geological formations (Fig. 1.2), but they can be simply grouped into four main types, depending on their lithological and hydrologic characteristics:

1. The western sector of the Iberian Peninsula (including most of Portugal) has mostly igneous granite and related rocks, as well as Paleozoic metamorphic materials (shale, schists, greywacks, gneiss, etc.), generically with low permeability. Acid rocks, such as granite, quartzite, or schist, are dominant in the areas that have the most rain (Galicia and Western Asturias), leading to a great variety of soils. Sedimentary rocks, such as limestone, lutite, and even gypsum, are frequently found in the eastern area, between Cantabria and the Pyrenees, hindering acidification.
2. There are areas with loose or semi-consolidated sedimentary materials (such as gravel, sand, and sometimes silt or clay) that cover the valley bottoms of the rivers (mainly the Ebro and Guadalquivir Rivers), and deposits of a similar nature that extend across the two large mesetas or tableaus (Duero and Tajo watersheds; Fig. 1.1), these are in addition to the Mediterranean deltas (the Llobregat and Ebro Rivers), and coastal areas, including the large plains, as in the Provinces of Castellón and Valencia (Eastern Spain), among others.
3. There are areas that are rich in carbonate materials, generally calcareous, having in general high permeability, sometimes forming spectacular karts. These sedimentary basins, filled with detrital deposits, were formed during the Neogene and the Quaternary Periods, where carbonated materials (such as limestone, dolomite, marls, and sometimes gypsum) are frequently dominant, forming the eastern and southern sectors of the Iberian Peninsula and Balearic Islands.
4. Especially in the Canary Islands, rocks are volcanic in nature; in the interior of the peninsula, there is some evidence of volcanos, such as in Campo de Calatrava (southern meseta) or in the vicinity of Olot (Catalonia, northeastern Spain).

1.2 Climate

This orography results in a multiplicity of climates in Spain (Fig. 1.3); knowing that the wet fronts flow from west (Atlantic Ocean) to east (Mediterranean Sea), all northern and western areas of the mountains are, in general, rainy. Mountains in Portugal are concentrated in the north (close to

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Fig. 1.1 Large geomorphological areas found in Spain

Galicia), the *Tras-os-Montes* and the *Serra da Estrela* Mountains, and they impede the entry of wet fronts to the north meseta castellano leonesa pen-plain, resulting in a semi-arid climate. In addition, all the territories on the southern or eastern slopes of the mountains are semi-arid or arid, depending on the distance from the ocean. According to that, we can consider clearly differentiated areas:

(a) *Humid Atlantic and Cantabrian areas*, from Galicia (west) to the Western Pyrenees (east). It is characterized by a large amount of precipitation (in general, more than 1,200 mm yr^{-1}), falling regularly throughout the year, and mild temperatures. Unlike other regions in Spain, the drought period is short, if there is any. The oceanic influence prevents severe frost most of the year.

(b) *Mountainous areas* (Pyrenees, *Sistema Central*, and *Sistema Ibérico* Mountains, *Cordillera Bética* and *Cordillera Penibética* Ranges). Annual precipitation in these mountains is usually more than 1,000 mm yr^{-1}; the summer water deficit should be moderate due to frequent summer storms and because of lower temperatures (below 11 °C).

(c) *Continental* areas (northern and southern mesetas or plateaus). This climate is characterized by wide seasonal and daily thermal ranges, with cold winters and hot summers. Precipitation, in the range of 400–600 mm yr^{-1}, is concentrated mostly in the autumn and winter; this usually means that temperatures range from 9 to 12 °C.

(d) *Mediterranean areas* (eastern, southern, and western areas of Spain). This climate is characterized by hot, dry summers, rainy autumns, and short, mild winters; there is a placid spring. Annual precipitation ranges from 500 to 800 mm yr^{-1}. Mean temperatures usually range from 12 to 15 °C.

(e) *Semi-arid and arid Mediterranean areas* (Central Ebro Valley and southeastern Spain). These areas have precipitation ranging from 150 to 350 mm yr^{-1} with typical and irregular distribution of these rains (mostly torrential in autumn), with long, dry summers and mild winters, which provide long water stress periods.

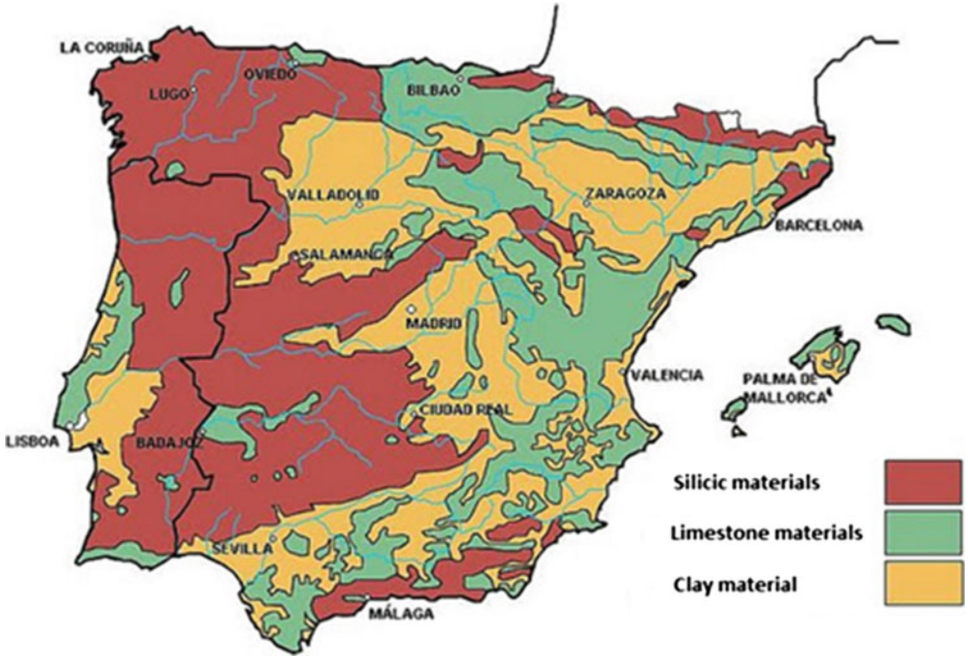

Fig. 1.2 Distribution of rock materials in Spain (volcanic Canary Islands are not included): *brown* signifies silicic Spain (acid materials, as granites, schists, and slates); *green* calcaric Spain (limes and calcaric rocks); and *yellow*, sedimentary Spain (clays and other sediments)

Fig. 1.3 Simple climate map of Spain indicating the rainy areas in *green*, higher than 800 mm yr^{-1}, arid areas in *orange*, lower than 300 mm yr^{-1}, and semi-arid areas in *yellow*

1.3 Soil and Humans

The abundance of arid lands and abrupt reliefs in Spain resulted in a tragic situation that has conditioned the history of the country. The best climatic areas have thin soils, mostly on steep slopes; the best deep soils are located in semi-arid or semi-arid pen-plains or valleys.

In addition, those limitations have perhaps the constant emigration of Spanish citizens to Latin America (mainly from Galicia, Extremadura, or Andalucía, and even from the Canary Islands or Portugal), resulting in a relatively low population density (in comparison with other European countries), i.e., lower than 50 people km^{-2} in practically the entire country, except for the hinterland of the big cities;

then, there is a strong contrast between the abandoned inner territories (Madrid, Seville, and Zaragoza are the exceptions), and the populated coastal border. Nowadays emigration is again taking place because of the recent economic crisis, after a few years of people arriving from Latin America and Morocco.

In addition, human activities have constantly changed the uses, management, and appearance of Spanish soils. The Romans increased the grain agriculture in Spain and promoted the distribution of sweet chestnut trees through eastern and southern Spain (probably chestnut forests were indigenous, especially in western Spain). But the Arab culture supplied a revolutionary tool for semi-arid Spain: the application of irrigation, permitting the cultivation of oriental or Mediterranean products (e.g., citrus fruits), in addition to the use of the horse—at first, as an effective commercial transport tool, and afterwards as an effective weapon (cavalry). Later on, this animal was decisive in the conquest of America and the Philippines (as well as Africa and Brazil for the Portuguese); in this way, the introduction to the Iberian Peninsula (later in the rest of Europe) of new products (potatoes, corn, tomatoes, pimentos, tropical fruits, cactus (*nopales*), cotton, etc.) enhanced the irrigation areas and drastically changed the use of Spanish (and Portuguese) soils. These facts have frequently changed the soil use during the history of Spain.

Nowadays many fields have been abandoned (due to the decrease in the population density in these fields, with coastal areas being the exception), following the process of the concentration of population in big cities; as a result, more land is incorporated as secondary forests (in the drier locations) or directly to re-afforestation (sub-humid and humid locations); in this way, some soils are improving the content of soil organic carbon. In fact, these conditioning geologic, climatic and edaphic factors also show that Spain is actually a confederation of countries (‘*autonomías*’), although they speak different languages even today (Fig. 1.4). In the north, Celtic characters are present in Galicia and Asturias (the northwest corner) and the Basque residents are in the majority in the western Pyrenees (northern Navarra included); meanwhile, the catalonians dominate in the eastern Pyrenees. Central Spain is comprised of Castilla and León (in the northern meseta) and Aragón in the Ebro River Valley; southern to the horizontal Sistema Central Mountains; from west to east are the Extremadura, *Castilla La Mancha* (in which Madrid is located, but as a separate

Fig. 1.4 Administrative division of Spain

federal-like district), the Valencia Kingdom, and Murcia. South of the *Sierra Morena* Mountains is Andalucía, best known for its famous Arabic heritage (especially in Córdoba, Granada, and Seville) and even with desert areas (in Almería, in the southeastern part), together with subtropical conditions (south of the *Sierra Nevada* Mountains). In addition, there are islands (Balearic and Canary) and little *autonomías* (Cantabria or *La Rioja*, the latter producing well-known wines), or African (Ceuta and Melilla) territories (see Fig. 1.6 in Appendix).

1.4 Soil Distribution and Characteristics

Climatological and geological factors condition the soil formation and even the distribution of soils, which is a function of these two main indicated factors. (A general overview concerning the soil occurrence in Spain is shown in Fig. 1.5.) The distribution of soils (thin soils on slopes and mountains in rainy areas and deep soils in semi-arid areas) shows the importance of the soil-water system in the genesis and distribution of the soils of Spain; there is no such thing as “Spanish soils.” Figure 2.1 in Chap. 2, provides essential information for understanding the subsequent chapters.

There is a strip that runs from west to east and overlaps all of northern Spain, setting the limits of the wet, mountainous Spain, where more evolutional soils can be found, including Podzols; nevertheless, Umbrisols, Cambisols, and, on steep slopes, Leptosols, are dominant.

North of the Sistema Central Mountains (sub-humid) there is an area (the Duero River watershed) that has soils with mixed Mediterranean and continental characteristics, where Paleosols are frequently found in the stabilized, non-eroded surfaces. Because of this, Cambisols, Luvisols, and Leptosols are found, sometimes exhibiting surprising red colors, if cultivated.

Typical Mediterranean soils are only evident south of the Central System. Cambisols, Luvisols, Gypsisols, and Leptosols are easily found in this area; sometimes they exhibit red colors (in stable surfaces), and sometimes white (when carbonates are dominant due to erosion). Vertisols appear in the large bottoms of the Andalusian valleys; in the marismas of the Guadalquivir River, saline soils are dominant when they have not been drained.

Arid soils are found in southeastern Spain (Almería and Murcia Provinces) and the Ebro River Valley. Cambisols, Calcisols, Regosols, and, sometimes, Fluvisols and Gypsisols are also found there; saline soils are also frequently found in the more arid districts.

Pristine soils are difficult to find in Spain. Human activities, including frequent wars in which Iberians, Celts, Normans, Greeks, Romans, Alans, Francs, Vandals (some authors think that “Andalucía” means “Land of Vandals”), Goths, Arabs, medieval kingdoms, Berbers, and the French and English and others were involved, in addition to numerous civil wars (the last one from 1936 until 1939) that have moved people from one part of the country to another. As a result, it is not unusual to dig a soil profile in an

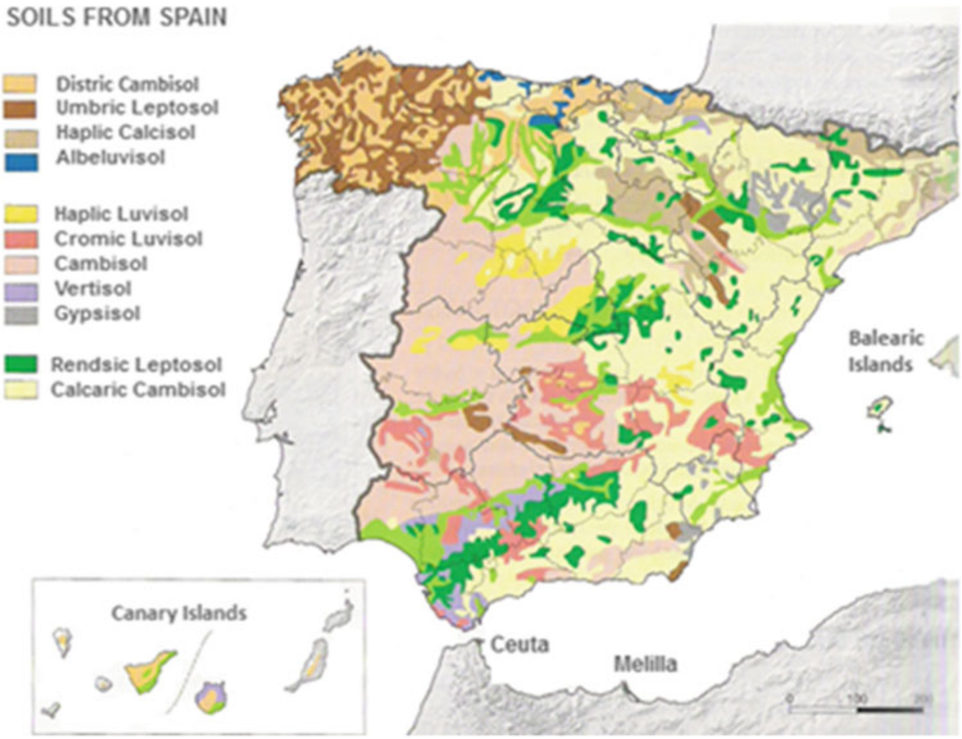

Fig. 1.5 Most abundant soil types in Spain, according to the FAO/UNESCO Classification (1988 version; see Appendix for equivalences in U.S. Soil Taxonomy)

apparently semi-natural forest in the mountains and find below it the remains of buildings or handicrafts, a few centimeters (or even meters) below the surface of the soil.

1.5 Soil Science in Spain

Soil Science in Spain has been influenced by the last Spanish Civil War (1936–1939). Before the war, the chief Spanish soil scientist was Emilio Huguet del Villar, who studied the soils (Huguet del Villar 1983) and vegetation of Spain and published the first Spanish soil maps (1929 and 1937). Unfortunately, as a consequence of the fascist coup led by Franco, many scientists fled to Latin America (mainly to Argentina and Mexico) and a few to the USA or Puerto Rico, with those supposed to have formed part of the Republican "intelligentsia" that remained in Spain having being killed or put in jail. After the civil war, those left remaining after the "*Junta de Ampliación de Estudios*" (established by King Alfonso XIII in 1907, but strongly enhanced during the Republican period; it was the main organization for Spanish science at the time) were incorporated into the newly created (by the dictatorship) *Consejo Superior de Investigaciones Científicas* (CSIC), with Jose María Albareda as secretary-general and the person responsible.

Prof. Albareda was author of a book titled *El Suelo* (The Soil, 1940), which shows that his main interest was precisely soil science. One of his main disciples was the geologist A. Hoyos de Castro, who wrote both editions of *Edafología* (Soil Science, 1955, 1961), after a first monograph, in collaboration with his colleague J.L. Martín Vivaldi (1950). Profs. Albareda and Hoyos de Castro sponsored a network of Institutes (called the Institute or Center of Soil Science, or related names) controlled by disciples of both scientists. In this way, similar centers of soil sciences were established in Barcelona, Granada, Murcia, Madrid, Salamanca, Santiago de Compostela, Sevilla, Tenerife, Valencia, and Zaragoza ("*Aula Dei*"), in addition to other little "stations," as in Almería, Badajoz, León, Málaga, or Pontevedra. This allowed having soil maps of practically all the Spanish provinces, at scales of 1:200,000 or 1:500,000, before 1980, published by the CSIC, the Ministry of Agriculture and, in some cases, by some local Institutions (e.g., *Diputación Provincial*). This enabled creating various soil maps of Spain, the more popular ones being 1:1,000,000; those appeared in 1958 (Ministerio de Agricultura 1958), 1966 (*Instituto Geográfico y Castatral*), and in 1968 (C.S.I.C.); in addition, each autonomous region has its territorial soil map, according to the peculiarities of its environment, even using a different soil classification system. Lastly, since 1985 some Spanish soil maps can be found at the "European Soil Portal," or the information included in those making up part of the *World Map of Soils*, edited by FAO-UNESCO.

Another political factor that promoted soil science in Spain was the temporary stay of Prof. W.L. Kubiëna in Madrid during World War II; his book, *Claves sistemáticas de suelos* (1953), had a great influence on the Spanish classification of soils until the adoption of other modern classifications, such as that encouraged by FAO/UNESCO/WRB or "7th Approximation" or the "USDA Soil Taxonomy" soil classification (USDA-ST).

Soil science improved in Spain, influencing the development of soil science in some Latin American countries, such as Chile or Mexico; nevertheless, the lack of democracy in Spain did not permit the scientific production to be known outside of Spain (except for Latin America), added to the difficulty in learning foreign languages because of international isolation. The main Spanish-language soil science journal in Spain and all of Latin America at that time was *Anales de Edafología y Agrobiología* (published by the Spanish CSIC), that was distributed in all Spanish-speaking countries and countries speaking Romance languages (Portugal and its colonies, Brazil, Italy, Romania, etc.).

Later, the new team responsible for the political direction of Spain after Franco established that Spain was more of an industrial than an agricultural country and decided to abandon or change the aim of the various institutes of soil science. Some of these institutes were changed to biological sciences, mainly focusing on molecular biology, with only a few remaining within the realm of soil science. Furthermore, the journal *Anales de Edafología y Agrobiología* succumbed during the opinion battle among the Spanish scientists, continuing the same editorial line (as a Spanish journal) and those who wanted to move it to a more international scope, replacing the editorial committee and made it compulsory to publish in English (the last volume appeared in 1989, after almost half a century); of course, the budget deficit of the CSIC also contributed to the sad loss of this well-known Spanish soil journal at the time.

A few years ago a new electronic journal appeared, the *Spanish Journal of Soil Science* http://sjss.universia.net, but it suffered from competition with other up-and-coming Latin American journals of soil science (*Ciencia del Suelo* from Argentina, *Agrociencia* or *Terra Latinoamericana* from Mexico, *Chilean J. of Agricultural Research* from Chile, *Suelos Tropicales* from Colombia, etc.), and mostly from the European and North American journals of soil science (which had a greater impact, which is very important in research evaluation).

One of the most well-known Spanish soil scientists is Prof. Carlos Roquero de Laburu; he is the co-author of the most popular book on soil science written in Spanish (Porta et al. 1994, 2003). I remember a conversation with him before his retirement. I asked him something like, "In your opinion, where are the best soils?" His answer was, "In all of Latin America, it is very easy to locate them. Look for a monastery!"

1.6 The Soils of Spain

The soils of Spain will be discussed in this book as follows:

In the second chapter, the classification and distribution of the Spanish soils will be reviewed. In the third chapter the soils of humid northern Iberia will be described. The fourth chapter will provide a picture of the soils of the arid southern and eastern Spain. In the fifth, the Mediterranean soils, dominated by red, will be explained, using the presence of olive trees as an indicator to distinguish whether these soils are climax or just Paleosols. Finally, the main challenges and issues relating to Spanish soils will be presented, especially those that need to be addressed in the coming years.

One of the main problems with soil maps is the soil classification used. In this book, the use of the USDA-ST has been preferred; nevertheless, because of the diversity of ecosystems and the federal structure of Spain, a lot of the original information is basically registered using the FAO/WRB soil classification system. This creates difficulties for the desired homogenization, because the basic data demanded in one system or another are different; where possible, both systems have been indicated. But because of the differences in exigencies, sometimes translation is no very easy further than the Great Group level, and for that, Table 1.1 for fast translation between both soil classifications is shown (in Appendix, where we find a rapid and rough equivalence between both systems). In addition, in Fig. 1.6 (also in Appendix) there is a map indicating the Spanish provinces; this can be a great help to readers who have no basic knowledge of Spanish geography.

Appendix

See Table 1.1 and Fig. 1.6.

Table 1.1 Equivalences of soil units between FAO/WRB and USDA Soil Taxonomy Systems

FAO/WRB Group (1998)	FAO/WRB Units (1998)	Soil taxonomy order	Soil taxonomy suborder	Soil taxonomy Great groups (2003)
Acrisols	*Haplic Acrisol*	*Ultisol*	*Xerult*	*Haploxerults*
		Ultisol	*Ustult*	*Haplustults*
	Humic Acrisol	*Ultisol*	*Udult*	*Hapludults*
Andosols	*Haplic Andosol*	*Andisol*	*Xerand*	*Haploxerands*
		Andisol	*Ustand*	*Haplustands*
	Vitric Andosol	*Andisol*	*Vitrand*	*Udivitrands*
		Andisol	*Vitrand*	*Ustivitrands*
		Andisol	*Torrand*	*Vitritorrands*
Arenosols	*Aridic Arenosol*	*Entisol*	*Psamment*	*Torripsamments*
		Entisol	*Psamment*	*Xeropsamments*
	Haplic Arenosol	*Entisol*	*Psamment*	*Ustipsammnets*
Calcisols	*Haplic Calcisol*	*Aridisol*	*Calcid*	*Haplocalcids*
		Inceptisol	*Xerept*	*Calcixerepts*
	Petric Calcisol	*Aridisol*	*Calcid*	*Petrocalcids*
Cambisols	*Aridic Cambisol*	*Aridisol*	*Cambid*	*Haplocambids*
		Inceptisol	*Xerept*	*Haploxerepts*
	Dystric Cambisol	*Inceptisol*	*Udept*	*Dystrudepts*
		Inceptisol	*Ustept*	*Dystrustepts*
		Inceptisol	*Xerept*	*Dystroxerepts*
	Eutric Cambisol	*Inceptisol*	*Udept*	*Eutrudepts*
	Gelic Cambisol	*Inceptisol*	*Cryept*	*Dystrocryepts*
	Haplic Cambisol	*Inceptisol*	*Ustept*	*Haplustepts*
		Inceptisol	*Ustept*	*Ustepts*
	Humic Cambisol	*Inceptisol*	*Udept*	*Udepts*
	Stagnic or Gleyic Cambisol	*Inceptisol*	*Aquept*	*Epiaquepts*

(continued)

Table 1.1 (continued)

FAO/WRB Group (1998)	FAO/WRB Units (1998)	Soil taxonomy order	Soil taxonomy suborder	Soil taxonomy Great groups (2003)
Chernozems	*Haplic Chernozem*	*Mollisol*	*Ustoll*	*Haplustolls*
Cryosols	*Clayic Cryosol*	*Alfisol*	*Cryalf*	*Haplocryalfs*
	Haplic Cryosol	*Entisol*	*Orthent*	*Cryorthents*
	Mollic Cryosol	*Mollisol*	*Rendoll*	*Cryrendolls*
Fluvisols	*Aridic Fluvisol*	*Entisol*	*Fluvent*	*Xerofluvents*
	Haplic Fluvisol	*Entisol*	*Aquent*	*Fluvaquents*
		Entisol	*Fluvent*	*Ustifluvents*
	Mollic Fluvisol	*Entisol*	*Fluvent*	*Udifluvents*
	Thionic Fluvisol	*Inceptisol*	*Aquept*	*Epiaquepts*
	Yermic Fluvisol	*Entisol*	*Fluvent*	*Torrifluvents*
Gleysols	*Arenic Gleysol*	*Entisol*	*Aquent*	*Psammaquents*
	Fluvic Gleysol	*Entisol*	*Aquent*	*Fluvaquents*
	Haplic Gleysol	*Entisol*	*Aquent*	*Epiaquents*
		Inceptisol	*Aquept*	*Epiaquepts*
	Histic Gleysol	*Entisol*	*Aquent*	*Hydraquents*
	Luvic Gleysol	*Alfisol*	*Aqualf*	*Epiaqualfs*
	Thionic Gleysol	*Entisol*	*Aquent*	*Sulfaquents*
Gypsisols	*Calcic Gypsisol*	*Aridisol*	*Gypsid*	*Calcigypsids*
	Haplic Gypsisol	*Aridisol*	*Gypsid*	*Haplogypsids*
Histosols	*Fibric Histosol*	*Histosol*	*Histosol*	*Fibrists*
	Folic Histosol	*Histosol*	*Histosol*	*Folists*
	Hemic Histosol	*Histosol*	*Histosol*	*Hemists*
	Sapric Histosol	*Histosol*	*Histosol*	*Saprists*
Kastanozems	*Haplic Kastanozem*	*Mollisol*	*Xeroll*	*Haploxerolls*
Leptosols	*Aridic Leptosol*	*Entisol*	*Orthent*	*Torriorthents*
	Gelic Leptosol	*Entisol*	*Orthent*	*Cryorthents*
	Gleyic Leptosol	*Entisol*	*Aquent*	*Epiaquents*
		Entisol	*Aquent*	*Hydraquents*
	Humic Leptosol	*Entisol*	*Orthent*	*Udorthents*
	Mollic Leptosol	*Mollisol*	*Udoll*	*Hapludolls*
	Rendsic Leptosol	*Mollisol*	*Rendoll*	*Cryrendolls*
Luvisols	*Chromic Luvisol*	*Alfisol*	*Xeralf*	*Palexeralfs*
		Aridisol	*Argid*	*Paleargids*
	Chromic or Rhodic Luvisol	*Alfisol*	*Xeralf*	*Rhodoxeralfs*
		Alfisol	*Ustalf*	*Rhodustalfs*
	Gleyic Luvisol	*Alfisol*	*Aqualf*	*Epiaqualfs*
	Haplic Luvisol	*Alfisol*	*Ustalf*	*Haplustalfs*
		Alfisol	*Ustalf*	*Paleustalfs*
		Alfisol	*Xeralf*	*Haploxeralfs*
		Aridisol	*Argid*	*Haplargids*
	Humic Luvisol	*Alfisol*	*Udalf*	*Hapludalfs*

(continued)

Table 1.1 (continued)

FAO/WRB Group (1998)	FAO/WRB Units (1998)	Soil taxonomy order	Soil taxonomy suborder	Soil taxonomy Great groups (2003)
Nitisols	*Haplic Nitisol*	*Alfisol*	*Xeralf*	*Palexeralfs*
		Aridisol	*Argid*	*Paleargids*
	Luvic Nitisol	*Alfisol*	*Ustalf*	*Paleustalfs*
Phaeozems	*Calcic Phaeozem*	*Mollisol*	*Xeroll*	*Calcixerolls*
Planosols	*Haplic Planosol*	*Alfisol*	*Xeralf*	*Palexeralfs*
		Aridisol	*Argid*	*Paleargids*
	Luvic Planosol	*Alfisol*	*Ustalf*	*Paleustalfs*
Podzols	*Haplic Podzol*	*Spodosol*	*Orthod*	*Haplorthods*
	Umbric Podzol	*Spodosol*	*Humod*	*Haplohumods*
Regosols	*Arenic Regosol*	*Entisol*	*Psamment*	*Quartzipsamments*
	Aridic Regosol	*Entisol*	*Orthent*	*Xerorthents*
		Entisol	*Orthent*	*Torriorthents*
	Gelic Regosol	*Entisol*	*Orthent*	*Cryorthents*
	Haplic Regosol	*Entisol*	*Orthent*	*Ustorthents*
Solonchaks	*Aridic Solonchak*	*Entisol*	*Orthent*	*Torriorthents*
	Haplic Solonchak	*Aridisol*	*Salid*	*Haplosalids*
Umbrisols	*Gelic Umbrisol*	*Inceptisol*	*Cryept*	*Eutrocryepts*
	Haplic Umbrisol	*Inceptisol*	*Udept*	*Udepts*
		Inceptisol	*Ustept*	*Ustepts*
	Hyperdystric Umbrisol	*Inceptisol*	*Xerept*	*Dystroxerepts*
	Hyperdystric Umbrisol	*Inceptisol*	*Udept*	*Dystrudepts*
	Hyperdystric Umbrisol	*Inceptisol*	*Ustept*	*Dystrustepts*
Vertisols	*Calcic Vertisol*	*Vertisol*	*Ustert*	*Calciusterts*
		Vertisol	*Xerert*	*Calcixerert*
	Chromic Vertisol	*Vertisol*	*Xerert*	*Haploxererts*
	Haplic Vertisol	*Vertisol*	*Ustert*	*Haplusterts*
	Mollic Vertisol	*Vertisol*	*Udert*	*Hapluderts*

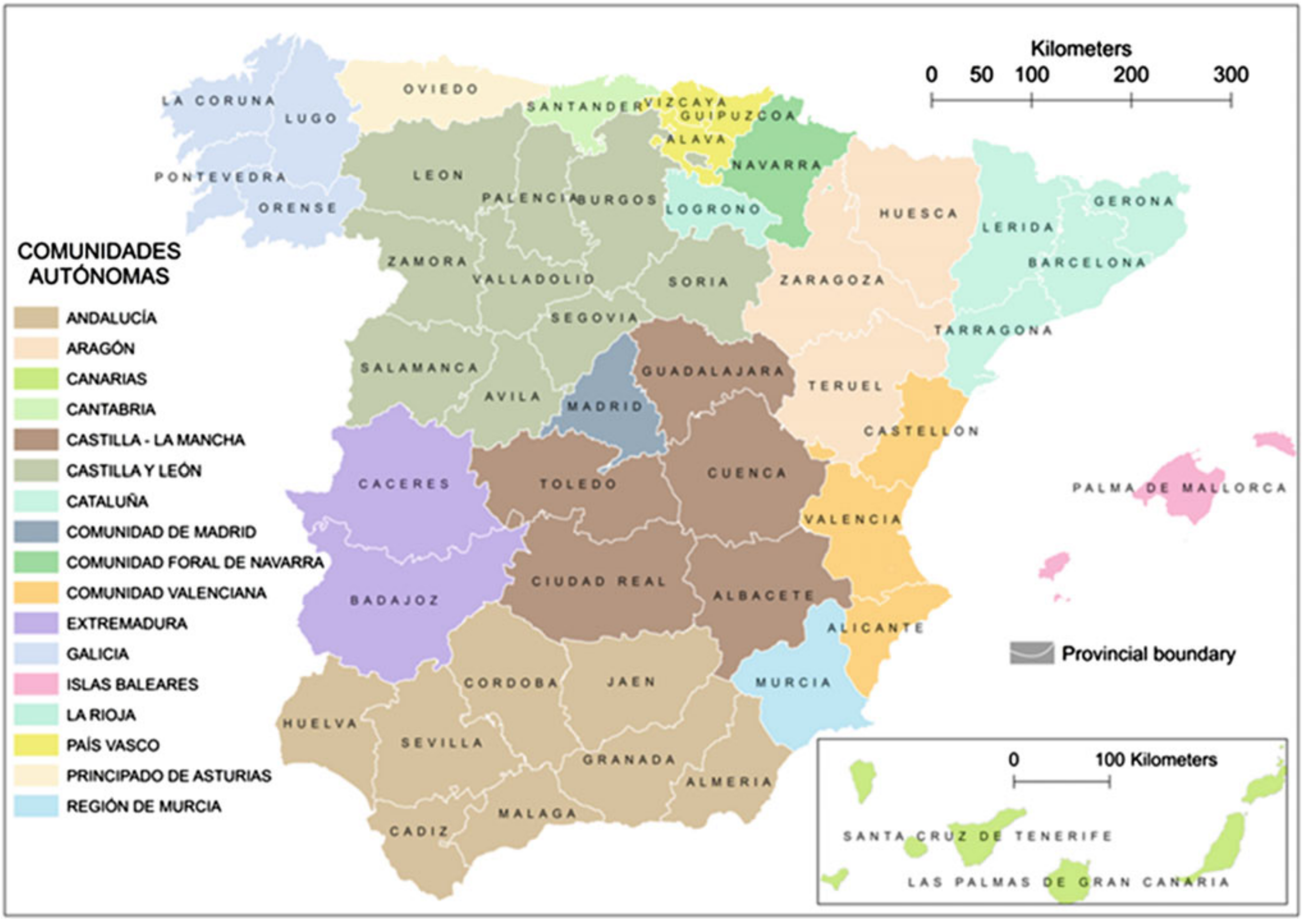

Fig. 1.6 Map indicating the Spanish provinces (see former complementary Fig. 1.4)

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Soil Distribution and Classification

2

Vicente D. Gómez-Miguel and David Badía-Villas

2.1 Introduction

As we move along a territory, anyone can see how the landscape changes while it shows its diversity: plateaus, valleys, forests, fields, pastures, etc. In fact, every landscape has its own combination of soil-forming factors, e.g., climate, parent materials, topography, organisms, and time. These soil-forming factors control the conditions under which the soil-forming processes operate and therefore they determine the soil type at any given location. Soil mapping provides a lateral variation in space with regard to soil types conferring knowledge about soil properties, components and function.

This chapter will describe the main soil types and their distribution along the Spanish geography based on the soil map of the Atlas of Spain's National Geographic Institute at a scale of 1:1,000,000 (Gómez-Miguel 2005). It was done from many previous works (CSIC, 1968; Gómez-Miguel and Nieves, 1990–1998; Gómez-Miguel, 2007b; Huguet del Villar, 1937; SEIS, 2001; Tamés, 1968), according to the guidelines of the *Soil Survey Manual* (1951–1993) and following the methodology of Soil Taxonomy (USDA 1975, 1999, 2006) with synonyms for the WRB provided. (See the Appendix at the end of this chapter; in it, the main equivalences relating to the WRB and the Soil Taxonomy Systems can be found for readers who want a quick equivalence between both soil classification systems.)

It should be noted that all the generalizations made here relate only to specific Spanish conditions. The use of a specific toponymy has been carefully considered and the detailed usage decision implies more precise information, although it can be needed to consult the *Geographic Concise Gazetteer of Spain* (IGN 2006). (For readers who are not familiar with the administrative organization of Spain, please see Fig. 1.6 in Chap. 1 (Appendix)).

2.2 Soil Temperature and Moisture Regimes

Soil taxonomy gives special relevance to the temperature and soil moisture regimes, which are used to define the categories as orders (Gelisols and Aridisols), suborders (Xeralf, Xerult, Xerert, etc.), groups (Xerorthent, Xerofluvent, etc.), subgroups (Aquic, Xeric, Ustertic, etc.), or families (thermal, mesic, etc.).

The temperature regime is intended to assess the thermal influence of climate on soil properties (and crops). This scheme has been calculated from the mean annual temperature of the soil (MATs) at a soil depth of −50 cm (which corresponds to the average annual temperature of the atmosphere plus 1 °C), using the relationship between altitude, latitude, and soil temperature to assign the temperature regime of each unit. Taking these into consideration in Spain, the following temperature regimes can be distinguished: cryic, mesic and thermic. The cryic temperature regime (MATs between 0 and 8 °C, not reaching a summer mean temperature of 15 °C) is the only one that appears in the categories used in the map that corresponds to soils that develop in colder areas at high altitudes (above 1600–1700 m asl in the north and 1700–1800 m asl in the south of Spain). The remaining regions have largely mesic regimes (8 °C < MATs < 15 °C) and a smaller number belong to the warmer thermic temperature regime (15 °C < MATs < 22 °C).

The moisture regime aims to assess the soil water properties (and plant water availability) being determined by the absence or presence of water in the soil's profile depth colonized by roots (moisture control section), as determined during the plant-growing season and also during most of the year. Accordingly, the udic moisture regime on the map (dark

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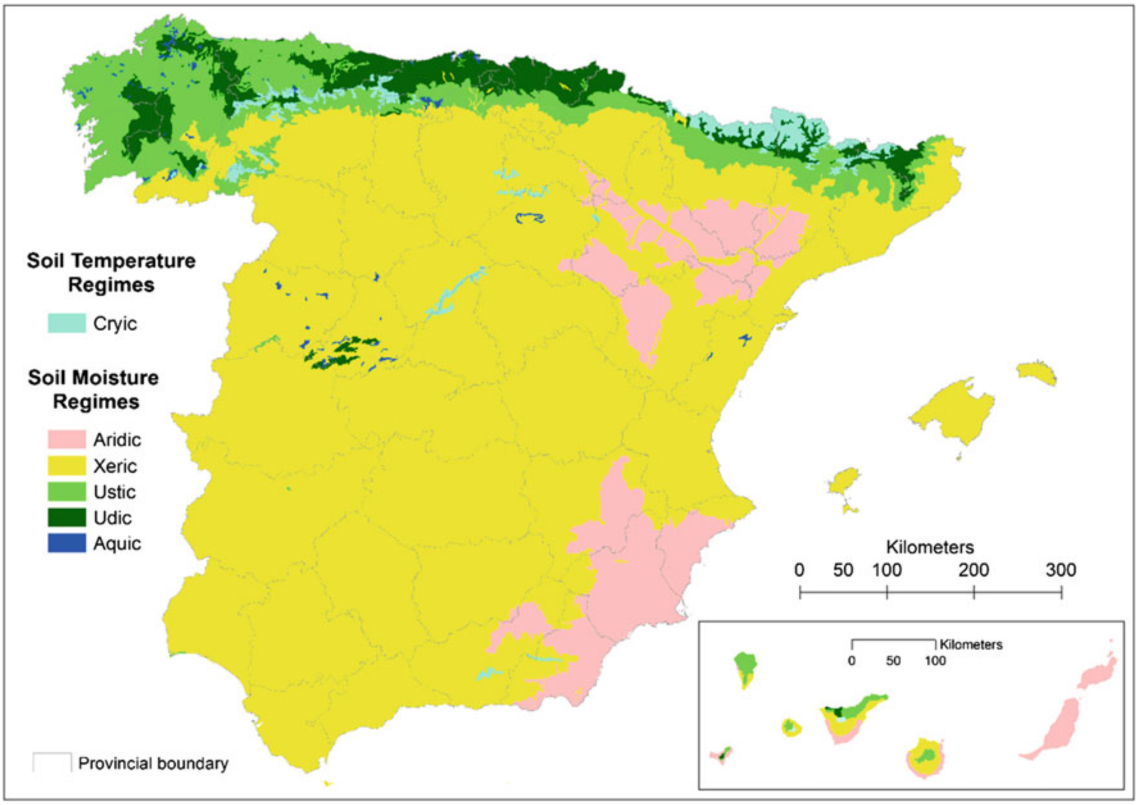

Fig. 2.1 Soil temperature and soil-moisture regimes in Spain: *green* represents wet soils during most of the year; *yellow* shows soils that are completely dry during summer; and *pink* signifies soils that are dry during most of the year (Gómez-Miguel and Nieves 1992)

green in Fig. 2.1) can be distinguished; it is characteristic of soils in which most years the moisture control section remains wet for at least 90 days and is not dry for 45 consecutive days during the four months that follow the summer solstice, which is essentially reduced to the north of Spain. The ustic (light green in Fig. 2.1) with some moisture in the warm season, represents an intermediate situation between the udic regime and xeric or aridic regimes prevailing in the Mediterranean and arid regions of Spain, respectively.

Although the applicability of the ustic concept to Spain seems to be an aberration (more typical of a monsoon climate), it is also true that many observations in the transition zone between other regimes meet the requirements of the ustic regime; xeric (yellow in Fig. 2.1, which is typical of a Mediterranean climate, in which most years the moisture control section remains completely dry for at least 45 consecutive days during the 4 months that follow the summer solstice and also are completely wet at least 45 days in a row during the 4 months that follow the winter solstice). The aridic or torrid (pink in Fig. 2.1) are markedly arid, with a moisture control section that is dry more than half of the time, with less than 90 days of moisture in the soil.

The aquic moisture regime is virtually impossible to map at this scale, although it is used in the described taxonomic units. Specifically, hydromorphic areas (aquic conditions), irrespective of the climatic region in which they are located (azonal character), and aquic and hydromorphy moisture regimes are commonly observed under circumstances of a high water table or heavy water contributions in poorly drained landforms (depressions, watersheds, etc.).

2.3 Soil Geography: Description of Taxonomic Units

In Spain we have mapped 10 of the 12 soil orders considered in Soil Taxonomy (Fig. 2.2), many of them in a short distance, facilitating educational use (Badía et al., 2013b). The Entisols and Inceptisols comprise more than three-quarters of Spain's surface area, while Aridisols and Alfisols account for only a bit more than one-sixth of the geography. The remaining orders do not even reach 2.5 % of the total land (Table 2.1).

2.3.1 Alfisols (Photos 2.1, 2.2 and 2.3)

Alfisols are characterized by an Argillic endopedon (subsurface horizon—in this case a *Bt* genetic horizon) and also by a base saturation greater than 35 %. The profile's development takes place throughout alternating rainy and

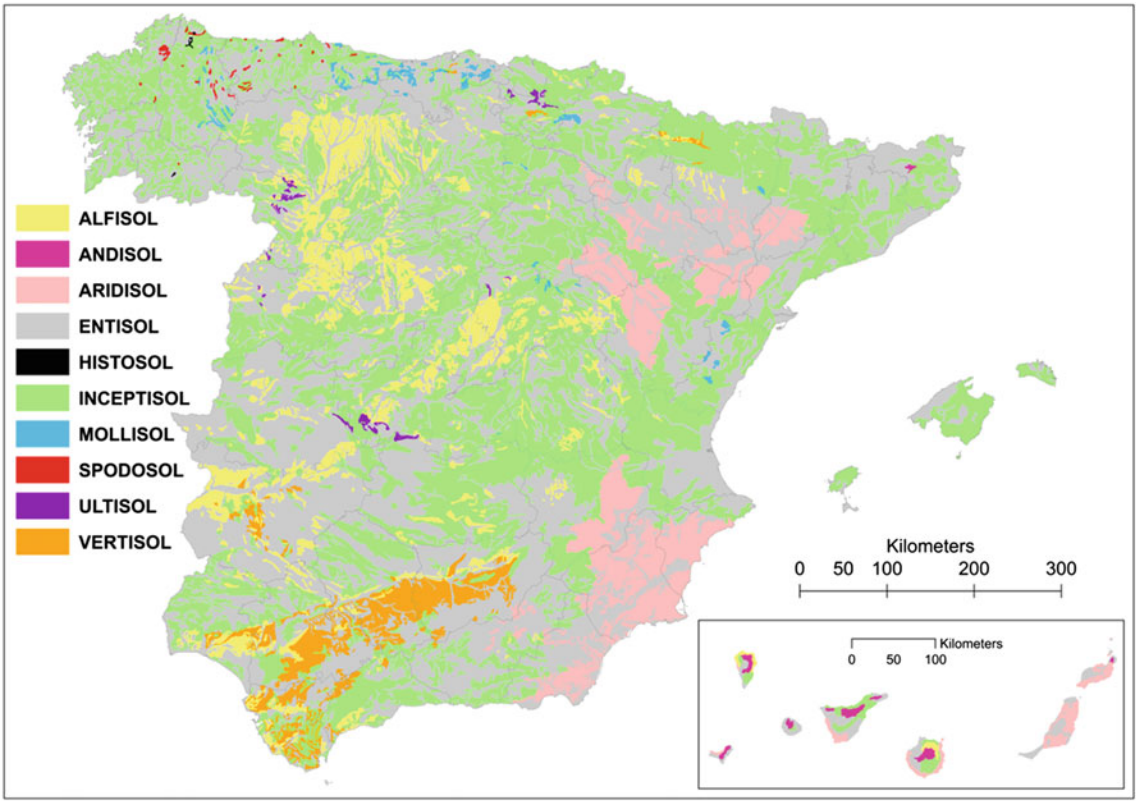

Fig. 2.2 Distribution of soil orders (Gómez-Miguel 2005)

Table 2.1 Size and proportion of the various soil orders found in Spain

Orders	Surface (km^2)	Percentage of the total land
Alfisol	61,861	12.3
Andisol	533	0.11
Aridisol	28,355	5.60
Entisol	200,421	39.9
Histosol	86	0.02
Inceptisol	190,517	37.9
Mollisol	7,490	1.50
Spodosol	645	0.13
Ultisol	889	0.18
Vertisol	11,990	2.40
Miscellaneous land	3,244	0.64
Total	506,030	100

cold seasons, which facilitate the eluviation of clays dispersed in water, once carbonates have been leached, and with other drier periods, which cause the flocculation and subsequent accumulation of clay in the Argillic horizon. With regard to the Argillic horizon, a genetic albic (*E*) is related, which consists of the residual horizon (eluvial) from which clay and free iron oxides have migrated (has segregated primary minerals), so it has taken on a whitish color composed of large amounts of sand and silt.

The characteristics of the Argillic horizon have important implications for the fertility of Alfisols, their use, development and management; in this way, the content and type of clay particles determine the characteristic high cation exchange capacity as a reserve of potential nutrients (fertility potential) and the percentage of basifier cations (base saturation) as a reserve of available nutrients (current fertility).

Alfisols are formed in relatively young surfaces (so as to maintain a significant reserve of primary minerals called

Photo 2.1 Alfisol (Haploxeralf) in Ainzón (Province of Zaragoza)

Photo 2.2 Alfisol (Palexeralf) in Malpica de Tajo (Province of Toledo)

phyllosilicates or, in general, clays, etc.), on stable positions (i.e., free of soil erosion and other disturbances) during at least the last millennium. Their preferential location in high river terraces does not diminish the importance that also takes place in other, more or less stable lithologies and geomorphologies (*rañas*, sandy, arkosic deposits, etc.).

Alfisols can dispose of an adequate drainage system, resulting in very high irrigation suitability, provided that the Argillic horizon is not excessively thick and its clay content relative to the surface horizon is not very high, or, as in the case of the fluvial terraces, it rests on a layer of gravel. Moreover, the natural laminar erosion and frequent leveling carried out by man constitute a significant risk to these soils, because if the topsoil (*Ap*) is eroded, the Argillic horizon—by means of its higher clay content—causes soil waterlogging; in addition, it also restricts plant germination and growth (for example, by surface crusting) in any case.

In Alfisols, the suborders are defined by the moisture regime (aquic, udic, ustic or xeric) or temperature (cryic), while the group is defined by the existence (or not) of a given horizon (hardpan, fragipan, kandic, albic, glossic, calcic, petrocalcic, natric) or related to a diagnostic agronomic importance property (hydromorphy, plinthite, layers, abrupt limit, rubefaction).

In Spain, Alfisols are not linked to any special climate, although they are more widely distributed throughout the xeric moisture regime (Fig. 2.3) that prevents their further evolution.

Alfisols occupy a total of 12.3 % of the country's land (61.9 km^2), which puts them in the third order of surface soils (although possibly in first place from an economic and social standpoint). Obviously, not all Alfisols can be included on the map in detail (for example, on the Island of La Gomera). For this reason, an asterisk [*] will indicate the soil units or horizons identified and/or described in Spain that are not mappable due to their minimal surface and/or socioeconomic importance. Alfisols are preferably engaged to cultivate short cycle crops and forages. This agricultural potential is limited by other features that define the lesser categories, i.e., hydromorphy (Epiqualf), very low temperatures (Haplocryalf), abrupt boundary (Paleustalf and Palexeralf), natric horizon (Natrixeralf*) or albic horizon (Albaqualf*) (Table 2.2).

2.3.1.1 Aqualfs: Epiaqualfs

Among the Aqualfs there is the group of Epiaqualfs that are located in waterlogged areas characterized by an aquic moisture regime affecting the ponding part of the profile.

Photo 2.3 Alfisol (Rhodoxeralf) in Cidamón (La Rioja)

Therefore, they can be defined as Alfisols (with a genetic horizon Btg) whose water table is near the surface for at least a few weeks of the year, although the water table may fall during the dry season. In some regions, rice is cropped, but when other crops want to be introduced, the excess of water must be eliminated from the profile (artificial drainage). Argillic horizons with an aquic regime are rare in Spain and have only been mapped as secondary soils along 1,472 km^2 in some flat areas with a specific lithology.

Epiaqualfs have been reported on to the west of Santa Amalia (Badajoz Province in western Spain) or in the region of Daroca (Zaragoza), north of Ampudia and La Cara (Valladolid and Salamanca respectively, in central Spain), or Sector-Laguna Río Blanco Calderón (the Soria Province), in the foothills of the Sierra de Guadalupe (Cáceres) and platforms of the Guadiana River Valley. Epiaqualfs have also been described in the Tiétar Valley (Province of Cáceres) in a relatively large area that extends towards the east (Campo Arañuelo); these are associated with Palexeralfs with a strong hydromorphism. In this same area, of the Montehermoso *rañas* (a Spanish term that describes a sedimentary formation composed of quartzite cobbles with a fine matrix—clays and oxides—that are situated in the foothills, *glacis*; *rañoide* refers to a raña-like formation; and rañas were formed during the early Pleistocene, when weather was drier and cold, but with sufficient rainfall to move the clay within the soil). These soils are associated with Ultisols, in the same way as the rañas and rañizos of the Province of León, which also coexist with additional associations of Palexeralfs. When Aqualfs have an albic horizon (*E*), they are classified as Albaqualfs*; these are located in specific landforms, such as the rañas of the Province of León (which are associated with Epiaqualfs).

2.3.1.2 Cryalfs: Haplocryalfs

The Haplocryalfs have a frigid or cryic temperature regime, and are associated with steep slopes but well drained (because the parent materials are often coarse colluvial deposits). The coincidence of a cryic regime and an Argillic horizon is rare in Spanish latitudes; the evolutionary sequence *C* -> *Cg* -> *Bg* -> *Btg* usually stops at the first terms.

About 155 km^2 of Haplocryalfs has been mapped, mainly as inclusions; they are found in the Pyrenees, between the Canfranc and Piedrafita de Jaca locations, including the valleys of Ordesa and Monte Perdido, and Artiés (Provinces of Huesca and Lleida). These soils are covered with conifers and grasses adapted to climatic and soil constraints.

2.3.1.3 Udalfs: Hapludalfs

The Hapludalfs are well-drained Alfisols that, at some point, could have developed under a forest cover. Given the distribution of the udic regime (associated with steep slopes in Galicia, the Cantabrian and Pyrenean mountain ranges), Hapludalfs are not common in Spain, covering an area of 1,187 km^2, distributed as main soils in northern Cantabria, the Basque Country, Navarra, Huesca and Lleida. In other areas, mainly northern Spain, they appear only as secondary soils and inclusions.

Hapludalfs have been reported in the Province of Guipuzcoa on volcanic rocks and broken reliefs of Eibar, Azkoitia, Bergara and Zumarraga, and in the valley of Oria and Berastegui; on Astigarra and Irun marls, as well as Bergara and Orexa; on limestone of Azcoitia and Elduaien, together with Zerain and Ataun; on colluvium in Aitzgorri; between the Deva and Oria Rivers in Santullano and Callezuela; and, finally, on stable topographies of Lejona and Portugalete. Hapludalfs have also been identified further east, in the fluvial terraces of the Gállego and Cinca (Huesca) Rivers or the Garonne River Valley (Lleida). Even in the Canary Islands, they have been sited (in the udic region of the Tenerife, Hierro, and Gomera Islands, as for example, at Monte del Cedro). Even though Hapludalfs are characterized by high water availability, their great erodibility has nonetheless limited their agricultural use and sustainability.

2.3.1.4 Ustalfs

The suborder of Ustalfs is determined by the ustic moisture regime. Their natural vegetation is typically of a xerophytic

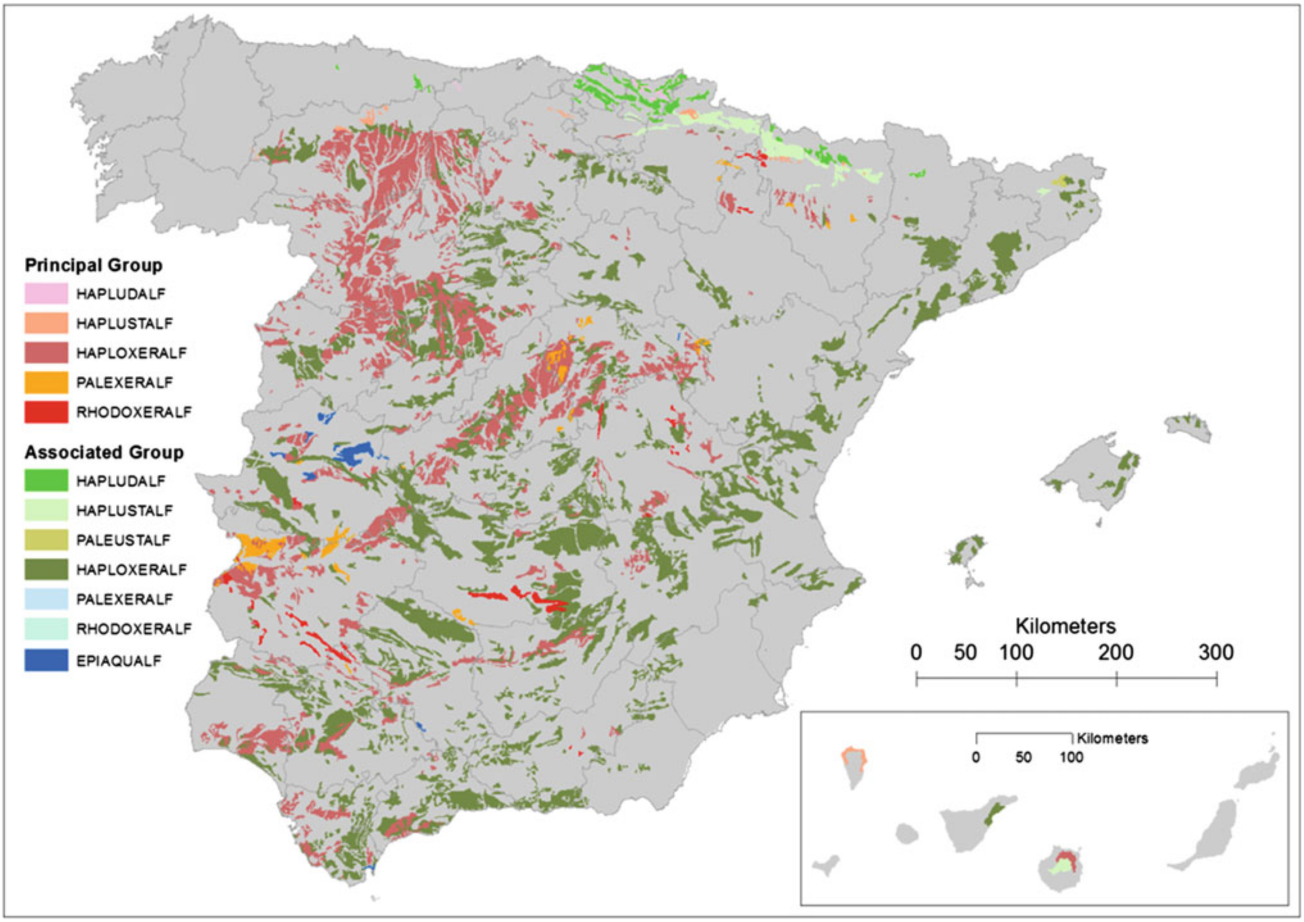

Fig. 2.3 Distribution of Alfisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear associated with various other soils

Table 2.2 Extension and proportion of Alfisols (by suborders and groups) found in Spain

Order	Suborder	Groups (2003)	Surface (km^2)	(%)
Alfisol 61,861 km^2 (12 %)	Aqualf	Epiaqualf	1.47	0.29
	Cryalf	Haplocryalf	155	0.03
	Udalf	Hapludalf	1.19	0.23
	Ustalf	Haplustalf	1.65	0.33
		Paleustalf	27.4	0.01
		Rhodustalf	251	0.05
	Xeralf	Haploxeralf	44.9	8.79
		Palexeralf	3.05	0.60
		Rhodoxeralf	9.59	1.90

nature (prairie or savanna), and crops must therefore be adapted to irregular drought conditions.

The division into groups is first undertaken by the existence of some features or horizons (duripan*, plinthite*, or kandic*, natric* horizons), followed by the development of the Argillic horizon: Paleustalf (indicating old age), Rhodustalf (with rubefaction) and Haplustalf (modal).

Haplustalfs

The Haplustalfs group is the widest (1,647.6 km^2) within the suborder of the Ustalfs, occupying the most stable sites of the ustic border regime. Haplustalfs are present as the major soil types, especially in the northern parts of the Provinces of Navarra and Huesca. Also, they are disclosed between the city of Vitoria and the Montes de Vitoria (Alava) as well as in the geomorphologically stable surfaces between Santulano and Callezuela in Asturias or the ustic areas of the region north of Aguilar de Campo, Cervera de Pisuerga, Encartaciones (Provinces of Palencia and Burgos), west of Carballo, and areas of the Montes de Castelo and Noreña (Galicia). Between the Aragón River and Jaca (Huesca) there is an ustic central strip in which Haplustalfs are associated with Vertisols (Usterts); with the Ustifluvents, the Usterts can be found as inclusions between the right bank of the Allones River and Malpica, around the Fervenza reservoir, and on the slopes of the Jallas River in Castriz (Galicia).

Finally, in the Canary Islands, Haplustalfs appear in the ustic area in the north part of the Island of La Palma, in the northwest area of Tenerife, and in the central region of Gran Canaria island predominantly at altitudes above 350 m asl (sometimes with Rhodustalfs, as, for instance, in the region between Arucas and Teror), being an important source for "*sorribas*" (a local way to improve crop soils using allochthonous material).

Paleustalfs

Paleustalfs are extremely aged Ustalfs, having required geomorphological stability. The argiluviation is accompanied by other processes, such as the formation of Petrocalcic horizon (Petrocalcic Paleustalfs), rubefaction (Rhodic Paleustalfs), leaching bases (Ultic Paleustalfs), and planosolization. Paleustalfs have only been mapped as secondary associations and represent no more than 27.4 km^2. These soils have been described only as inclusions in Biescas (north of Huesca). The abrupt boundary is an important condition for the exploration of Argillic material by the plant root system and therefore suited for agricultural use.

Rhodustalfs

Rhodustalfs develop Argillic horizons with a deep red color ($\geq$2.5 yr hue, value of 3 or less). Nevertheless, the dry value must not exceed the wet value by more than one unit, a condition that is interpreted as evidence of rubefaction related to a highly evolutionary degree. The rhodic diagnosis character is very demanding (even more than the traditional name of *terra rossa*), and the soil must be very red to conform. Therefore, considering a poor spatial representation of the ustic moisture regime, these soils have been mapped only as inclusions, and they represent barely 251.3 km^2. Rhodustalfs have been identified in the Canary Islands and in areas associated with the Haplustalfs described above, and in areas associated to Ustepts at medium altitudes of the northern slopes of the Tenerife Island comprising highly evolved ancient volcanic cones (Carboneras).

2.3.1.5 Xeralfs

Xeralfs are Alfisols with a xeric moisture regime that encompasses Spain's prevailing environmental regime. Under natural climatic conditions, these soils are specifically intended for dryland Mediterranean crops (such as barley, wheat, grapes, olives, almonds, etc.). However, artificial irrigation has expanded both the number of crops and their productivity. The division into groups is first done by determining some features or horizons (duripan*, natric*, fragipan*, plinthite*), and afterwards by the development of the Argillic horizon, namely Rhodoxeralf (with rubefaction), Palexeralf (old age), and Haploxeralf (modal).

Haploxeralfs

The group of the Haploxeralfs includes all those Xeralfs that do not meet the requirements of the other groups. The subgroup differentiation is made according to decisive properties from a management optimization perspective, characterized by discontinuous Argillic or bands (Lamellic Haploxeralf), sandy (Psammentic Haploxeralf), have a calcic (Calcic Haploxeralf), base saturation less than 75 % (Ultic Haploxeralf) or dark-colored epipedon rich in organic matter (Mollic Haploxeralf), and can evidence rather uncharacteristic horizons (Typic Haploxeralf).

In Spain, Haploxeralfs are the most extensively found Alfisols (44,480 km^2) and occupy the most stable geomorphological units under the xeric moisture regime. Haploxeralfs abound on the left bank of the Duero River in a wide strip that crosses Madrid from the northeast to the southwest and reaches Extremadura at the foothills of the Sierra de Guadalupe (Extremadura) and the shuttle platforms of the Guadiana Valley. Haploxeralf inclusions appear interspersed with Xerorthents and Xerumbrepts around Villardevós, Oimbra and Monterrey (Orense) and in Villarreal, mixed with Palexeralfs Epiaqualfs and even Xeropsamments.

Haploxeralfs and Rhodoxeralfs (associated with Entisols and Inceptisols) are found in the Penedés region (Barcelona). They also appear in southern Spain, in the area of influence of the Piedras River, east of Villablanca (Huelva), and north and south of the Sierra Pelada (Granada). In the center of Spain, they appear on Plio-Pleistocene parent material as north of the Guadiana, east of Zafra (Badajoz), and south of Miajadas (Province of Cáceres).

Associations of Rhodoxeralfs and Haploxeralfs (with Inceptisols) are found west of Begíjar on calcareous sandstones; in western Valenzuela on variegated gypsiferous marls (with Vertisols), and in the headwaters of the Jaén River on limestone (with Entisols), as well as in the sands of the coastline (with Xeropsamments) and as inclusions with other Entisols in the north of the Redondela.

Haploxeralfs and Palexeralfs are found in the Fonz and Ager villages (in the Provinces of Huesca and Lleida), in the foot slopes of the Serra de Pàndols (Tarragona); in Rinsoro; south of Sangüesa (Navarra); on the left bank of the Júcar River near of Villar de Ves (Albacete), and in the south of Almendralejo (Badajoz). In addition, they can be found in the *rañas* and *rañoides* of northwestern Spain (*páramo Leonés*).

In northwest Spain, Alfisols predominate over the clays and marls of the Tierra del Pan (Zamora) and of the Esla River terraces; they also appear in the Castilian Leonese Basin of Tierra de Campos. The Alfisols are represented by Haploxeralfs, associated with Rhodoxeralfs and Palexeralfs; together, they may appear as Epiaqualf inclusions, in specific areas as the confluence of rivers and streams or in endorheic depressions (Lampreana shire in the Province of Zamora). Further south, across the Duero River, the Haploxeralfs set a border that begins in Fermoselle (Zamora), continues in Valdeadávila, Masueco, and Hinojosa, extending between San Felices and Villavieja, and even in the surroundings of Sancti Spíritus, Matilla and Rollan (Province of Salamanca).

In central Spain (Castilla-La Mancha and Castilla y León), Alfisols are often associated with Inceptisols and Entisols—for example in the lower terraces of the Esla and Cea Rivers, near their confluence; in both intermediate and low alluvial terraces of the Cea's left riverbank; in the possible Pliocene limestones of the Páramo (Piña de Campos, Olmos, Melgar, Villegas, etc); and in terraces of the Duero, Portillo, San Miguel and north of Iscar (Valladolid). Finally, Alfisols are associated with Psamments in the sands of Tierra de Pinares (Valladolid) and in the surrounding areas (e.g., Cuesta de Cuellar, Province of Segovia).

In the Spanish Levante, Haploxeralfs (e.g., Manises) and Rhodoxeralfs (e.g., segart) are found, as well as other Xeralfs in Alzira, Albaida, Sierra del Espadà, Boqueres, Requena, Safor, Marina Alta, and Bernia.

In southern Spain, in Andalusia, the Haploxeralfs are arranged on fluvial terraces, in particular along the Guadalquivir River and also in the region of Algeciras (Province of Cádiz). The Haploxeralfs are associated with Xerorthents and Xerochrepts in Los Palacios (Sevilla), Guadalcacín in Conil (Cádiz), and in Alameda (Málaga); they are associated with Chromoxererts in Almonte and with Rhodoxeralfs between San Bartolomé and San Silvestre as well as in the region of *El Condado* located in the Province of Huelva. In addition, Haploxeralfs are also found in the regions of Alcor and Utrera, east of Dos Hermanas (Sevilla), as well as in Chiclana (Cadiz Province). In the south of Huelva and Cádiz, the Haploxeralfs are associated with Xeropsammens and Palexeralfs, with Epiaqualf inclusions (e.g., in Barbate); they are also found in eastern Andalusia, between Estepona and the Marbella ramblas (Province of Granada), and south of Antequera (Province of Málaga).

In central of Spain, the Xeralfs again dominate on stable reliefs of various materials as the alluvial deposits of major rivers or in arkoses and marls of the countryside, together with the limestones of the Paramo Pontiense. In this context, the Haploxeralfs between Madrid and Ciudad Real stand out, in particular on the terraces of the Jarama, Henares, Tajuña, Tajo, Guadiana, Jabalón and Guadazaón Rivers. Sometimes Haploxeralfs are associated with Palexeralfs and Rhodoxeralfs (Santos de la Humosa, Campo de Calatrava), or even Psamments (from Arenas de San Juan to Villarobledo).

In the Balearic Islands, Haploxeralfs can be found in Mallorca, especially between the western and central ranges (Palma, Inca, and La Puebla) associated with Xerochrepts, Xerorthents, and Rhodoxeralfs (south of Manacor). In Menorca there are Haploxeralfs on the Island of Colom and also on the islands of Formentera and Ibiza, the last characterized by Rhodoxeralf inclusions.

In the Canary Islands, Haploxeralfs and Palexeralfs are found in the xeric area of the islands, mainly to the east and southeast of Tenerife and Gran Canaria.

In southeastern Spain, (limited to the xeric and aridic moisture regimes), Haploxeralfs predominate, sometimes associated with Haplargid, on terraces of the main rivers (Almanzora, Zujar, Chirivel, Luchena, Taibilla, and Corneros). In Almería, Palexeralfs and Haploxeralfs (associated with Haplargids and Paleargids) are found, for example, in the Cabo de Gata Cape, which under an aridic moisture regime evolved into Petrocalcids, i.e., Campos de Níjar and Dalías, etc.

Palexeralfs

Palexeralfs are Xeralfs whose properties are age-related, evolving from Calcic Palexeralf (with calcic horizon) to Petrocalcic Palexeralf (with petrocalcic horizon) and abrupt boundary or (planosolization). This abrupt boundary is an important constraint of the Argillic colonization by the root system, and, therefore, for its agricultural use.

Palexeralfs have been mapped as main soils, or as associations or inclusions on older surfaces (Plio-Pleistocene) in the Provinces of León and Palencia, Huesca, Madrid and Guadalajara, as well as the central area of Extremadura; these soils occupy a total area of 3,049 km^2. The Palexeralfs also appear with Rhodoxeralfs and inclusions of Epiaqualfs in the rañas of Salamanca (e.g., Arroyo Serradilla and Cabaco), in the Province of Cáceres (Montehermoso, Monterrubio, Sierras de Guadalupe, Campo Arañuelo), Badajoz (Almendralejo, Albuera, and northern Llerena) and headers of various rivers of the Provinces of Zamora and Palencia. As already mentioned, Palexeralfs have also been described in association with Haploxeralfs in the arid areas of Almería.

Photo 2.4 Andisol (Haploxerand) in Tenerife (Canary Islands)

Rhodoxeralf

Rhodoxeralfs occupy a total area of 9,593 km^2 in Spain, often in conjunction with Haploxeralfs. Besides having an Argillic horizon with intense rubefaction (typical of Rhodoxeralfs), they may also have either a calcic (Calcic Rhodoxeralfs) or a Petrocalcic (Petrocalcic Rhodoxeralfs) horizon. Derived from topsoil erosion, the Argillic horizon was characteristically intensely red, emerging to the surface as evidenced by the names of places (Almagro, Rubiales, etc.).

Their main distribution was mentioned in the previous section on Haploxeralfs. As already noted, Palexeralfs are distributed throughout central Spain, in Zamora (in towns such as Fuentesauco, Fermoselle and Fuentelapeña, and in the terraces of the Esla and Cea Rivers), Palencia (Carrión, Piña de Campos), Cáceres (Roca de la Sierra, Miajadas, Sierra de Guadalupe), Segovia (Sierra de Pradales) and Cuenca (Honrubia) ciudad Real (Almagro). Furthermore, Palexeralfs can also be found in eastern Spain, as, for instance, in the Provinces of Castellón (L'Alcalatén) and Valencia (Dènia, Llíria, Requena), and even on the Island of Menorca.

2.3.2 Andisols (Photo 2.4)

Andisols are characterized by andic properties in most of the profile (Photo 2.4) (equal to or more than 60 % of the thickness within a depth of −60 cm or to a cemented or lithic contact). Umbric, melanic and cambic horizons are the most common diagnostic horizons to classify Andisols.

Andisols are deep soils that developed on volcanic materials arranged in layers (pumice, volcanic ash and pyroclastic materials). Amorphous materials containing aluminum, silica, and organic matter or glass matrix dominate its exchange complex. The variable charge is high, while the permanent is low. Andisols contain a high organic matter content, a high phosphorus fixation capacity, and they hold a significant moisture retention capacity.

According to these properties, the agricultural potential of Andisols is very high. Sustainable agriculture frequently involves contributions of phosphorus and, in the case of more acidic Andisols, mineral amendments to complete and balance the exchange complex and allow for the control of aluminum toxicity. Andisols with stratified volcanic ash, as in the case of recent volcanism, may present lithological discontinuities, which create specific problems related to tillage or irrigation (e.g., drip bulb formation). For use in civil engineering, Andisols encompass problems related to the fragility of the volcanic materials and thixotropic properties.

Andisols developed in volcanic regions of the Iberian Peninsula and especially in the Canary Islands (Fig. 2.4). Furthermore, in the eastern part of Spain there are volcanic materials on the hill of Agras (Cofrentes, Valencia), the Columbrete archipelago in Castellón (Illa Grossa, La Ferrera, La Foradada and El Carallot), in the Campo de Calatrava in Ciudad Real (Piedra, Yesoza, Cabeza Galiana, Lomillos) and, finally, the Almería coastal area from Carboneras to Cabo de Gata. Some other soils with andic properties have also been reported in Galicia, the Basque Country and Navarra.

The Andisols of the Canary Islands are undoubtedly the best represented. They are known as "*tierra de monte*" (forest soil) or "*tierra de polvillo*" (land of dust). The Andisols are found to the north of the western mountain regions of the islands and are found between variable altitudes varying from 450 to 2000 m asl. Under exposure to a very humid climate, the altered volcanic materials have lead to the formation of allophanic and amorphous materials composed of iron and aluminum hydroxides that have evolved into kaolin clays and gibbsite.

The suborders of Andisols differ according to the soil temperatures and moisture regimes, as well as by the existence of certain horizons (placic and melanic), and otherwise through the peculiar properties or materials such as volcanic glass.

Andisols have been mapped in the Vitritorrands, Haplustands, Udivitrands, Ustivitrands and Haploxerands groups (Table 2.3). The Andisols mapped across Spain occupy a surface close to 533.2 km^2.

2.3.2.1 Torrands: Vitritorrands

Vitritorrands are Andisols with an aridic-torric moisture regime and a permanent wilting point of less than 15 %.

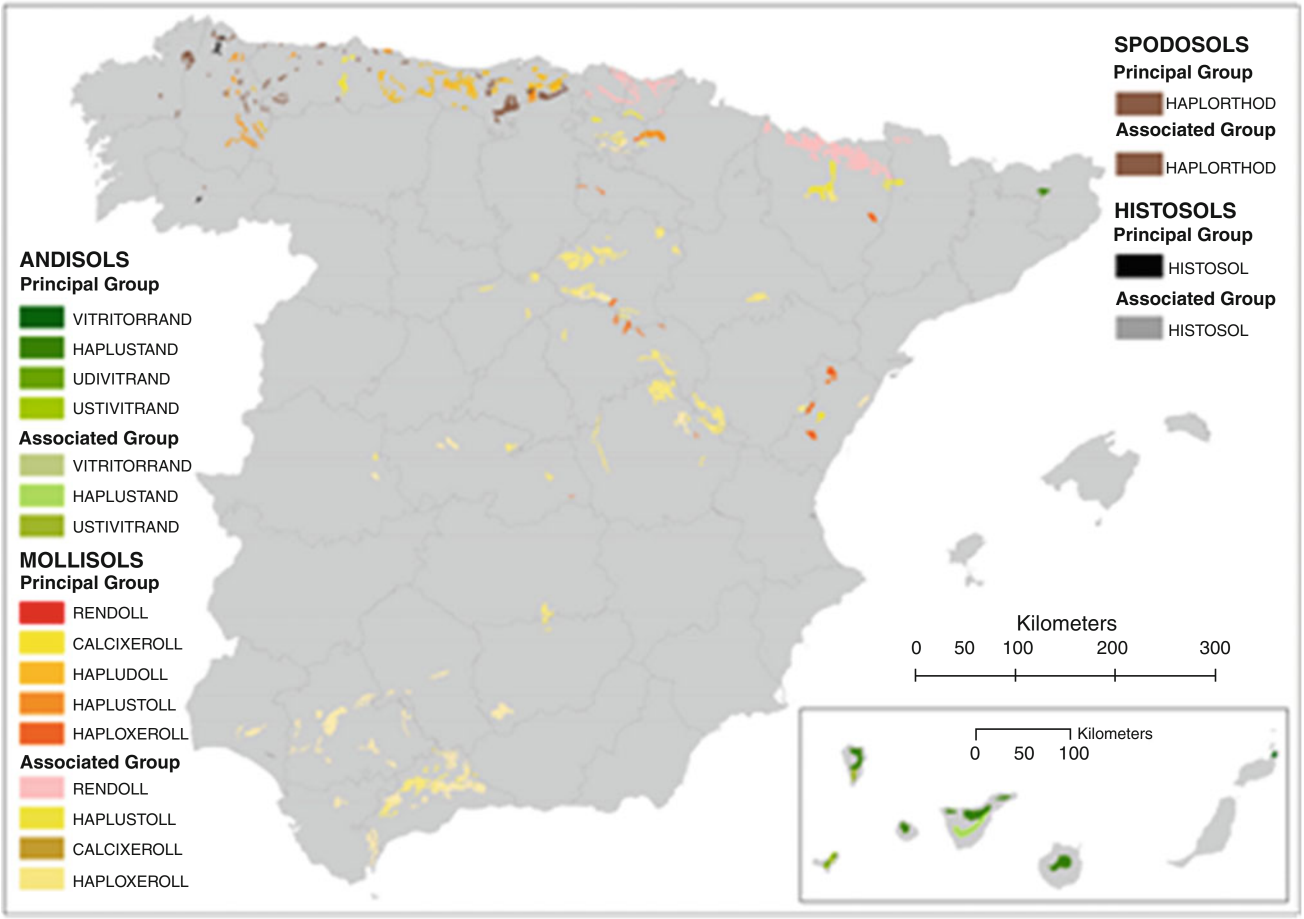

Fig. 2.4 Distribution of Andisols, Histosols and Spodosols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear associated with various other soils

Table 2.3 Extent and proportion of Andisols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Groups (2003)	Surface (km^2)	(%)
Andisol 533.2 km^2 (0.11 %)	Torrand	Vitritorrand	23.1	<0.01
	Ustand	Haplustand	441	0.09
	Vitrand	Udivitrand	15.0	<0.01
		Ustivitrand	36.6	0.01
	Xerands	Haploxerands	17.4	<0.01

Vitritorrands have been reported on the Islands of Lanzarote and El Hierro. Specifically, the Island of Lanzarote, under an aridic moisture regime, has volcanic materials from many different ages: the Miocene (Ajaches and Famara), Plio-Quaternary (center), recent (north) and historical (eighteenth century), extending over one-third of the island. Vitritorrands have been normally identified on recently found materials (ashes and coladas), consisting of a scarce thickness and sometimes affected by salinity. These soils consist of sandy or silty textures. Vitritorrands are in general developed on a hilly relief and are usually highly erodible (Teguise-Haria). With regard to the Island of El Hierro, which shows a significant homogeneity of volcanic materials, Vitritorrands are present in the coastal area up to 200 m asl north, 600 m asl south and 700 m asl to the southwest (Guarazona, Isora and Taibique).

2.3.2.2 Ustands: Haplustands

Haplustands are the most widely found; they occupy a surface close to 440 km^2. They have been mapped in La Garrotxa (Olot, Girona) and especially in the Canary Islands.

In relation to Gran Canaria Island, Haplustands have been described in association with Ustivitrands under an ustic soil moisture regime strip that is located above the xeric regime at altitudes below 450–550 m asl (north) and 750–900 m asl (south). On the Island of Tenerife, Haplustands have been described in association with Ustivitrands at midlatitudes in the northern slopes (Icod-Puerto de Santa Cruz-La Laguna) and north of the watershed linking Anaga to Volcano Negro. On the Island of Gomera, Haplustands are found in association with Dystrudepts and Udorthents, and at altitudes below 500 (north) and 900 (south) m asl, i.e., Garajonay, Manantiales, etc.

Haplustands are associated with Ustivitrands in the ustic region of the Island of El Hierro, located between the arid coastal strip and the udic soil moisture regime, at an altitude of about 900–1000 m asl (southeast of Sabinosa, east of Abagu, north of San Andrés). The Island of La Palma has Haplustands associated with Ustivitrands (in the north), between the aridic (in the northwest), and the udic environment (Barlovento Sector-Los Catalanes-Puntagorda).

2.3.2.3 Vitrands

Vitrands are characterized by a sandy texture having a low moisture storage capacity and a limited nutrient retention capability, typified also by high erodibility.

Udivitrands

Udivitrands represent an area of about 15 km^2; they are associated with Hapludands* at an altitude above 1,000 m asl (La Guancha, La Orotava) in Tenerife, east of Sabinosa on the Island of El Hierro, south on the Island of La Palma (the Cumbrecita), etc. Sometimes they are associated with volcanic cones, in which cases they are distinguished by a duripan horizon (Durivitrands*). There are inclusions on the Island of La Gomera.

Ustivitrands

Ustivitrands have been mapped in an area of about 36.6 km^2. They have been described in association with Haplustands on Gran Canaria Island (Cruz de Tejeda), Tenerife (Sector Icod-Puerto de Santa Cruz-La Laguna, from Anaga to Volcano Negro), on the Island of El Hierro (Valverde South, East Sabinosa), and on the Island of La Palma (Sector Barlovento-Los Catalanes-Puntagorda).

2.3.2.4 Xerands: Haploxerands

Haploxerands have been mapped in an area of only 17.4 km^2; their inclusions have been described on Grand Canary Island in the xeric strip between the aridic coastal strip of the south and the ustic regime, as in Tenerife, on the north side (between La Orotava and La Laguna), and to the south (below Punta Oeste-Guía de Isora-Granadilla).

Photo 2.5 Aridisol (Petrocalcid) in Fuerteventura (Canary Islands)

2.3.3 Aridisols (Photo 2.5)

Aridisols constitute the only soil order defined by their aridity degree. These soils have an aridic (torric) soil moisture regime, i.e., they lack water available to plants over extended periods of time. The soil control section has been primarily conditioned by a climatic aridity, which can also influence the profile properties and their position in the relief (thin top soil, high stone content, low moisture retention or excessive runoff).

Considering the taxonomy of Aridisols, suborders are separated according to the temperature regime, the existence of highly soluble salts (salic horizon) or other diagnostic horizons (duripan, argillic, calcic or cambic horizons). Aridisols' taxonomy separates suborders according to the temperature regime (cryic) and with the function of the existence of very soluble salts (salic horizon) or other diagnostic horizons (duripan, argilic, calcic or cambic). These same properties are also used for the group classification, together with other characteristics such as the composition, abrupt limit, and other horizons (petrocalcic, petrogypsic, natric, anthropic) present between −100 and −150 cm from the soil surface.

In Spain, Aridisols are widely spread out in the Middle Ebro Basin (Huesca, Zaragoza, Lleida), the Calanda Desert (Teruel), southeast of the Peninsula (see Chap. 4) and in the Canary Islands, as well as in saline areas often related to endorheic areas. Aridisols occupy a total of 28.4 km^2 in Spain, representing more than 5.6 % of the national territory (Table 2.4) and thus constituting the fourth soil order of

Table 2.4 Extent and proportion of Aridisols (by suborders and groups) found in Spain

Order superficie (proporción)	Suborder	Groups (2003)	Surface (km^2)	Percentage (%)
Aridisol 28,355 km^2 (5.64 %)	Argid	Haplargid	3,643	0.72
		Paleargid	46.4	0.01
	Calcid	Haplocalcid	16,194	3.20
		Petrocalcid	1,224	0.24
	Cambid	Haplocambid	4,350	0.86
	Gypsid	Calcigypsid	425	0.08
		Haplogypsid	197	0.04
Total				5.15

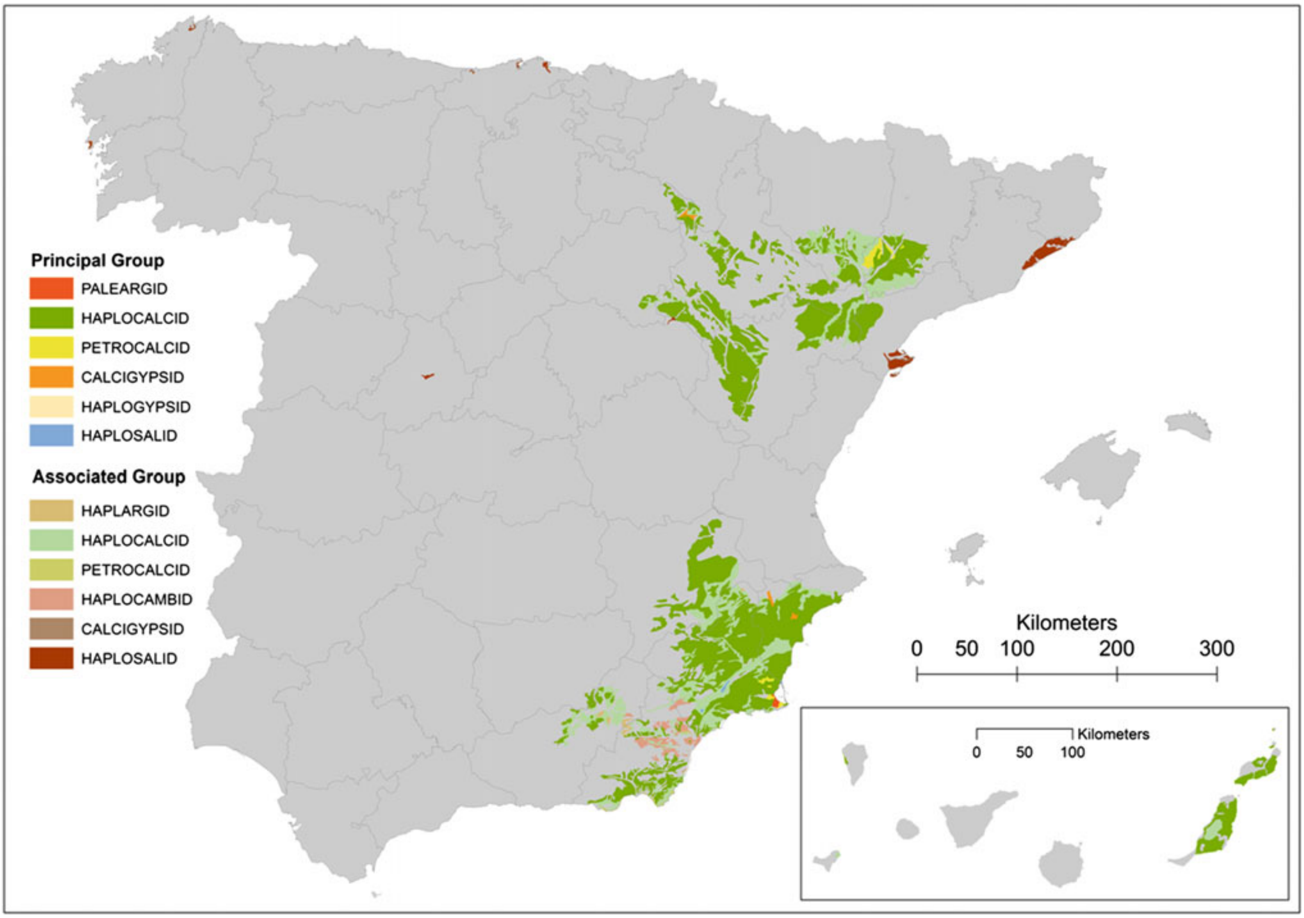

Fig. 2.5 Distribution of Aridisols (excluding inclusions); (Gómez-Miguel 2005)

major surface extension. They have been mapped in the following groups: Haplargids, Pleargids, Haplocalcids, Petrocalcids, Haplocambids, Calcigypsids, Haplogypsids, and Haplosalids (Fig. 2.5).

2.3.3.1 Argids

Argids are Aridisols that contain an Argillic horizon with a relative clay accumulation derived from the upper horizon. They evidence clay illuviation (slikensides) and their thickness ranges between 7.5 and 15 cm, depending on the profile's case.

Haplargids

Haplargids are modal Argids (that is, they do not have abrupt boundaries, hardpans or petrocalcic, nitric, very thick Argillic, gypsic or calcic horizons); Haplargids cover a total area of 3,643 km^2 and have only been mapped as associations or inclusions.

Haplargids can be assimilated into Haploxeralfs except under the current aridic moisture regime, which suggests that they must have formed within different climatic conditions than those of the present, and so they may constitute the memory of a wetter past, i.e., a paleosol (Badía et al. 2013a).

Haplargids are associated with Calcids and Cambids and are described, for example, on the glacis and other allochthonous deposits in the headers of the rivers in the Province of Zaragoza (terraces of the Jalon, Huecha, and Jiloca Rivers), on glacis and marls located west of Mezalocha, and even in the northwestern region of Corella and Alfaro (La Rioja) or north of Alicante.

Haplargids have been described as being associated with Petroargids in the Bajo Maestrazgo from Càlig at Alcalà de Xivert (Castellón) and in Almería (Campos de Nijar and Dalias, Cabo de Gata). In Murcia, they are found in the Cenajo reservoir and in the surrounding Sierras. In the Canary Islands, they are limited to elevations below 200 m asl in the most arid part of Tenerife, between Los Cristianos and Punta Abona, in Fuerteventura between Garafía and Llanos, and also in Gran Canaria.

Paleargids

Paleargids are Argids whose clay illuviation process has been very intense, requiring geomorphological stability conditions, a favorable climate, and/or a long-term period of development. Paleargids have either a very thick Argillic horizon or a very sharp limit. It is regarded that the illuviation process itself has gradually closed the pores of the upper limit of the horizon, resulting in an abrupt boundary, or has overlapped several horizons of clay accumulation (very thick horizon). In any case, it seems that their genesis may have not occurred in the current geo-climatic conditions (paleoclimate), hence the name's prefix ("pale").

Paleargids occupy an area of only 46.4 km^2 in Spain. They have been identified in very localized points such as east of Algar (Cádiz) and also in the Canary Islands, associated with Haplargids in the plains and hills of lower elevation of the Betancuria Massif (Fuerteventura). However, Paleargids have been identified as the main soil type south of the Mar Menor Lagoon (Murcia).

2.3.3.2 Calcids

Calcids are Aridisols with movement and/or accumulations of secondary origin carbonates in the profile (see Calcixerepts).

Haplocalcids

Haplocalcids have a calcic horizon (accumulation of 15 % carbonates or higher in a horizon 15 cm or thicker, and 5 % or greater than the overlain horizon) and totally lack a petrocalcic horizon. They are the most prominent group among Aridisols; they occupy a total area of 16,194 km^2 and have been mapped as main soil, associations, and inclusions.

Haplocalcids are abundant in the southeast region of the Iberian Peninsula: in Murcia (east of the Sierra de Carrascoy, Columbares, Algarrobo, and La Muela on calcareous detrital materials, conglomerates and red clays), in Granada (east of Guadix) and Almeria (Campo de Níjar, Depression of Tabernas-Sorbas, in the groove of the Andarax River syncline), on Triassic limestones that border the Betic Range (Sierras –Mountains—of Gador, Nevada, Filabres, Estancias Alhamilla, and Cabrera). They also appear in Granada (Fardes River Basin, Hoya de Guadix, Baza, southern Vega de Granada), east of Malaga, and in the foothills of Sierra del Cabezon (Alicante). In the península's northeast, Haplocalcids are found among the Cinca and Segre Rivers, in the Provinces of Huesca and Lleida.

Haplocalcids have been identified in various places on the Canary Islands—for example, in the Plio-Quaternary basalts and Miocene glacis pertaining to the reliefs of the Island of Lanzarote; they are associated with Torriorthents in the glacis of the Island of Fuerteventura. Haplocalcids are the best-represented Aridisols of the Island of Tenerife and are preferentially located in the southern part of the island, between Los Cristianos and Punta Abona, above 200 m asl to the southeast, and 300 m to the southwest. Haplocalcids, associated with Petrocalcids, appear on the Island of La Gomera in the coastal strip (except for the north-northeast) below an elevation of 300 m asl, and at isolated points throughout the island of El Hierro (east of Valverde). In La Palma, Haplocalcids (associated with Petrocalcids and Torriorthents) are found in various slopes of the island (i.e., Garafía, Puntagorda and Los Llanos).

Petrocalcids

Petrocalcids are Aridisols characterized by a calcic horizon that has been massively cemented, generating a petrocalcic horizon (see Petrocalcic Calcixerept); they cover a total area of 1,224 km^2 and have been mapped as main soil, associations, and inclusions. Petrocalcids are located, inter alia, on the terraces and glacis associated with the Middle Ebro River and its tributaries (from Zaragoza to Lleida, throughout Huesca) in northeast Spain (Badía et al. 2008, 2009). In southeast Spain they can be found in Murcia (Campo de Cartagena, Totana, Fuente Alamo, Yecla and Pinoso), Granada (Hoya de Baza), and Almería (Campos de Nijar and Dalias).

In the Canary Islands, Petrocalcids have been found on Miocene materials in Ajarches and Famara (Lanzarote); in the plains and hills located at lower elevations of the Island of Fuerteventura; and in the southern part of Tenerife, between Los Cristianos and Punta Abona. As already mentioned, Petrocalcicds and Haplocalcids can be found along the coast of La Gomera and La Palma.

2.3.3.3 Cambids

Cambids are Aridisols typified by a cambic horizon (no hardpan or petrogypsic or petrocalcic horizons between −100 and −150 cm from the surface). These soils show an incipient alteration process that involves a morphological change in relation to the bedrock (*R*) and the alteration zone (*C*) forming the cambic endopedon (*Bw*). The cambic horizon is characterized by a manifested evidence of alteration, rubefaction, development of soil structure, and loss of carbonates and without meeting the requirements of other soil endopedons by features such as color, structure, etc., which take precedence over those inherited from the starting material.

Among the Cambids, the typical Haplocambids can be found over an area of 4,350 km^2 and mapped either as main soils, associated, or inclusions. They are located in Almería on conglomerates (Garrucha), in Albacete (Elche de la Sierra, Sierra de Alcaraz), on metamorphic rocks in Almería (Sierras de Gador, Nevada, Filabres, Estancias, Alhamilla, Cabrera), on acidic materials of the Sierras of Pardos and Santa Cruz (county of Daroca, Zaragoza) and also north of Alicante. In the Canary Islands, the Haplocambids are associated with other Aridisols that have already been mentioned.

2.3.3.4 Gypsids: Calcigypsids and Haplogypsids

The solubilization, intense movement, and accumulation of gypsum in arid zones leads to the formation of Gypsids, i.e., they are Aridisols including a gypsic horizon. Among the Gypsids, the Calcigypsids (425.4 km^2 with associations and inclusions) and the Haplogypsids (197.2 km^2) abound; they appear only as associations and inclusions. Gypsids are located in central Spain in the moors of the Northern Castilian Plateau, drained by the Valderaduey, Sequillo, Hornija, Cevico Rivers, and others; they can also be found in the valleys of the Amarguillo, Cigüela and Riánsares Rivers.

Gypsids abound in the Middle Ebro Valley on Miocene gypsum in Bardenas, Cinco Villas, Monegros and the bajo Aragón counties; they are dotted with about a hundred of depressions or salt marshes and therefore associated with Salids. In view of this, Gypsids are mainly located in the Province of Zaragoza and surroundings, with some continuity to the east and south of the Provinces of Huesca and Lleida. Gypsids are also occasionally found on the Island of Fuerteventura, even with Petrogypsids*.

2.3.3.5 Salids

Salids are Aridisols with an accumulation of salts more soluble than gypsum (salic horizon) either at the surface by water evaporation, or in deep layers by washing.

Haplosalids

Haplosalids cover a total surface area of 2,276 km^2, and have been mapped as main soils, associations and inclusions (Fig. 2.5). Haplosalids have been reported in many areas of Spain, in both plateaus (for instance, in the main valleys of the Ebro, Duero, Tajo and Guadalquivir Rivers). In particular, Haplosalids have been found in:

- Endorheic depressions and evaporation basins forming lagoons in Castilla La Mancha (Acequión and Tirez Lagoons, Fuente la Higuera and Anorias, the Sabinar); also in the Ebro River Basin (Ballobar, Bujaraloz, Calanda, Corella, Alfaro, Andosilla, San Adrián, Calamocha) and in the Duero River Basin (Amblés Valley, La Moraña, Peñaranda, *Tierra de Medina*, the Armuña, Tierra of Arévalo, Lampreana-Villafáfila, etc.); or in Valencia (La Sagra, Racer, Totana, Barbaje, and La Janda and the depressional area of Serpis in Beniarres and Alcoy).
- Large-scale tectonic depressions (the Saladar, Pétrola, etc., in Albacete).
- Karst depressions, such as Daimiel, Gallocanta, and La Yunta.
- Saline springs such as Cazanuecos, Zotes del Páramo, Ardón, or in the Monegros Desert.
- With deltas and estuaries of major rivers: Ebro, Llobregat, Segura, Tinto and Odiel, Guadalhorce, Guadalete, Guadalquivir, Arroyo de San Pedro, etc.
- with marshes and ponds or other areas of marine influence scattered along the Spanish coastline, including southern Ibiza and Mallorca

Haplosalids have also been described in the Canary Islands (on Miocene materials in Ajarches and Famara on the Island of Lanzarote), in the coastal marshes of the major valleys (Grand Tarajal and Vinamar), on the Island of Fuerteventura, and in the coastal lowlands and endorheic areas in the southern part of Tenerife (between Los Cristianos and Punta Abona).

Aridisol Technology

Using Aridisols for agriculture is limited by the lack of water. In sustainable irrigated agriculture, Aridisols management involves the monitoring and reduction of the profile's salinity, which involves the use of a leaching fraction; this is associated with drainage systems to remove the saline water. Some Aridisols, such as Gypsids, provoke solifluxion and subsidence problems caused by gypsum solubility as well as concrete corrosion. Other Aridisols have a shallow effective soil depth, caused, for example, by the presence of a petrocalcic (Calcids) horizon. When there is a layer of low permeability and contrasting texture (abrupt boundary), as in the case of Argids, agricultural management problems are related to soil fertility and water infiltration. Regarding chemical components, salts more soluble than gypsumas_as for instance NaCl (salids)—can cause several severe crop problems (plant osmotic and specific ion imbalance effects), or on the soil (loss of structural stability by sodicity) (Badía et al., 2011). Also problems arising from the abundance of active limestone such as immobilization of phosphorus and iron chlorosis (affecting sensitive crops such as stone fruits, grapes, etc.), and disadvantages derived from sulfate ions on plant qualities and product processing of specific crops (e.g., vineyards). Overcoming these soil problems and providing irrigation, high temperatures guarantee good agricultural production in Aridisols.

2.3.4 Entisols (Photos 2.6, 2.7, 2.8, 2.9 and 2.10)

Entisols are mineral soils characterized by a scant evolution with no diagnostic horizons. Sometimes this is due to erosion that favors and promotes the continuous rejuvenation of the soil, and sometimes to a profusion of quartz and other non-weatherable minerals, as in the case of igneous material. Other causes must be sought in soil development braking or slowing in regularly water-saturated environments and/or cold, and, finally, also due to human actions. For all of the above-mentioned reasons, the following Entisols can be distinguished: Aquents, linked to flooded areas; arents, linked to reliefs modified by man (terraces, *sorribas*, etc.); mountain areas (Orthents); those of alluvial plains (Fluvents); and sandy landscapes (Psamments).

Entisols are, together with Inceptisols, the most extensive soil class found in Spain. They occupy nearly 40 % of the national surface area (200.4 km^2) and are distributed throughout all types of climates and geographical situations (Fig. 2.6).

With regard to Entisols, the following groups have been mapped: Epiaquents; Fluvaquents, Hydraquents, Psammaquents, and Sulfaquents; Torrifluvents, Udifluvents, Ustifluvents, and Xerofluvents; Cryorthents, Torriorthents, Udorthents, Ustorthents, and Xerorthents; and finally Quartzipsamments, Ustipsamments, and Xeropsamments (for details, see Table 2.5).

Although the fragmentation and dispersion of Arents* cannot always be mapped, some are of great interest to agriculture or forestry, and, above all, have resulted in great socioeconomic importance. To this suborder of soils belong those particularly modified by human activities: inter alia, terraces for forestry use, agricultural use (e.g., Ribeira Sacra, Galicia), or recovered spaces in opencast mining (Badía et al. 2007) and landfills where urban and industrial materials are disposed. A special mention should be made of the sorribas, an artificial preparation of soil in particular areas, such as in the Canary Islands for the transportation of materials from other nearby areas, also evident in the changes typical of La Geria and the Island of Lanzarote.

The enormous heterogeneity of Entisols does not allow for an overall evaluation of their agricultural or technological properties at an order level, which must therefore be carried out at a group level.

Photo 2.6 Entisol (Epiaquent) in Sobradillo (Province of Salamanca)

Photo 2.7 Entisol (torriarent) in La Geria (Lanzarote Island, Canary Islands)

Photo 2.8 Entisol (Quartzipsamment) in Peñafiel (Province of Valladolid)

Photo 2.9 Entisol (Xerofluvent) in Oión (Álava)

2.3.4.1 Aquents

Aquents consist of flooded Entisols in which the pedogenesis is slowed down by an anaerobiosis effect. Aquents present aquic conditions and sulfidic materials, or a permanent saturation and dark colors with Fe^{2+}. Some Aquents have a thin mud surface layer, emit a strong smell associated with hydrogen sulphide, or have a gray-green color caused by reduction.

Photo 2.10 Entisol (Xerorthent) in Ambel (Province of Zaragoza)

Epiaquents

Epiaquents are Aquents with a perched watertable and saturated conditions in the surface layers, as evidenced by a typical gray reduction color; if they need to be cultivated, proper drainage techniques must be applied.

Epiaquents are the most prevalent group among the Aquents suborder and have been mapped in an area of 1,503 km^2. They have been identified in geographically dispersed areas nonetheless, with highly defined geomorphological conditions and an impeded drainage caused by:

- the existence of natural or artificial barriers (terraces, glacial moraines, levees, dikes, etc.) or
- the fact that there is no natural outlet for water (endorheic areas, oxbow lakes, wetlands and lagoon edges), where water input is continuous and the permeability is reduced (marshes, estuaries, deltas, mangroves, etc.).

In northwest Spain (specifically in Galicia), Epiaquents have been found in the region of Insua, the Muroños River, and south of Carballo, in usually flooded areas of the Eume and da Pedra River Valleys, in areas of influence by Minho, and in the Copeito Lagoon, north of Rey Castro, etc., as well as in the Parga River south of Escaderas.

In the center of the Iberian Peninsula, Epiaquents have been mapped in Lampreana, Quero, Villacañas, Tirez, and Pétrola; at the river mouths of Sequillo, Salado, and Hornija; south of Ataquines and northwest of Avila; El Pobo de

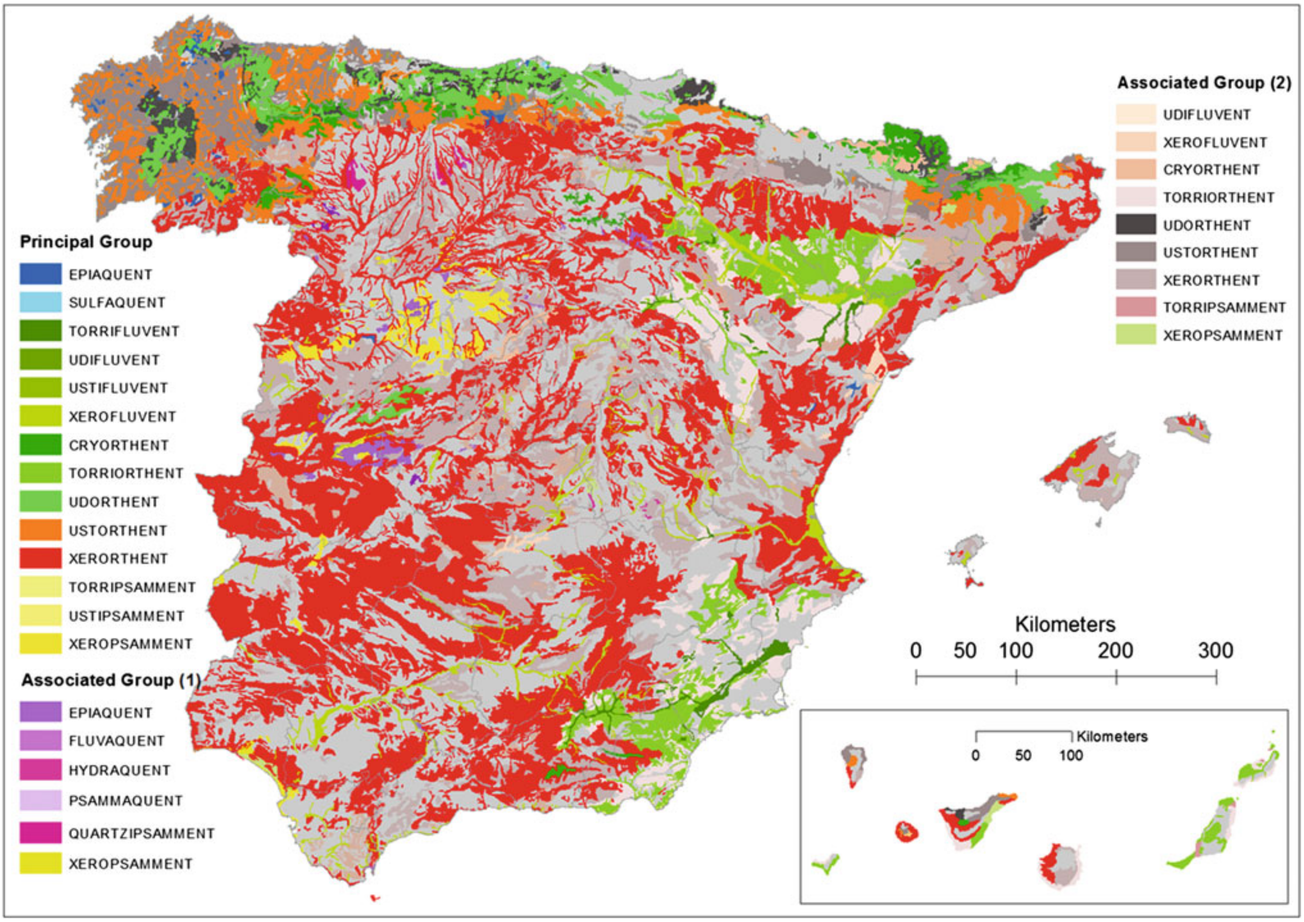

Fig. 2.6 Distribution of Entisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

Dueñas, in the vicinity of Rivera de Azaba; and in the Agueda River, near Ciudad Rodrigo.

In northern Spain, Epiaquents are located in the Sierra de Valdemurrio and La Vega, south of Reinosa, and in the Ebro Reservoir, Puerto del Pozazal and Puerto del Escudo (Cantabria), in Las Omañas (León), east of Guardo (Province ofPalencia), in Bejar and Navaluenga Bejar (Salamanca). Epiaquents also appear in raña areas (Hiendelaencina Guadalajara, Montes de Toledo); in all these cases, Epiaquents are interspersed with Fluvaquents and other hydromorphic soils. With regard to the rest of Spain, Epiquents can be found in the northeast, i.e., the marshes of L'Empordà (Girona) or the Ebro River Delta, and in eastern Spain, in Javea, Oliva, Chert, etc. In southern Spain, Epiaquents have been described in the Guadalquivir Marshes, Guadalete, etc. (Province of Sevilla) and at the head of the Río Blanco River in Córdoba.

There are also Epiaquents in deltas, estuaries and tidal zones of influence together with Sulfaquents, Hydraquents, Fluvaquents and even Haplosalids. These soil mixtures can be found both in northern Spain (Galicia, Asturias, Catalonia, Cantabria) as well as in the south (Huelva).

Fluvaquents

Fluvaquents occupy a small surface (160 km^2) and have only been mapped as associated soils or inclusions. Fluvaquents are found in the Ría de Munguía (Province of Vizcaya), in the river valley of Araguri (Pamplona), and in the depressed and coastal areas of the Province of Tarragona. Epiaquents associated with Fluvaquents appear in the places listed above.

Hydraquents

Hydraquents possess a thin mud surface layer, emit a strong smell associated with hydrogen sulphide, or have a reduced gray-green colored matrix and are thixotropic, with a subsidence index (n) greater than 0.7.

The n-value is calculated as:

$$n = (A - 0.2\,(s + S))\,/\,(c + 3\,(\mathrm{SOM})),$$

Table 2.5 Extent and proportion of Entisols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Group (2003)	Surface (km^2)	(%)
Entisol 200,421.4 km^2 (39.86 %)	Aquent	Epiaquent	1,503	0.30
		Fluvaquent	160	0.03
		Hydraquent	19.5	<0.01
		Psammaquent	13.1	<0.01
		Sulfaquent	53.6	0.01
	Fluvent	Torrifluvent	1,627	0.32
		Udifluvent	294	0.06
		Ustifluvent	441	0.09
		Xerofluvent	14,172	2.80
	Orthent	Cryorthent	4,784	0.95
		Torriorthent	20,197	3.99
		Udorthent	9,858	1.95
		Ustorthent	17,720	3.50
		Xerorthent	125,265	24.75
	Psamment	Quartzipsamment	286	0.06
		Torripsamment	118	0.02
		Ustipsammnet	24.3	<0.01
		Xeropsamment	3,886	0.77
Total				39.63

where A = % soil moisture; s = % silt; S = % sand; c = % clay; and SOM = % soil organic matter.

These soil characteristics cause mechanical problems of access and management of Hydraquents, both in relation to agricultural and livestock use.

Hydraquents occupy a small area of Spain's national territory (19.5 km^2) and have only been mapped as associated soils; they are located in marsh and coast areas. Hydraquents have been reported, associated with Salorthids and Sulfaquents, in some areas of tidal influence of the estuaries, such as in the arc formed by the Cabos de Corrubedo, Falcoeiro, and Santa Eugenia (Galicia).

Psammaquents

Psammaquents are sandy Aquents that often lack redoximorphic features (iron concentrations and segregations), primarily because the original material—mainly quartz—is very poor in Fe. Psammaquents occupy a small area in Spain (13.1 km^2) and have only been mapped as associated soils. Psammaquents appear only at particular points, such as in the littoral spit bars (Perillo, A Coruña), in the Ebro Delta (Tarragona), in Dehesa of El Saler (Valencia), and along barrier beaches and coastal or sandy depressions (Doñana, Province ofHuelva).

Sulfaquents

Sulfaquents are Aquents that accumulate sulfidic materials between a soil depth of −20 to −50 cm and have an n value of less than 0.7 or less than 8 % clay, and may have buried histic organic materials. Sulfidic materials (of an organic or mineral origin) contain oxidizable sulfur compounds, have a pH above 3.5, and are permanently saturated with water (predominantly brackish).

If instead of their natural habitat (marshes, etc.), Sulfaquents are either drained or exposed to aerobic conditions, their sulfidic materials oxidize, forming sulfuric acid, which lowers the pH to below 3.0, inducing the formation of Al and Fe sulphates (e.g., as in the Tinto and Odiel Rivers, in the Province of Huelva). The yellow-colored iron sulfate (jarosite) results from redoximorphic conditions that characterize some of the sulfuric horizons of Sulfaquepts* (acid sulphate soils).

In Spanish latitudes, the best choice for keeping Sulfaquents is in natural parks, reserves, wetlands, etc. In other regions, the recovery of Sulfaquents has been justified by social and economic needs (e.g., in Holland, due to land scarcity), with the most common crop systems usually consisting of rice, pastures, or meadows.

Sulfaquents occupy just a small area in Spain (53.6 km^2). They are found in coastal marshes and depressions, having been mapped only as a main soil type in some Galician and Cantabrian territories. Sulfaquents have been described in some of the areas of influence of specific tidal estuaries of Galicia, as in Coruña (Perillo), Betanzos, Ortigueira, south of the estuary of Cedeira, Ferrol, Ría de Vivero, or in the arc formed by the ends of Corrubedo and Falcoeiro, and Santa

Eugenia, Rías Orinon, San Martín de la Arena and San Vicente, as well as in other areas of Cantabria and in the bays of Santander and Santoña, which are associated with Hydraquents and salids. Sulfaquents also appear in the Ebro Delta, in estuaries and other areas of tidal influence in the Levant or north of Spain (San Vicente, Pedreña, and Santoña, etc.) associated with other soil types.

2.3.4.2 Fluvents

Fluvents are soils that have developed on young alluvial matter (on terraces and fans, deltas, or link surfaces with low slopes) affected by aggradation. The deposition of new sediments by successive river floods or by gravity movements in gentle slopes inhibits the formation of diagnostic horizons accompanied by SOM-level fluctuations associated with stratifications, i.e., fluventic properties: those that contain more than 0.2 % soil organic carbon (SOC) up to −125 cm from the soil surface, or an irregular decrease with depth and hillsides with slopes less than 25 %.

Fluvents are fertile, because of the thickness of the soil and natural fertility related to the SOM mineralization. Some of the most important civilizations in the history of mankind developed when these soils were used; they include the Tigris and Euphrates, the Nile, the Indus, etc.). Proper handling of these soils must exploit these advantages, allowing root growth to explore the desired profile's area (for example, by means of irrigation), while preventing the risk of salinization. Fluvent soils are not associated with any particular climate (intra-zonal soils); they therefore appear in cold temperature regimes (Gelifluvents* or Cryofluvents*) as well as in other warmer environments with any moisture regime (Torrifluvents, Udifluvents, Ustifluvents, and Xerofluvents) and also aquic (Fluvaquents).

Torrifluvents

Torrifluvents are Fluvents that have not been exposed to cold temperatures and have an aridic or torric moisture regime (see Aridisols). Torrifluvents cover a total Spanish surface area of 1,626 km^2, typical of the alluvium of large rivers and the associated hydrographic network. The Torrifluvents abound in the valley of the Ebro River, southeast of the Iberian Peninsula, and in the Canary Islands. Specifically, Torrifluvents have been identified in northeast Spain, in the central part of the Ebro River Valley and its tributaries (the Martín, Guadalope, Matarraña, Jalón, Cinca, Segre Rivers, etc.), in southeast Spain, i.e., in the Province of Almería (Andarax and Adra Rivers), and in the Provinces of Alicante and Murcia (Segura, Vinalopó, Sangonera, Guadalentín, Almanzora Rivers, etc.).

On the Canary Islands there are Torrifluvents associated with Xerofluvents and Ustifluvents in the valleys of Guimar, Erjos, etc. (Tenerife Island), in San Nicolas and Llanos de Arinaga (Gran Canaria) and on the Island of Lanzarote, related to Calcids, on the recent glacis of the Miocene massifs.

Udifluvents

Udifluvents are Fluvents distinguished by wet weather, with an udic soil moisture regime (see Udalfs) and typified by warm temperatures. They have been mapped in an area comprising 294 km^2 of Spain, mostly in siliceous alluvial sediments in udic areas of Galicia, Asturias, Cantabria, the Basque Country, Navarre, and northern Aragon.

Specifically, Udifluvents have been described in the estuaries of Getxo, Bermeo (the Basque Country), also depending on their moisture regime, Udifluvents together with Xerofluvents and Ustifluvents in Castilla and León, concretely, in the drainage network formed by the Orbigo, Esla, Cea, Valderaduey, and Carrion Rivers, etc.

Ustifluvents

Ustifluvents are Fluvents with an ustic moisture regime, exposed to rain during the warm season and to warm temperatures. They cover a national Spanish area of 441.4 km^2 and are located in some areas of Galicia, Asturias, Cantabria, the Basque Country, Navarra, Northern Aragón, and Catalonia.

In particular, Ustifluvents have been found in the Miño Valley, spanning from nearby Tomino to beyond Salcidos (Galicia) and also in the river valleys between Dobro and Rianjo Pas (Cantabria), as well as in the Besaya River (Basque Country). Usifluvents together with Fluvaquents are found in the poorly drained bottom areas in the north of the Cinca Valley (Aínsa, Province of Huesca).

Ustifluvents have also been found associated with Haplustalfs between the right riverbank of Allones and Malpica (A Coruña), around the Fervenza reservoir, Sierra de Faro (Pontevedra) and on the slopes of the Jallas River (in Castriz, Province of La Coruña). Finally, they have also been described as inclusions in the Provinces of Lugo and Orense.

Xerofluvents

Xerofluvents are Fluvents with a xeric moisture regime (see Xeralfs) subject to rain in the cold season (Mediterranean) and exposed to warm temperatures. They are the group of Fluvents with the highest surface area in Spain, covering a total of 14,172 km^2, usually located near main rivers.

Xerofluvents have been discovered in the northeastern rivers of Spain between Navarra, La Rioja, Aragón, and Catalonia, such as the Oja, Najerilla Iregua, Leza, Ega, Tordera Rivers, and the Ebro up to its outlet, as well as in the headwaters of the Irati and Arga, in the Foix, Gaya, Francolí and Siurana Rivers. In addition, Xerofluvents are also found in the rivers of central Spain (Duero, Pisuerga, Júcar, Guadiana, Cigüela, etc.) as well as in those of southern Spain (Guadiana, Guadalquivir, etc.).

Xerofluvents associated with Xerorthents are found in isolated areas of the Provinces of Zamora (the Duero and Esla, Aliste and Castrón, Trabancos, Zapardiel, and Arganza Rivers); Salamanca (in the Tormes, Huebra, Gavilanes, and Rivera de Canedo Rivers); and the Cáceres (the river valleys of Alagon and Alberche); Badajoz (Guadiana Valley, Alcarrache and Godelid, Nogales Rivera, and Limonetes).

In the Balearic Islands, Xerofluvents have been identified on the Island of Palma de Mallorca along the Sóller coast near Santa Maria del Camí. In addition, they have been mapped in the southern half of the Island of Menorca, on the Island of Cabrera, and also south of the Island of Ibiza. In many other areas, Xerofluvents are associated with Torrifluvents, Xerorthents, Xerepts and Haploxeralfs, Epiaquents, or Xeropsamments.

2.3.4.3 Orthens

Orthents are Entisols that do not satisfy the requirements of belonging to any other suborder; they have a better drainage system than Aquents, they lack the human influence more than arents*, they lack the sandy texture of Psamments, and they show a regular soil organic matter content decrease with depth, unlike Fluvents. Orthents are the most widespread Entisols, sometimes because they are located on slopes (often steep, where erosion constantly rejuvenates soil until rocks outcrop), and in other circumstances because of the short time that has not left a mark on many of these soil types (e.g., scant soil depth), mainly due to reasons related to the mineralogy and petrology of the rock. The management of these soils is conditioned by their position in the landscape, for their effective shallowness and low fertility. Under these circumstances, the use of these soils in agroforestry is very problematic due to access difficulties and mobility, including the need for drastic and costly measures to modify the profile (balconies, terraces, etc.), by fertilization requirements, and/or by the lack of water. The Orthents nomenclature varies according to the temperature regime (Cryorthents) and moisture regime (Torriorthents, Ustorthents, Udorthents or Xerorthents).

Cryorthents

Cryorthents are Orthents located within a cold climate, whose annual average temperature ranges between 0 and 8 °C and the average summer temperature is below 15 °C to a depth of −50 cm. Cryorthents have been mapped in a total area of 4,784 km^2, located mainly in high altitude mountain areas across Spain. Specifically, Cryorthents are found in the Central Pyrenees (northern areas of the Provinces of Huesca and Lleida), the Cantabrian Mountains (Picos de Europa, Sierras de los Ancares y las Omañas, Somiedo y Pajares, Peña Labra), the Massif Galician-Leonese (Cabeza de Manzaneda), the Iberian Range (Sierras of Demanda, Urbión, Cebollera and Cameros), the Betic Range (Sierra Nevada), and on top of the Teide (Tenerife).

Torriorthents

Torriorthents are Orthents characterized by an arid climate (torrid). For agricultural management, it is essential to introduce irrigation and control salinity on specific lithologies. Torriorthents have been mapped in a total area of 20.2 km^2, mostly in the Middle Ebro Valley from the Rioja Baja, south of Navarra (Bardenas Reales), south of the Provinces of Zaragoza and Huesca (Monegros Desert), Teruel (Desert of Calanda), and around the city of Lleida.

Torriorthents also abound in the southeast Iberian Peninsula, from Albacete (north of the Rio Mundo, Isso, Ontur and surroundings) to Almería (in volcanic materials of the Cabo de Gata region, in graphite mica schists of the region of La Garrucha, in the Vera depression, and in gypsum around Sorbas), as well as in Granada (Baza region). Torriorthents are also interspersed with Xerorthents in the Provinces of Málaga, Jaén, Murcia, etc.

Torriorthents have also been reported on the Island of Tenerife from Granadilla (in the south and at sea level) and in the steeper areas of Ajarches and Famara (Lanzarote) as well as interspersed with Haplocalcids and Petrocalcids, between Garafía and Los Llanos (Island of La Palma).

Udorthents

Udorthents are Orthents with an udic moisture regime (see Udalfs) and are exposed to warm temperatures. They occupy a total area of 9.9 km^2, found mainly in Galicia, Asturias, the Basque Country, in the Provinces of Avila and Cáceres, in Cantabria (Pesues, Roiz), Navarra (Sierra de Abodí, Isaba), Huesca (Benasque, Aneto), Lleida (Artiés), and the Islands of Tenerife and La Palma.

Ustorthents

Ustorthents are Orthents with an ustic moisture regime (see Ustalfs) and are subject to warm temperatures. They occupy a total surface area of 17,720 km^2 throughout Spain,with a similar distribution to that of the Udorthents. In addition, it is necessary to highlight their presence in the mountains of Zamora (Segundera, Culebra, Cantadores), Lugo (Sierras de Cadeira in Modoñedo, Lorenzana and in the south and southeast of Becerreá, northeastern Padrairo), or between Cáceres and Salamanca (in the Sierra de Gata and the Rock of France, respectively). They also appear in the westernmost region of the Canary Islands in the highest peaks of the Grand Canary and La Gomera Islands.

Xerorthents

The Xerorthents are Orthents with a xeric moisture regime (see Xeralfs), i.e., with rainfall in the Mediterranean cold season and warm temperatures. The Xerorthent group is the most significant among the Entisols and it occupies more than half of the total proportion of Entisols. Xerorthents have been mapped across a total area of 125.3 km^2 over most of the Iberian Peninsula and the Balearic Islands, as well as in the areas south of the western Canary Islands.

Xerorthents have been found in the most rugged parts of the Sierra de la Demanda, Sierra de la Bellanera, south of Tierra de Cameros, and north of the mountains of Obarenes and across the Cantabrian ranges; to the west of the Arga River and in the Irati forests, and between Noain and Eós. In addition, they are found in the villages of Rillo, Chelva, and Pedralba, in Castillejo, Baños, La Parrilla, Cogeces or Campaspero on marls and limestones, in Roa and San Juan on Neogene sandstones, and in the Sierra de la Demanda Mountains (Boceguillas) on Mesozoic and Paleozoic materials (Honrrubia). They have also been discovered on the strongest reliefs of the mountain foothills of slate and quartzite of the Sierras of Guindos, Navajarra, Fuertelengua, etc., as well as on the strongest reliefs of slate and quartzite (Sierras de Puertollano), endogenous rocks (Sierra Madrona), in the most unstable marls of Las Lomas, on dolomitic limestone mountains in Segura, Cazorla and Del Pozo, in the reliefs of the Sierra Morena Mountains, on slate and quartzites of the Sierra Boyera and Peñarroya-Pueblonuevo, between Yecla and Villena, and from Estepa to the Borno reservoir.

Xerorthents are also associated with Ustorthents in the Provinces of Zamora, Ciudad Real, Huelva, and others. Likewise, Xerorthents associated with Inceptisols and with Alfisol inclusions have been mapped in the northwest part of the island of Mallorca in connection with the high domains of mountains (Puig Mayor, 1453 m asl), in the areas of southwest Cape Favorix (Menorca), to the south of the Island of Ibiza (related to secondary and tertiary limestones), and in general throughout the islands of Formentera, Cabrera, and Conejera. Finally, Xerorthents also appear in southern Tenerife, especially on recent sediments, in areas of steep slopes, in ravines, and on slopes of recent lava flows.

2.3.4.4 Psamments

Psamments are Entisols characterized by sandy textures and with a low stoniness (containing less than 35 % of coarse elements throughout the soil control section). Psamments are therefore a very unusual soil type and have developed in areas where sand has accumulated (paractual or fossil), such as dune systems, costs, barriers, shoals and spits, river accumulations, etc., where their evolution has been slowed precisely because of this sand excess and the consequent alteration difficulty.

Psamment management is mainly influenced by the multiple properties derived from their coarse texture: low fertility, low moisture retention and rapid infiltration, all of which reduce the effectiveness of irrigation. These soils can withstand highly specialized crops (such as asparagus, endives, or even citrus or vineyards) on account of their easy tillage.

The suborder of the Psamments is divided into groups according to temperature (Cryopsamments) and moisture regimes (Torripsamments, Ustipsamments, Xeropsamments, and Udipsamments), together with mineralogy features (Quartzipsamments).

Quartzipsamments

Quartzipsamments are Psamments consisting of over 90 % of resistant minerals (e.g., quartz) in the sand fraction. Quarzipsamments have been mapped as associated soils or inclusions, occupying an area of only 286.3 km^2, for example in the Cubillas (Province of Granada) and Júcar Záncara Rivers in the Province of Cuenca.

Torripsamments

Torrisamments are Psamments with an aridic-torric moisture regime (see Aridisols) that are not exposed to cold temperatures. In the case of torripsaments, irrigation becomes more indispensable than for the rest of the Psamments, in view of agricultural use and salinity control. They have been mapped across a total surface of 118.2 km^2 in the southeast areas of the Iberian Peninsula, e.g., in the Campo de Níjar (Almería) or Manga del Mar Menor (Province of Murcia). Torripsamments are also found in the eastern zones of the Canary Islands: northwest of the Island of Lanzarote and Graciosa, in coastal formations, beaches and dunes, as in Jandia, and dunes of Corralejo, Fuerteventura Island, and the Island of Tenerife north of Medano.

Ustipsamments

Ustipsamments are Psamments with an ustic moisture regime (see Ustalfs). They have been mapped in a total area of 24.3 km^2 along the ustic coast of Galicia, e.g., Cambados, where they are associated with Psammaquents; moreover, they are also located in the antique Roman gold mining region of las Médulas (Province of León).

Xeropsamments

Xerosamments are Psamments comprising a xeric soil moisture regime (see Xeralfs). They have been mapped across a total area of 3,886 km^2, mainly in the central and southwestern parts of the Iberian Peninsula. In fact, the most

Photo 2.11 Histosol (medihemist) in El Puerto de los Tornos (Cantabria)

important areas in which these soils are located are the central part of the Duero River Basin and its tributaries, such as the Duratón, Adaja, or Pisuerga in Tierra de Pinares, Cuesta de Cuellar and those associated with sands (in the Provinces of Valladolid, Segovia, Zamora, etc.). They can also be found occasionally in the sandy areas of both the Mediterranean Sea and the Atlantic Ocean.

2.3.5 Histosols (Photo 2.11)

Histosols comprise organic soils, colloquially known as "peat." Their establishment requires specific formation factors such as cold weather and water saturation, concave topography, acid parent material, vegetation adapted to the above factors and, finally, time (from the late Pleistocene). About 85.5 km^2 of Histosols have been mapped, basically in northern Spain (Table 2.6).

In particular, the most representative Histosols are located in Galicia: Sierras de Capelada, Sierra del Xistral, and south of the Montes de Buyo, the Ancares, and Courel, Serpe, Suido, Queixa, Grova Barbanza and also in the Massif of Cabeza de Manzaneda, and the Antela Lagoon.

Table 2.6 Extent and proportion of Histosols (by suborders and groups) found in Spain

Order	Suborder	Group (2003)	Surface (km^2)	Percentage (%)
Histosol	Fibrist	Histosol	85.5	0.02
	Folist			
	Hemist			
	Saprist			

More localized, acidic peats (Cryohemists and Cryofolists) and mesotrophic (Cryosaprists) soils are found in the Pyrenees of Huesca (Aguas Tuertas, Ansó) and Lleida (Alt Àneu), in the Cantabrian mountain range (the Port of the Tornos) and in the Central System (Sierra de Guadarrama, Sierra de Gredos). In addition, there are eutrophic peats in Daimiel (Ciudad Real) and even in southern Spain: the Madre peatland (Province of Huelva) and the Padul peatland (Province of Granada). Inclusive, there are peats bound to brackish waters along the Mediterranean coast, from the Ebro Delta to the delta lagoons of Castellón (Parc de Cabanes-Torreblanca) and also in Valencia (Pego-Oliva, Sueca, and Cullera).

Histosols are scarce and highly fragile, and their decomposition rate is accelerated when they are drained. They have assorted functions:

- They are actively used as substrates and organic amendments for gardening and in agriculture.
- They have been traditionally used as fuel (energy sources) due to their high organic C content.
- They perform numerous environmental functions, including C sinks and biological habitats.
- They are extremely valuable for preserving archaeological and paleontological heritages.

2.3.6 Inceptisols (Photos 2.12, 2.13, 2.14, 2.15, 2.16 and 2.17)

Conceptually, Inceptisols consist of poorly developed mineral soils that are characterized by light-colored surface horizons (epipedion ochre) and subsurface horizons, as, for instance, the cambic, (petro) gypsic, (petro) calcic, hardpan, or fragipan. Inceptisols occupy a large number of landforms, from alluvial terraces to mountain areas; they are also present in most climates, especially in the warm Mediterranean regions (Fig. 2.7). All in all, Inceptisols occupy a large area of Spain, along with the Entisols. They occupy nearly 38 % of the national area (190,517 km^2) and are distributed throughout all climates and various geographical situations. Most of the Inceptisols have high agricultural potential, although when located in the xeric and ustic moisture regimes, they require irrigation. In mountain areas, their exploitation is limited to forestry or livestock.

The following soil groups have been mapped: Epiaquepts, Dystrocryepts and Eutrocryepts; Dystrudepts, Eutrudepts (or associated); Dystrustepts, Haplustepts (or associated), and, finally, Calcixerepts, Dystroxerepts and Haploxerepts (Table 2.7).

Photo 2.12 Inceptisol (Halaquept) in Doña Blanca (Province of Cádiz)

Photo 2.15 Inceptisol (Gypsic Haploxerept) in Villamayor de Santiago (Province of Cuenca)

Photo 2.13 Inceptisol (Dystroxerept) in Ponferrada (Province of León)

Photo 2.14 Inceptisol (Typic Haploxerept) in Tabuenca (Province of Zaragoza)

2.3.6.1 Aquepts

Aquepts consist of wet Inceptisols characterized by a slow drainage system and being constantly waterlogged; their properties are determined by the influence of a high water

Photo 2.16 Inceptisol (Calcixerept) in Jerez (Province of Cádiz)

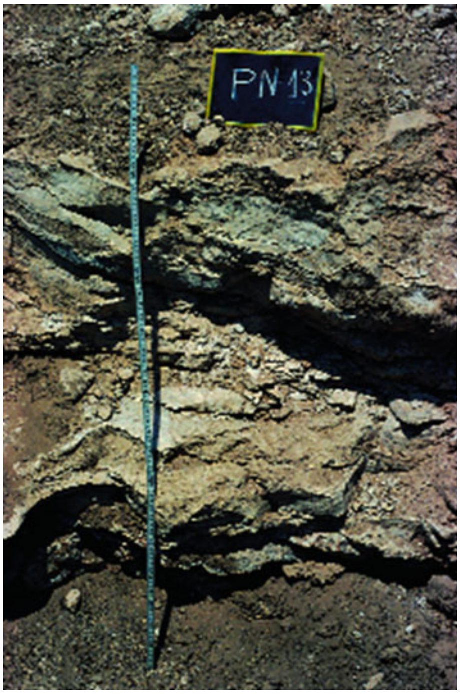

Photo 2.17 Inceptisol (Petrocalcic Calcixerept) in Pinoso (Province of Alicante/Alacant)

table that implies that the soil formation is slowed down due to anaerobiosis. From a practical standpoint, waterlogging in Aquepts is brought on by the presence of soil redox state generated spots together with gray-colored reduction zones.

Epiaquepts

Epiaquepts are found in epi-saturated conditions, characterized by a perched water table. Under these conditions, agricultural use requires the implementation of drainage techniques. In Spain, Epiaquepts cover a total surface area of 806.7 km^2; they are located in scattered areas, yet are found under defined geomorphological conditions, in which drainage is impeded by natural or artificial barriers (terraces, moraines, spits, dikes, etc.). Otherwise, they can also be found in places where there is no natural water outlet (endorheic areas, abandoned meanders, wetlands, and lagoon edges), else, water inputs are continuous and the ground has a reduced permeability (marshes, estuaries, deltas, mangroves, etc.).

Epiaquepts have been reported in some parts of the Ebro Delta (Tarragona), in the Marsh of the Natural Park of Pego-Oliva (Valencia), at the head of the Rivera de Mazán, at the Fountain of Corcho, or Tiétar (Province of Cáceres), and on both banks of the Duero River in Laguna de Duero (Province of Valladolid). There are also Epiaquepts associated with Epiaquents, Fluvaquents, and other soil types in many Spanish provinces.

2.3.6.2 Cryepts

Cryepts are Inceptisols localized in cold climates (having average temperatures of between 0 and 8 °C and a summer average temperature of less than 15 °C at a soil depth of −50 cm). Given their thermal limitations, the use of Cryepts is limited to forestry (e.g., conifers) or raising livestock (e.g., summer grazing).

Cryepts are located in the mountainous areas and at high altitude peaks throughout Spain, in more stable and less eroded zones than Cryorthents. The suborder of the Cryepts is further subgrouped into the Dystrocryepts with a total area of 3,079 km^2, and the Eutrocryepts are spread over 727.6 km^2. The Cryepts are found in the Central Pyrenees (Huesca and Lleida), the Iberian Range (Moncayo), Picos de Europa, Manzaneda (Ourense), Sanabria (Zamora), Sierra of Demanda and Urbión (Province of Soria), Somosierra-Navacerrada System (Madrid), Sierra Nevada (Granada), Teide (island of Tenerife), and Garajonay (island of La Gomera).

2.3.6.3 Udepts: Dystrudepts and Eutrudepts

Udepts are Inceptisols with a free-draining soil system and comprise an udic moisture regime. In Spain they are primarily located in Galicia, in the Cantabrian Mountains, and also in the Pyrenees. Depending on the soil base saturation,

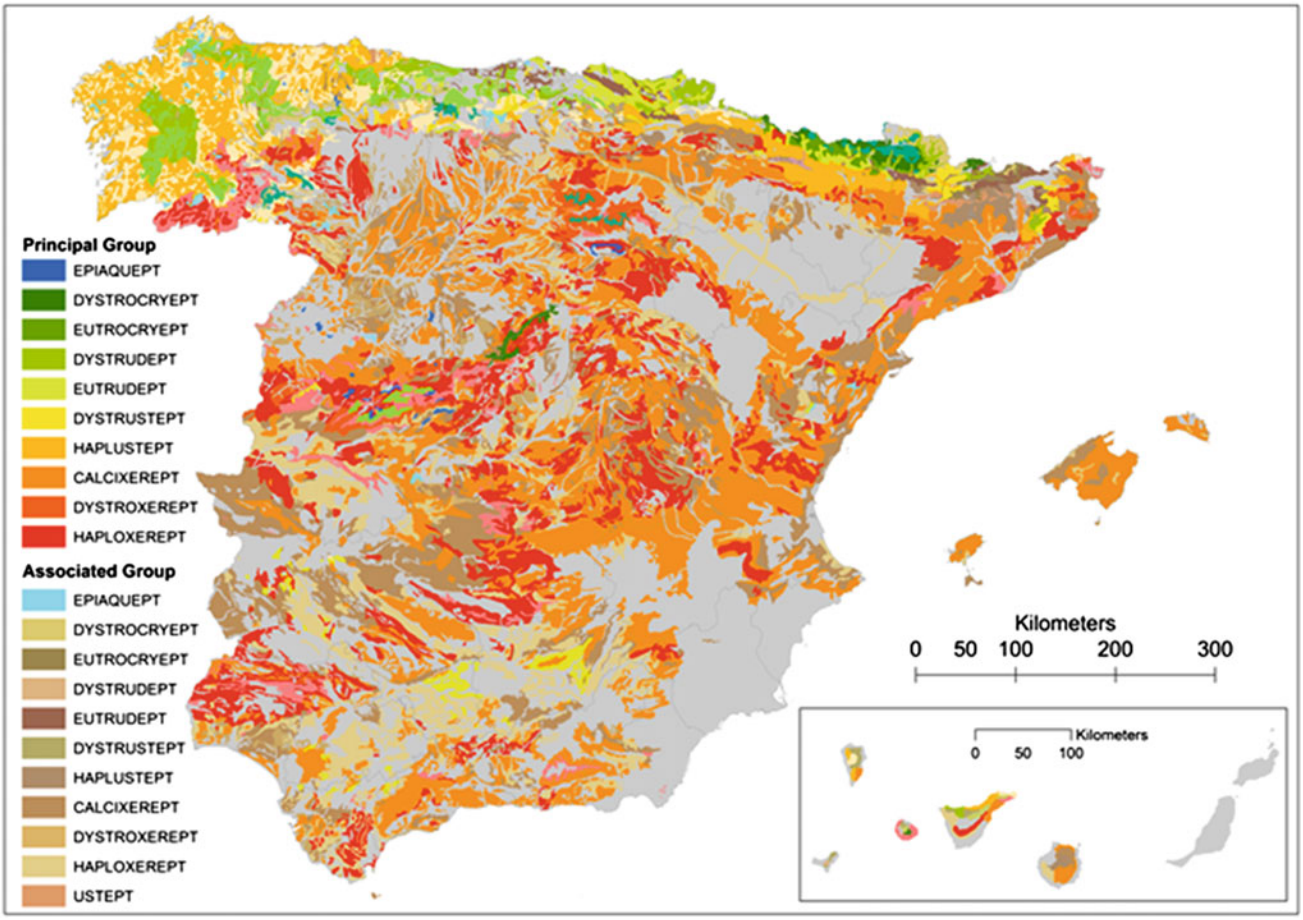

Fig. 2.7 Distribution of Inceptisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

Table 2.7 Extension and proportion of Inceptisols (by suborders and groups) found in Spain

ORDER surface (%)	Suborder	Group (2003)	Surface (km^2)	Percentage (%)
Inceptisols 190,517.1 km^2 (37.89 %)	Aquept	Epiaquept	806.7	0.16
	Cryept	Dystrocryept	3,078.5	0.61
		Eutrocryept	727.6	0.14
	Udept	Dystrudept	7,867.4	1.55
		Eutrudept	3,177.0	0.63
		Association	9.3	<0.01
	Ustept	Dystrustept	8,771.9	1.73
		Haplustept	13,973.7	2.76
		Association	297.1	0.06
	Xerept	Calcixerept	69,691.4	13.77
		Dystroxerept	11,775.9	2.33
		Haploxerept	70,340.6	13.90
Total				37.65

Udepts are further classified in Dystrudepts and Eutrudepts. Dystrudepts occupy a total surface area of 7,867 km^2, while Eutrudepts cover 3,177 km^2.

Given their high moisture availability, Udepts are used for forestry, and if their relief is not marked, also for cultivation. Specifically, Udepts can support intensive agriculture, although their location may determine the occurrence of erosion and soil truncation. The terracing of Udepts and their subdivision into plots undertaken in these soils with an ultimate prospect to perform intensive agriculture (often smallholders), determines the formation of a very characteristic landscape (such as in the case of certain regions of Galicia). Udepts have been mapped as main, minor and inclusions over wide areas of the wetter zones of the Basque Country, Asturias, Cantabria, Galicia, Navarra, Aragon, and Catalonia.

2.3.6.4 Ustepts: Dystrustepts and Haplustepts

Ustepts are Inceptisols characterized by rain in the warm season (continental characteristics) and with an ustic moisture regime. When located on slopes, Ustepts are normally engaged in forestry or grazing and, more rarely, designated for crops. Specifically, Ustepts can withstand exploitation under a relative performance, yet often they display drought-associated problems. In addition, Ustepts also have active erosion processes that can cause the disappearance of the epipedon (soil truncation), especially if drastic structural changes are made for more intensive agricultural uses. In Spain, two kinds of Ustepts are found: Dystrustepts, covering 8,772 km^2, and Haplustepts, distributed over 13,974 km^2 and classified as main soils, secondary and inclusions. They are found in a wide range of areas: Galicia, the Basque Country, north and west of Castile and Leon, north of Catalonia, in the Provinces of Asturias, Cantabria, Navarra and Huesca, between the Provinces of Salamanca and Cáceres, and also in the western part of the Canary Islands.

2.3.6.5 Xerepts

Xerepts are Inceptisols that are typical of the Mediterranean climate zones, exposed to a xeric soil moisture regime. Xerepts' management is limited mainly by the lack of water, even sometimes for the winter crops. Some of the limitations of these soils are, for instance, a scarcely effective soil depth (presence of Petrocalcic), low fertility, or low SOM content, surface crusting, salinization or alkalinization, chlorosis, etc.

Xerepts represent more than three-quarters of the total surface area of the Inceptisols; Calcixerepts, Haploxerepts, and Dystroxerepts have been mapped across most of the Iberian Peninsula and the Balearic Islands, as well as in the western part of the Canary Islands.

Calcixerepts

Calcixerepts are Xerepts with carbonate accumulations such as calcic or Petrocalcic horizons. The processes of formation and destruction of the calcic/Petrocalcic horizons have great environmental importance, as they involve an accumulation or release of inorganic C from the ground. Either by natural or human-generated changes, these processes are activated in one way or another and interact directly with the greenhouse effect.

Calcixerepts are typified by various management problems, such as shallow soil depth (e.g., lithic or Petrocalcic Calcixerepts), poor drainage (Aaquic Calcixerept), alcalinity (Sodic Calcixerept), and, more generally, by iron chlorosis (Typic Calcixerept).

Calcixerepts occupy a total national surface area of 69,691 km^2, distributed (as main soils, secondary and inclusions) over a nationwide area with the exception of the wettest areas, including high and steep regions.

Dystroxerepts

Dystroxerepts are Xerepts, which have a reduced base saturation. Dystroxerepts cover a total Spanish surface area of 11,775.9 km^2. Cultivation of these soils requires an input of amendments in order to increase, balance, and activate the cation exchange complex. Dystroxerepts are located throughout the Provinces of Ourense, León and Palencia, Zamora, Toledo, Cáceres, Badajoz, Ciudad Real, Huelva, Barcelona, and in specific areas of the Canary Islands.

Haploxerepts

Haploxerepts have been mapped over a wide area of Spain comprising a total of 70,341 km^2, distributed as main soils, secondary, and also as inclusions. Prominent among the many places in which they are located, Haploxerepts have been reported in western Grañén (Province of Huesca), in the most stable areas of Sanabria, Aliste, and Sayago (Province of Zamora), on the right riverbank of Valderaduey, on both sides of the Sequillo (North Duero River), also often associated with Xerorthents in the slates of the Dañador Reservoir (Province of Jaén), in Navas del Madroño (Province of Cáceres), in the Sierra de San Pedro (also the Province of Cáceres), west of Fregenal de la Sierra, and northwest of Fuente Cantos (Province of Badajoz), etc.

2.3.7 Mollisols

Mollisols (Photo 2.18) are soils with thick, dark surface horizons, rich in organic matter, porous, and with a good-quality structure (mollic epipedon). Regarding management (from a theoretical standpoint), Mollisols should be aimed at achieving a sustainable agriculture with the least possible negative interference on the humification-mineralization balance. Because of their high fertility and formation conditions, Mollisols are highly productive soils, even though their mismanagement (excessive tillage, null supply of organic amendments) can cause a mineralization increase of the humification, which has provoked Mollisol degradation and their gradual disappearance in many parts of Spain.

Photo 2.18 Mollisol (Calcixeroll) in Foncea (La Rioja)

Mollisols have been mapped only across 7,490 km^2, which represents less than 1.5 % of the national surface area, in a very scattered manner and only rarely as main soils (Fig. 2.4). Specifically, the following groups of Mollisols have been observed in Spain: Cryrendolls, Calcixerolls, Haploxerolls, Haplustolls, and Hapludolls (Table 2.8).

2.3.7.1 Rendolls: Cryrendolls

Rendolls are Mollisols that have evolved on highly calcareous materials (>40 %) in cold or wet areas. Of the two groups in which Rendolls are subdivided, only Cryrendolls with a cryic temperature regime appear in Spain. Cryrendolls have been mapped on a total surface area of 714 km^2 normally associated with Inceptisols or Entisols, or as inclusions in the high altitude limestone massifs of the country. Therefore, Cryrendolls are located in the Pyrenees (West Somport, Huesca), in the Cantabrian Mountains (Picos de Europa Mountains, Cantabria), and also in the Iberian Range (Sierra de la Demanda or Arandio in the Provinces of Burgos, La Rioja, and Soria).

2.3.7.2 Udolls: Hapludolls

Udolls are well-drained Mollisols, comprising an udic moisture regime (see Udalfs). Among the Udolls, only the Hapludolls have been mapped in Spain across a surface area of 972.7 km^2, specifically in Galicia, the Cantabrian Mountains and the Pyrenees. In general, Hapludolls have been reported on in the northern part of the Province of Huesca (in the wet areas between the Gállego and Cinca Rivers or in the cold areas between Canfranc and Piedrafita de Jaca). Hapludolls also abound in the Province of Lugo (in the areas of influence of the limestone crags located south and southeast of Becerreá, Doncos, Meira, Mondoñedo, west of Torrelavega, northeast of Padrairo, west of the Sierra San Román, and south of Vilarchao). Hapludolls are also common in the Province of Asturias (between Ribadesella and Nueva), in the Province of Vizcaya (east of Plencia and Kortezubi), in the Province of Guipuzcoa (eastern Zumarraga, Sierra of Aitzgorri, Peña Urdala), or in Navarra (in the Mountains of Aralar). Hapludolls are usually used for forestation activities and occasionally also for crops (e.g., potatoes in the region of Salvatierra, Álava).

2.3.7.3 Ustolls: Haplustolls

Ustolls are Mollisols with rain in the warm season (monsoon). In Spain, only Haplustolls have been mapped, which are preferentially located in Galicia, western Provinces of Zamora and León, the Cantabrian Mountains, and the Pyrenees. Specifically, a total of 1,003 km^2 of Haplustolls have been mapped, distributed as main, secondary, and soil inclusions developed on base-rich rocks exposed to an ustic soil moisture regime. Haplustolls are usually used for forestation activities and grazing, although occasionally also for crops.

Haplustolls can be found in the northern and central parts of the Province of Navarra and in the northern region of the Province of Huesca, Lleida (the Aran Valley, Pallars Sobirà), Barcelona (Berguedà), Castellón (Morella), León (Bierzo), Asturias (Sierra de Muriellos), and alternating with Hapludolls in various sites mentioned above in the Provinces of Lugo and Guipuzcoa.

2.3.7.4 Xerolls

Xerolls are Mollisols with a xeric soil moisture regime. In Spain, only Haploxerolls and Calcixerolls have been mapped, sparsely distributed as main soils, secondary and inclusions in various parts of the peninsula and the Balearic Islands, as well as in the southern parts of the western islands.

Haploxerolls

Haploxerolls represent more than two thirds of the Mollisol surface in Spain, having been mapped over 4,531 km^2. There are Haploxerolls in the Provinces of Álava (e.g., Salvatierra), Navarra (Pamplona), Huesca (south of Benabarre), Tarragona (Tortosa), Castellón (Vinaroz), Lleida, Soria, Burgos (Bureba and Belorado), Cuenca, Albacete (Villanueva de Alcardete), Valencia (Llíria), Ciudad Real (Alcaudete-Valdepeñas), Cáceres (Coria, Torrejoncillo and Peraleda), Badajoz (Almendralejo, Santos de Maimona, Fuente del Mestre, between the Entrín and Rivera de los Limonetes Rivers), Huelva (north of Azud de Matavacas), La Rioja (in the region of Tierra de Cameros, between Haro

Table 2.8 Extension and proportion of Mollisols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Group (2003)	Surface (km^2)	(%)
Mollisol 7,489.5 km^2 (1.49 %)	Rendoll	Cryrendoll	714.0	0.14
	Udoll	Hapludoll	972.7	0.19
	Ustoll	Haplustoll	1,002.9	0.20
	Xeroll	Calcixeroll	268.6	0.05
		Haploxeroll	4,531.4	0.90

Table 2.9 Extent and proportion of Spodosols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Group (2003)	Surface (km^2)	Percentage (%)
Spodosol 645.4 km^2 (0.11 %)	Humod	Haplohumod	74.0	0.02
	Orthod	Haplorthod	571.4	0.09

and La Bastida), Sevilla (Puebla del Río), and in the Provinces of Málaga and Cádiz.

Calcixerolls

Calcixerolls occupy a total surface area of 268.6 km^2 and are found mainly in the Provinces of Barcelona (region of L'Anoia), Castellón (Vinaroz), Lleida, Tarragona (Tortosa), Zaragoza (Fuendetodos, Daroca, Embid, Montes de Zuera), Teruel (Santolea), Huesca (Camporrells), Seville (Constantina, Marchena), Segovia, Cáceres, Granada, and Málaga, among others.

2.3.8 Spodosols

Spodosols are soils comprising an illuviation subsurface horizon of organic matter and also containing iron and aluminum sesquioxides (endopedon spodic, *Bs*). Spodosols are highly acidic, display low fertility, contain excessive permeability of the eluvial horizon, and sometimes characterized by a cementation of the Bs horizon. Taking all these properties into consideration, these soils are most frequently used for forestry.

Throughout Spain, Spodosols occupy only a small area consisting of 645.4 km^2 (about 0.13 % of the national surface), located in small and widely scattered spots typified by cold and wet environments with acidic lithologies (Fig. 2.4). Only two suborders of Spodosols have so far been mapped in Spain: Humods and Orthods (Table 2.9).

2.3.8.1 Humods: Haplohumods

Only a total surface area of 74 km^2 of Haplohumods has been mapped across Spain, in all cases as inclusions. In particular, Haplohumods associated with haplumbrepts have been identified in the Montes de Asturias (e.g., in the Sierra de Sobia), Cantabria (north of Roiz), Lugo (north of Puebla and in the Sierra of Navia, Rañadoiro), and also in the Lleida Pyrenees (in the county of Pallars Sobirà associated with Cryods*).

2.3.8.2 Orthods: Haplorthods

About 571.4 km^2 of Haplorthods have been mapped as main soils, associations or as inclusions, mainly in northern Spain in the autonomous communities of Galicia, Asturias, Cantabria and the Basque Country.

Haplorthods have been identified, interspersed with Dystrudepts in the Provinces of Santander (Sierra de Peña Labra, Sierra del Escudo, Montes de Ordunte, Ucieda Mountains, north of Roiz, etc.), Oviedo (Alto de Fito, Grandas of Salime, Castropol, Loma de la Arganza, Cabo Vidio, Callezuelo, in the areas surrounding the catchment areas of Cape Vidio and Salas), Lugo (Cabaleiros mountains and northern Oro Valley, Lagoa, Maciñeira, Sierra del Mirador and northeast of Cadabo), La Coruña (east of Pontes de Garcia Rodriguez, north of Ortigueira) and Ourense (north of Ginzo of Limia, south of Maceda, north of Rua and Taboadela and in the surrounding influence areas of the Antela Lagoon). Haplorthods have been found with associations of Entisols in the Provinces of Salamanca (Sierra of Francia) and Cáceres (Sierra of Villuercas), and with Ultisol associations in Navarra (Urbasa) and Vitoria (Port of Azaceta and Herrera), and to Fluvaquents associated with Epiaquents in Madrid (north of the Port of Pozazal); they are also associated with cryods* in the Catalan Pyrenees (Vall d'Arán, Molló), and Andorra. Finally, inclusions can be found on quartzite sandstones, spetially under beech and Scots pine forests of the Iberian System (Moncayo).

2.3.9 Ultisols

Ultisols have an Argillic or kandic horizon (similar to an Argillic one, but with a cation exchange capacity lower than 16.0 cmol$_c$ kg^{-1}) and a low base saturation, which decreases progressively in the subsurface layers. The prefix "ult" is related to the word "last" and is associated with their advanced alteration state.

Ultisol formation requires a humid climate with some seasonal contrast, allowing for base leaching with a clay

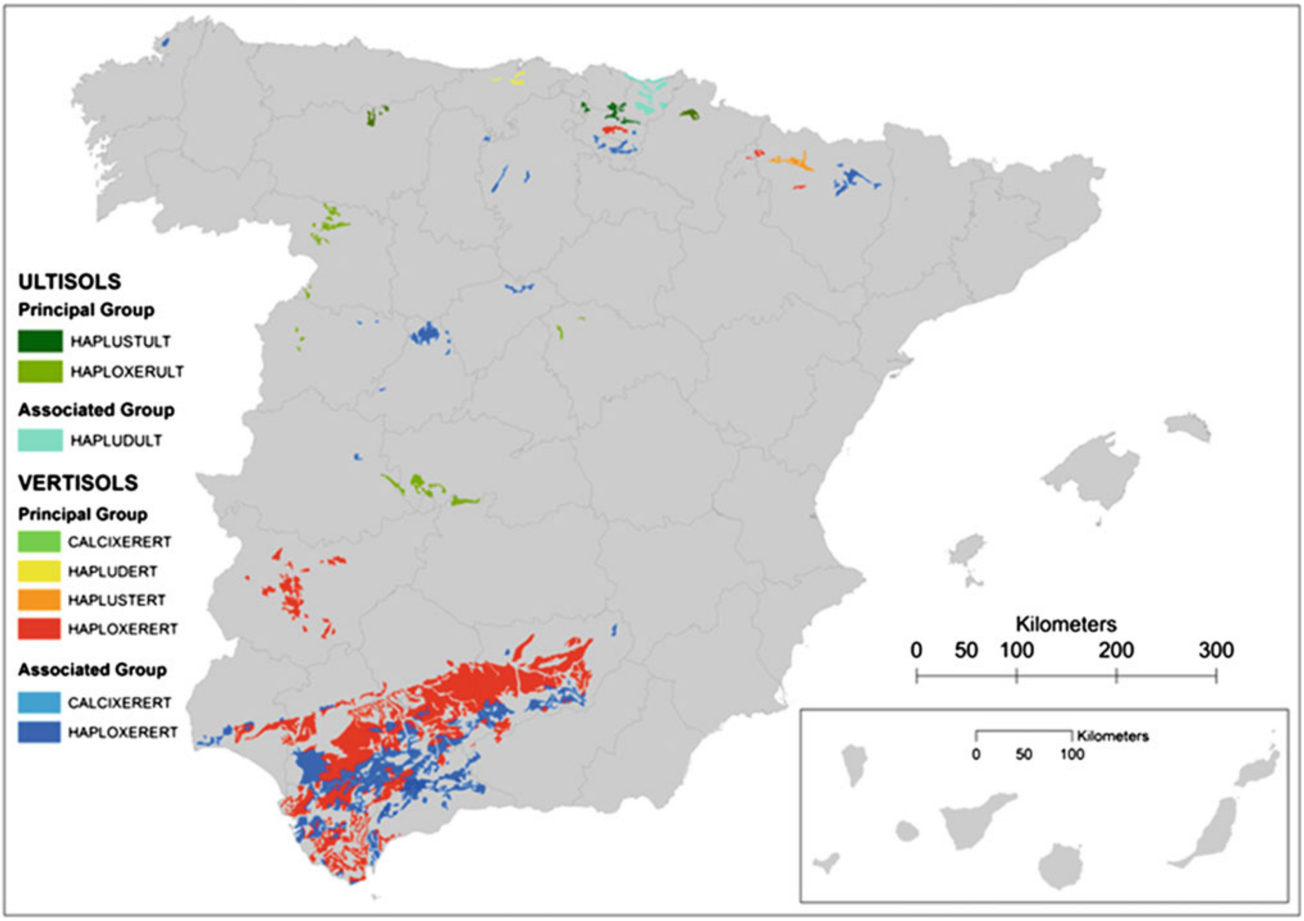

Fig. 2.8 Distribution of Ultisols and Vertisols (excluding inclusions; Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

accumulation. It also requires a stable and mature surface, as in the case of rañas, dating at least to the beginning of the Quaternary period.

Ultisols are extremely acidic soils with a low base saturation (<35 %) and a high concentration of exchangeable aluminium, with clay accumulation in the endopedon composed of kaolinitic clay mineralogy (low cation exchange capacity and pH-dependent charge), and with a high Fe and Al oxide and oxyhydroxide content. Taken together all of these properties, Ultisols are generally considered to be unproductive soils, except for very specific acidophilus crops (e.g., tobacco). Agricultural use requires organic amendments and lime treatment to increase the pH, which enables controlling the Al^{3+} toxicity (generally saturated above the 60 % capacity value for sensitive crops), and also the availability of P (adsorption is related to Fe oxides, Al, Mn, and amorphous or weakly crystalline aluminosilicate).

The Ultisols mapped in Spain (Fig. 2.8) constitute only 0.18 % of the total national area (888.6 km^2), while only the Haploxerults, Haplustults and Hapludults groups have been mapped across the Spanish territory (Table 2.10).

2.3.9.1 Udults: Hapludults

The Udults are freely drained Ultisols found in wet areas and exposed to an udic moisture regime (see Udalfs). In Spain, Hapludults have only been mapped (91.9 km^2) as secondary soils and with a very scattered distribution across the national territory.

Hapludults have been described in the northern mountains of Álava, on the shales and siltstones of Igeldo, Eibar, Loyola, Lasarte and Bedaio and in the region of Oñate, Tolosa (Guipúzcoa) as well as south of Lequeitio (Vizcaya). In the Canary Islands, Hapludults have been described on the island of Tenerife, where they have been exposed to a wet climate and are among the oldest substances on the island (as in the Massif de las Mercedes and La Esperanza), in the humid northeast of the Island of La Palma, and on Grand Canary Island (around Valleseco).

2.3.9.2 Ustults: Haplustults

Ustults are Ultisols exposed to rain in the warm season and encompassing an ustic moisture regime. Only Haplustults have been mapped (194.7 km^2) as main soils, minor, or

Table 2.10 Extension and proportion of Ultisols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Groups (2003)	Surface (km^2)	(%)
Ultisol 888.6 km^2 (0.18 %)	Udult	Hapludult	91.9	0.02
	Ustult	Haplustult	195	0.04
	Xerult	Haploxerult	602	0.12

Photo 2.19 Spodosol (Haplorthod) in Roupar-As Pontes (Province of A Coruña)

Photo 2.20 Ultisol (Palexerult) in Paradaseca (Province of León)

inclusions in the north of the Province of León as well as in the central area of the Basque Country (Ochandiano) and Navarra.

2.3.9.3 Xerults: Haploxerults

Xerults are Ultisols that appear under a xeric moisture regime. The suborder of Xerults is further divided into two groups: Palexerults* and Haploxerults (Photos 2.19, 2.20).

Although Palexerults* have been found on more evolved and stable surfaces (such as old *rañas*), they have not been mapped, owing to their scarcity. Therefore, the only Xerults mapped in Spain are Haploxerults (602 km^2); they occupy the most stable xeric areas of the Province of León, west of the Provinces of Zamora and Salamanca, north of the Provinces of Guadalajara and Cáceres, and in parts of the Montes de Toledo.

2.3.10 Vertisols

Vertisols are characterized by vertic properties, typified by intense cracking, shrinkage and retraction processes (Photos 2.21, 2.22) that are mostly related to changes in humidity and caused by the abundance of expansive clay minerals (smectite). The wide separation between smectitic clay sheets allows for the entry of water between sheets, in turn causing a volume change while facilitating soil structuration, resulting in a high cation exchange capacity, high thermodynamic stability, and high iron content.

Many Vertisols are commonly developed in concave positions (depressions). Under these stable geomorphological positions, Vertisols are very good agricultural soils that have been fundamental for the increase in human population. However, if located on slopes, they present erosion problems causing the disappearance of the epipedon (truncation), which finally determines the formation of an eroded landscape—as is the case in certain regions of the Guadalquivir Valley (western Andalusia). The quantity and quality of clays gives Vertisols a high plasticity and adherence that might limit soil tillage and farm access; the low permeability and soil volume changes condition the determined irrigation management, plus the construction and maintenance of civil infrastructures (stability of buildings, road leveling,

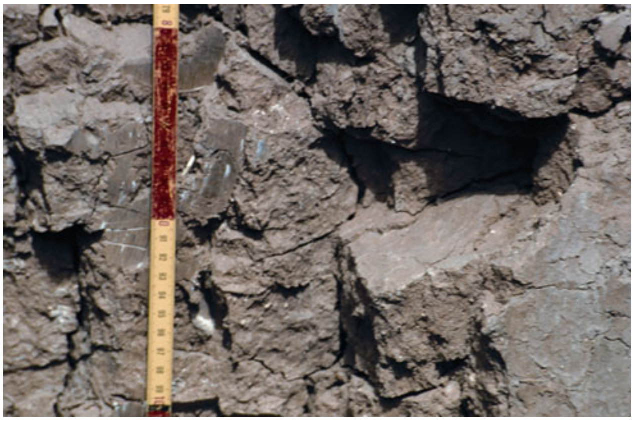

Photo 2.21 Wedge-shaped soil aggregates and slickensides in a haploxerert in Marchena (Province of Sevilla)

Photo 2.22 Vertisol (Chromoxerert) in Talamanca del Jarama (Province of Madrid)

alignment of canals and power lines, etc.) and inclusive plant types since perennial crops will suffer greatly from the seasonal cracking processes.

In Spain, Vertisols occupy a total surface area of 11,990 km^2 and are classified in specific groups: Hapluderts, Calciusterts and Haplusterts, and Calcixererts and Haploxererts, all of which ocupy less than 2.4 % of the nation's total area and distributed over all types of climates and situations (Table 2.11).

2.3.10.1 Uderts: Hapluderts

Uderts are Vertisols seen in areas with an udic moisture regime (see Udalfs). In Spain, only Hapluderts have been mapped (37.3 km^2); these soils comprise an electrical conductivity higher than 4.0 dS m^{-1} or a pH above 5.0. Hapluderts are normally used in forestry or grazing and, to a lesser extent, in crops. Hapluderts have been mapped as main soils in Cantabria; thus, they have been described in association with Entisols and Inceptisols in locations south of the villages of Liaño, Solares, and Cartes (Province of-Santander). In addition, Hapluderts are also found in the Province of Alava, in the upper Teno volcano (Island of Tenerife), north of Fagayesto-Santa Brigida (Gran Canaria Island), as well as in the northern part of the Island of La Palma (between Barlovento and Los Franceses).

2.3.10.2 Usterts: Calciusterts and Haplusterts

Usterts are Vertisols exposed to rainfall in the warm season, i.e., ustic moisture regime (see Ustalfs). In Spain, they are used for forestry or grazing, and only under very specific conditions for crops. There are only two groups of Usterts: Calciusterts (with a calcic horizon) and Haplusterts (modal one). The Haplusterts have been mapped only as a main soil type in the northwest of the Province of Huesca, over a total surface area of 87.6 km^2. In addition, Haplusterts have been occasionally described on the Islands of La Gomera, Tenerife, and El Hierro. With regard to Calciusterts, a total of 17.5 km^2 have been mapped, yet only as inclusions. Specifically, Calciusterts have been identified with Haplustalfs on the Island of La Palma (between Barlovento and Los Catalanes).

Both soil groups have also been mentioned in the Inner Depression of the Central Spanish Pyrenees (Province of Huesca) on eocene marls, although more than Vertisols, they seem to belong to other orders (Entisols and Inceptisols), with some vertic properties (Badía et al., 2015). Therefore, the soils of Val Ancha de Jaca (Province of Huesca) don't have smectites, and the clay content is moderate (about

Table 2.11 Extent and proportion of Vertisols (by suborders and groups) found in Spain

Order surface (%)	Suborder	Group (2003)	Surface (km^2)	(%)
Vertisol 11989.6 km^2 (2.38 %)	Udert	Hapludert	37.3	0.01
	Ustert	Calciustert	17.5	<0.01
		Haplustert	87.6	0.02
	Xerert	Calcixerert	4,530.7	0.90
		Haploxerert	7,316.5	1.45

30 %) as is the soil extensibility (COLE < 0.06 cm cm^{-1} in most horizons). However, topsoil cracking in lower slope profiles is common and seems to be related to strong evaporation during the dry season. Its low liquid limit (usually less than 30 %), low aggregate stability (lower than 25 % in Ap horizons), and high subsidence value ($n > 0.7$) could explain high dispersivity, sliding and scarce soil evolution despite a relative humid climate. Both wetting and freezing processes easily fragment the regolith, which is especially rich in dolomite. The low porosity, mainly vesicular, and a poor structure, facilitate waterlogging in the wet season, which leads to soil reduction processes, especially in deep soil horizons at the lower parts of hillslopes. These soils are found between Jaca and the Aragón River (Province of Huesca) near the border with Navarra (Badía et al., 2015).

2.3.10.3 Xerert: Calcixererts and Haploxererts

Xererts are Vertisols exposed to rain in the cold season (Mediterranean); they constitute the suborder that occupies the largest surface area of Vertisols. Xerert management is conditioned by drought; the irrigation of crops cultivated during the summer can seriously affect soil mechanisms and vertic properties, inclusive trigger all the unwanted effects described for the order.

In Spain, two groups of xererts have been mapped—those with calcium or Petrocalcic (calcixererts), and those holding modal one (haploxererts).

Haploxererts have been mapped as main soils, secondary, or inclusions north of the Iberian Peninsula (Provinces of Burgos and Álava, Navarra and Huesca), in central Spain (Provinces of Ávila, Segovia, Guadalajara and Toledo, Cáceres), in southern Spain, both in the Guadiana River Basin (Provinces of Badajoz and Huelva) and in the Guadalquivir River Basin (Andalusia). Haploxererts occupy a total surface of about 7,317 km^2.

On the other hand, a total national surface area covering 4,531 km^2 of calcixererts has been mapped. They can be found, associated with Haploxerert, in the Andalusian countryside (where they are called “black soils” or “*tierra de bujeo*”), i.e., south of the Guadalquivir River, mainly in the Provinces of Seville, Jaén, Córdoba, and Cádiz and, to a lesser extent, in the Provinces of Huelva, Málaga, Granada and Almería. They have a multipurpose dedicated crop (cereals, cotton, sugar beet, grass, sunflower, etc.).

Appendix

See Tables 2.12 and 2.13.

Table 2.12 Correlations between Soil Taxonomy (USA) and WRB (FAO)

Orders Spanish surface (%)	Suborder	Great groups (2003)	Presence in soil map unit	Surface (km^2)	Percentages (%)	FAO Units (1998)
Alfisol 61861 km^2 12.30	Aqualf	Epiaqualf	3, 4, 5	1471.7	0.29	*Gleyic Luvisol* *Gleysol*
	Cryalf	Haplocryalf	5	154.6	0.03	*Cryosol*
	Udalf	Hapludalf	1, 3	1186.8	0.23	*Luvisol*
	Ustalf	Haplustalf	1, 3, 4, 5	1647.6	0.33	
		Paleustalf	3	27.4	0.01	*Planosol* *Nitisol* *Luvisol*
		Rhodustalf	5	251.3	0.05	*Chromic or Rhodic Luvisol*
	Xeralf	Haploxeralf	1, 3, 4, 5, 6	44480	8.79	*Luvisol*
		Palexeralf	1, 3, 4, 5	3048.7	0.6	*Planosol* *Nitisol* *Luvisol*
		Rhodoxeralf	1, 3, 4, 5, 6	9592.9	1.9	*Chromic or Rhodic Luvisol*
Andisol 533.2 km^2 0.11	Torrand	Vitritorrand	1, 3	23.1	<0.01	*Andosol*
	Ustand	Haplustand	1, 3, 4	441.1	0.09	
	Vitrand	Udivitrand	1	15	<0.01	
		Ustivitrand	1, 3	36.6	0.01	
	Xerand	Haploxerand	5	17.4	<0.01	
Aridisol 28355 km^2 5.64	Argid	Haplargid	3, 4, 5	3642.6	0.72	*Luvisol*
		Paleargid	1	46.4	0.01	*Planosol* *Nitisol* *Luvisol*
	Calcid	Haplocalcid	1, 3, 5, 6	16194	3.2	*Calcisol*
		Petrocalcid	1, 3, 4, 5, 6	1223.9	0.24	*Petric Calcisol*
	Cambid	Haplocambid	1, 3, 4, 5, 6	4350	0.86	*Cambisol*
	Gypsid	Calcigypsid	1, 3, 5, 6	425.4	0.08	*Gypsisol*
		Haplogypsid	3, 5, 6	197.2	0.04	
	Salid	Haplosalid	1, 3, 4, 5, 6	2276	0.45	*Solonchak*

(continued)

Table 2.12 (continued)

Orders Spanish surface (%)	Suborder	Great groups (2003)	Presence in soil map unit	Surface (km^2)	Percentages (%)	FAO Units (1998)
Entisol 200421 km^2 39.90	Aquent	Epiaquent	1, 2, 3, 4, 5, 6	1503.3	0.3	*Gleysol* *Gleyic Leptosol*
		Fluvaquent	3, 5	160	0.03	*Gleysol* *Fluvisol* *Gleysol*
		Hydraquent	4	19.5	<0.01	*Gleyic Leptosol*
		Psammaquent	3	13.1	<0.01	*Arenic Gleysol*
		Sulfaquent	1	53.6	0.01	*Thionic Gleysol*
	Fluvent	Torrifluvent	1, 3, 5	1625.9	0.32	*Fluvisol*
		Udifluvent	1, 3, 5	294	0.06	
		Ustifluvent	1, 5	441.4	0.09	
		Xerofluvent	1, 2, 3	14172	2.8	
	Orthent	Cryorthent	1, 3, 4	4783.9	0.95	*Gelic Leptosol* *Gelic Regosol* *Cryosol*
		Torriorthent	1, 2, 3, 5, 6	20197	3.99	*Aridic Leptosol* *Aridic Regosol* *Solonchak*
		Udorthent	1, 2, 3, 4, 5	9857.9	1.95	*Leptosol*
		Ustorthent	1, 2, 3, 4, 5, 6	17720	3.5	*Regosol*
		Xerorthent	1, 2, 3, 4, 5, 6	125265	24.75	
	Psamment	Quartzipsamment	4, 5	286.3	0.06	*Arenic Regosol*
		Torripsamment	1, 3, 5	118.2	0.02	*Arenosol*
		Ustipsammnet	1	24.3	<0.01	
		Xeropsamment	1, 3, 4, 5, 6	3886.2	0.77	
Histosol 85.5 km^2 0.02	Histosol	Histosol	1, 4, 5	85.5	0.02	*Histosol*
		(Fibrist, folist, hemist o saprist)				
Inceptisol 190517 km^2 37.90	Aquept	Epiaquept	1, 3, 4, 5	806.7	0.16	*Thionic Fluvisol* *Gleysol* *Stagnic or Gleiyic Cambisol*
	Cryept	Dystrocryept	1, 2, 3, 4, 5	3078.5	0.61	*Gelic Cambisol*
		Eutrocryept	1, 3, 5	727.6	0.14	*Gelic Umbrisol*
	Udept	Dystrudept	1, 2, 3, 5	7867.4	1.55	*Dystric Cambisol* *Umbrisol*
		Eutrudept	1, 3, 5	3177	0.63	*Eutric Cambisol*
		Udept	1, 2, 3, 5	9.3	<0.01	*Cambisol* *Umbrisol*
	Ustept	Dystrustept	1, 2, 3, 4, 5, 6	8771.9	1.73	*Dystric Cambisol* *Umbrisol*
		Haplustept	1, 3, 5	13974	2.76	*Cambisol*
		Ustept	1, 3, 5	297.1	0.06	*Cambisol* *Umbrisol*

(continued)

Table 2.12 (continued)

Orders Spanish surface (%)	Suborder	Great groups (2003)	Presence in soil map unit	Surface (km^2)	Percentages (%)	FAO Units (1998)
	Xerept	Calcixerept	1, 2, 3, 4, 5, 6	69691	13.77	*Calcisol*
		Dystroxerept	1, 2, 3, 4	11776	2.33	*Dystric Cambisol*
						Umbrisol
		Haploxerept	1, 2, 3, 4, 5, 6	70341	13.9	*Cambisol*
Mollisol 7489.5 km^2 1.49	Rendoll	Cryrendoll	2, 3, 6	714	0.14	*Mollic Cryosol*
						Rendzic Leptosol
	Udoll	Hapludoll	1, 5, 6	972.7	0.19	*Mollic Leptosol*
	Ustoll	Haplustoll	1, 3, 5, 6	1002.9	0.2	*Chernozem*
	Xeroll	Calcixeroll	1, 3, 5, 6	268.6	0.05	*Phaeozem*
		Haploxeroll	1, 3, 4, 5, 6	4531.4	0.9	*Kastanozem*
Spodosol 645.4 km^2 0.13	Humod	Haplohumod	5	74	0.02	*Podzol*
	Orthod	Haplorthod	1, 2, 3, 5, 6	571.4	0.09	
Ultisol 888.6 km^2 0.18	Udult	Hapludult	3	91.9	0.02	*Humic Acrisol*
	Ustult	Haplustult	1, 2, 5	194.7	0.04	
	Xerult	Haploxerult	5	602	0.12	
Vertisol 11990 km^2 2.38	Udert	Hapludert	1	37.3	0.01	*Vertisol*
	Ustert	Calciustert	5	17.5	<0.01	
		Haplustert	1	87.6	0.02	
	Xerert	Calcixerert	2	4530.7	0.9	
		Haploxerert	1, 3, 4, 5	7316.5	1.45	
Other soils (no mappable)				3243.6	0.64	
Total				506.03	100	

Table 2.13 Main equivalences between the U.S. Soil Taxonomy and the WRB systems

Order	Suborder	Groups (2003)	FAO units (1998)
Alfisol	Aqualf	Epiaqualf	Gleyc Luvisol Gleysol
	Cryalf	Haplocryalf	Gelisol
	Udalf	Hapludalf	Luvisol
	Ustalf	Haplustalf	
		Paleustalf	Planosol Nitisol Luvisol
		Rhodustalf	Cromic or Rhodic Luvisol
	Xeralf	Haploxeralf	Luvisol
		Palexeralf	Planosol Nitisol Luvisol
		Rhodoxeralf	Cromic or Rhodic Luvisol
Andisol	Torrand	Vitritorrand	Andosol
	Ustand	Haplustand	
	Vitrand	Udivitrand	
		Ustivitrand	
	Xerand	Haploxerand	
Aridisol	Argid	Haplargid	Luvisol
		Paleargid	Planosol Nitisol Luvisol
	Calcid	Haplocalcid	Calcisol Petric Calcisol
		Petrocalcid	
	Cambid	Haplocambid	Cambisol
	Gypsid	Calcigypsid	Gypsisol
		Haplogypsid	
	Salid	Haplosalid	Solonchak
Entisol	Aquent	Epiaquent	Gleysol Gleyic Leptosol
		Fluvaquent	Gleysol Fluvisol
		Hydraquent	Gleysol Gleyic Leptosol
		Psammaquent	Arenic Gleysol
		Sulfaquent	Thionic Gleysol
	Fluvent	Torrifluvent	Fluvisol
		Udifluvent	
		Ustifluvent	
		Xerofluvent	
	Orthent	Cryorthent	Gelic Leptosol

(continued)

Table 2.13 (continued)

Order	Suborder	Groups (2003)	FAO units (1998)
			Gelic Regosol Cryosol
		Torriorthent	Aridic Leptosol Aridic Regosol Solonchak
		Udorthent	Leptosol Regosol
		Ustorthent	
		Xerorthent	
	Psamment	Quartzipsamment	Arenic Regosol Arenosol
		Torripsamment	
		Ustipsammnet	
		Xeropsamment	
Histosol	Histosol	Histosol (fibrist, folist, hemist o saprist)	Histosol
Inceptisol	Aquept	Epiaquept	Thionic Fluvisol Gleysol Gleyic Cambisol
	Cryept	Dystrocryept	Gelic Cambisol Gelic Umbrisol
		Eutrocryept	
	Udept	Dystrudept	Dystric Cambisol Umbrisol
		Eutrudept	Eutric Cambisol
		Udept	Cambisol Umbrisol
	Ustept	Dystrustept	Dystric Cambisol Umbrisol
		Haplustept	Cambisol
		Ustept	Cambisol Umbrisol
	Xerept	Calcixerept	Calcisol
		Dystroxerept	Dystric Cambisol Umbrisol
		Haploxerept	Cambisol
Mollisol	Rendoll	Cryrendoll	Mollic Cryosol Rendzic Leptosol
	Udoll	Hapludoll	Mollic Leptosol Chernozem Phaeozem Kastanozem
	Ustoll	Haplustoll	
	Xeroll	Calcixeroll	
		Haploxeroll	
Spodosol	Humod	Haplohumod	Podzol
	Orthod	Haplorthod	
Ultisol	Udult	Hapludult	Humic Acrisol
	Ustult	Haplustult	
	Xerult	Haploxerult	
Vertisol	Udert	Hapludert	Vertisol
	Ustert	Calciustert	
		Haplustert	
	Xerert	Calcixerert	
		Haploxerert	

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Soils of the Temperate Humid Zone

3

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3.1 Introduction

The Spanish Temperate Humid Zone refers to a wide territory located in the northwest (Galicia) and northern Spain (Asturias, Cantabria and the País Vasco), bordered by the Atlantic Ocean in the west, the Cantabrian Sea in the north, the Community of Navarra in the east and the north of Portugal, the Communities of Castilla y León and La Rioja in the south. This territory comprises the following administrative areas: Galicia (29,574 km^2 of surface, 1,498 km of coast, 2,825,000 inhabitants) with four provinces—A Coruña, Lugo, Orense, and Pontevedra; Asturias (10,604 km^2 of surface, 350 km of coast, 1,117,370 inhabitants) with only one province; Cantabria (5,321 km^2, 284 km of coast, 541,885 inhabitants) with the Province of Santander; and the Basque Country (7,234 km^2 of surface, 246 km of coast, 2,130,783 inhabitants) with three Provinces—Álava, Guipúzcoa and Vizcaya.

These territories, representing altogether a surface of almost 53,000 km^2, with nearly 2,400 km of coastline, show common climatic characteristics that can be summarized by the abundance of rainfall that involves a high drainage and excludes or limits the summer dryness, allowing this wide area to be called, in general, the "Temperate Humid Zone." However, due to the different orography of the territory, particularly between Galicia and the other areas, which are deeply influenced by the Cantabrian Mountains that run parallel to the Cantabrian coastline, variations in the climate can be observed. These differences are mainly due, on the one hand, to the great differences in altitude (from sea level to over 2,500 m asl) and, on the other, to Mediterranean and continental climate influences well expressed in some areas of inner Galicia and particularly in the southern slopes of the Cantabrian Mountains and some inner valleys. Therefore, the area corresponding to the faces of these mountains oriented to the south, following by the Spanish central Plateau (Meseta), where even a Mediterranean climate is observed, was removed from this study; the same occurs with the Province of Álava where the area of the hydrographic basin of the Ebro River has been excluded as well, due to different climatic characteristics. In this context of temperate humid climate with contrasts in temperature and precipitation conditioned by relief and altitude, a remarkable diversity in the soil-forming factors, such as lithology, geomorphology, vegetation, and land use, determines a wide variety of soil types.

The aim of this chapter is to give a detailed and updated scientific view of the soils of this wide area, based on the vast knowledge of the soils of the temperate humid zone of Spain, available to us from our own work and that carried out by an earlier as well as great numbers of scientists nowadays, mainly pedologists, who deserve our sincere gratitude, particularly those that have introduced the study of the soils in Spain and its different regions.

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Location of the Spanish Temperate Humid Zone.

Base map: *Gran Enciclopedia Larousse*, 1984.

This chapter begins with a *state of the art* referring to this zone, Sect. 3.2, followed by Sect. 3.3, including the concept of soil and the study of the main factors influencing its formation, particularly parent material and geomorphology, climate, and vegetation and land use, as well as Sect. 3.4, dedicated to factors of soil degradation, mainly forest fires, and their main consequences, post-fire erosion and soil losses, promoted by the combination of high precipitation and deep mountain slopes in the study zone. Afterwards, a large section is devoted to the updated study of the taxonomy and classification of the Major Soil Types in the Spanish Temperate Humid Zone (Sect. 3.5), using the *World Reference Base for Soil Resources* 2006, first updated in 2007 (IUSS Working Group WRB 2007), mainly because this is the classification system that better fits the characteristics of the soils of the zone; this section comprises the identification of the main Reference Soil Groups (RSG) represented in the zone, reference soil groups (RSGs) and second-level units of the WRB in the study zone that also includes a table with tentative correlations between the RSGs of the WRB (2006) and the soil orders, and more significant lower categories of the Soil Taxonomy (2010) classifications for the soils of the study zone.

The detailed description of each RSG and the definition of the main type of soils (second-level units) within each RSG represented in the zone, mainly based on the physical, physic-chemical and chemical characteristics of the soil types, and their geographical distributions, are also presented and discussed in the subsections and corresponding tables. Finally, in the subsection on main biochemical and biological characteristics of the soils of the zone, a summarized account of these important properties for the functioning of the soils and the dynamics of the soil organic matter, which is a fundamental soil component directly related to the quality of the soils, is presented.

3.2 Soil Research History

There are historical precedents in Galicia on diverse soil studies since the eighteenth century, when in 1786 the *Memoria sobre el conocimiento de las tierras* was published and where the Asturian F. Consul Jove wrote about his particular point of view on the soil fertility of the Galicia and Asturia soils, defending the "new agriculture" and promoting the use of manure (Díaz-Fierros 2003). Similarly, in 1857 Olazábal produced the first soil studies of Vizcaya (the Basque Country), giving special consideration to the importance of natural vegetation and manuring for maintaining or improving soil conditions; he also argued for soil information to be included as part of the statistical accounting of the country, in opposition to some of his contemporaries, who judged the agricultural capability of land merely on the basis of the degree of slope.

Nevertheless, the presentation of "*Los tipos de suelos de Galicia*" by Huguet del Villar in the "*Reunión de la Sociedad Española para el avance de las Ciencias*," held in Santiago de Compostela in 1934 could be considered to be the introduction of the Soil Science in Galicia. This coincided with the development of a School of Pedology in Madrid that after the Spanish Civil War had great transcendence. Prof. Albareda, soil scientist and Secretary-General of the Spanish Council for Scientific Research (CSIC), initiated his formation in this school, which continued in Zurich (Germany) with Wiegner and with Russell in Rothamsted (U.K.); his ideas on the soil, which although dominated by soil chemistry, were a good description of the more current knowledge in soil science at the Central European School, were revealed in a course at the Foundation Cartagena, promoted by the Academy of Sciences, and edited in *El Suelo* (Albareda 1940) (Díaz-Fierros 2003). In 1952, Prof. Manuel Muñoz Taboadela, formed in the CSIC, under the tutelage of Prof. Albareda, arrived at the Faculty of Pharmacy of the University of Santiago de Compostela (USC), as Professor of Applied Geology (crystallography, mineralogy, pedology and hydrology) and later on Director of the Centro de Edafología y Biología Vegetal del CSIC (today the Instituto de Investigaciones Agrobiológicas de Galicia, IIAG-CSIC), inaugurated in 1958, on the campus of the USC. Together with Dr. Francisco Guitián Ojea, scientific researcher of the CSIC and senior lecturer at the USC, they initiated the study of the soils of Galicia, and later on those of the temperate humid zone of Spain. They defined and diversified various fields of the Galician soils, which were developed in doctoral theses assigned to the first generation of the Galician pedologists. Dr. Ramón Fábregas joined this group at the IIAG-CSIC, as the researcher responsible for the section on soil fertility. At that time, the lack of funds for research caused them to contact Spanish and international enterprises, such as CALFENSA, Fundación Martín Escudero, NESTLE, and others, which financed some of the projects related to soil fertility, such as soil liming, introduction of lucerne in the Galician prairies and the transformation of scrublands into mountain pastures. In 1963 Prof. Muñoz Taboadela died at age 42, and Prof. Guitián Ojea, already Professor of Pedology and Agricultural Chemistry at the USC, continued the study of the soils of the temperate humid zone of Spain, thereby opening new lines of research.

In 1977, the brochure "*XXV años de estudios de Edafología en Santiago 1952–1977*" (Guitían Ojea and Carballas 1977) and in 2003, the book *50 Aniversario de la Edafología en Galicia* (Carballas et al. 2003) were edited. This book, dedicated "To Prof. Francisco Guitián Ojea (considered the "father of the Galician pedologists" by themselves) and to the memory of Prof. Manuel Muñoz Taboadela (†), pioneers in the study of the soils of Galicia," consists of a description of the organization and staff (91, and numerous granters and quite a lot of national and international people that had made stays or had collaborated in research projects) of the institutions (11) dedicated to the study of the soils; the docent (subject matter) and scientific (lines of research) activity; the research projects (460); PhDs (60), D.E.A and others (210); and the scientific publications: books (57), books translated into Spanish (8), book chapters (136), articles in journals (1,714), congresses organized (15), and communications to the Congress (1,050), as well as maps and other information.

This important work allowed call the "*Pedological School of Galicia*" to the numerous research groups formed around Prof. Guitián Ojea, whose members, mainly those of the first (Prof. Tarsy Carballas, who after 22 years as the main researcher of the Guitián group, specialized in soil organic matter and created the "Department of Soil Biochemistry" in the IIAG-CSIC), and the second (Prof. Francisco Díaz-Fierros, mainly focused on climate, soil water, soil physical properties, soil erosion, and agricultural soils in the Faculty of Pharmacy; and Prof. Felipe Macías, mainly dedicated to the mineral components of the soil and their alteration, the recovery of contaminated soils, and soil taxonomy and cartography in the Faculty of Biology) generations were afterwards the germen of numerous new groups of research within the same school dispersed throughout the three Galician Universities, Centers of the CSIC, and other Institutions and enterprises. Today, most of the pedologists of Galicia (a staff about 75) are grouped in the "Territorial Delegation of the Spanish Society of Soil Science in Galicia", whose president is Dr. Montserrat Díaz-Raviña, Scientific Researcher of the CSIC in the IIAG-CSIC.

Before and after broaching the cartography of the soils of the temperate humid zone, much research on soil science, of paramount importance, was carried by Prof. Guitián Ojea and his numerous colleagues.

Galicia has a rich and complicated geology, which was thoroughly studied by the universally well-known Galician geologist, Prof. Isidro Parga Pondal, who created the "Laboratorio xeolóxico de Laxe" when he was expelled from the USC because of his political ideas, and the numerous students from 16 European universities in France, the Netherlands, Germany, Portugal, Switzerland, the United Kingdom, etc., especially from the University of Leiden, arrived at the school in the summer, together with their professors (Capdevile, Den Tex, Floor, Matte, and others), to perform their PhDs, under the supervision of Prof. Parga Pondal, studying a given zone (Parga-Pondal et al. 1964). A great number of doctoral theses were completed, some of them edited in the Galician language. Among his numerous publications, the *Mapa Geológico de Galicia (1963)* and those of its four provinces, the *Mapa Geológico de la Peninsula Ibérica (1970),* normally used as references by the Spanish pedologists, and particularly by those of Galicia, as well as two cartographies of the Macizo Hespérico Peninsular (1962 and 1982), should be noted. He has received numerous national and international distinctions and awards.

Fig. 3.1 Cliff in the basic-ultrabasic complex of Cabo Ortegal—Sierra of the Capelada (*Photo* Serafín J. González Prieto, IIAG-CSIC)

The enormous scientific work of Prof. Parga Pondal, after his retirement in 1969, was translated to the Foundation Isidro Parga Pondal located in El Castro, Sada, A Coruña.

It is important to mention that nowadays the geology of the basic-ultrabasic complex of Cabo Ortegal—Sierra of the Capelada, located in the northwest area of the Galician territory, between Cedeira and Cariño, where the waters of the Atlantic Ocean joint those of the Cantabrian Sea (Fig. 3.1), and "the more ancient rocks of the Iberian Peninsula are found," initially studied by Parga Pondal and then by many contemporary geologists (Martínez Catalán et al. 2010; English version, 2007), is to be proposed as a "geopark" to UNESCO, for the development geotouristic and cultural of Galicia (Macías Vázquez et al. 2013). From the edaphic point of view, the richness of its lithology, mainly ultramafic rocks (peridotites and dunites serpentinized), and mafic rocks (eclogites, granulites and amphibolites), permit finding Leptosols and Umbrisols with *andic* properties and even Andosols as well as Ferralic Umbrisols and Ferralsols Dystric, depending on the predominance of organo-aluminic complexes or clays of low activity and *ferralic* properties, respectively.

Prof. Guitián Ojea has given great importance to soil formation factors, which condition the soil properties and evolution, producing a great number of edafic processes and much edafodiversity within the limits of the climatic and topographic conditions: (1) parent material, varying from ultramaphic rocks to rocks constituted only of quartz and carbonates within a frame dominated by granitic rocks and the metamorphic of low degree, slate or schist (Guitián Ojea and Carballas 1969); (2) climate (Guitián Ojea and Díaz-Fierros 1967), taking into account that the elevated pluviometry and easy drainage favor a subtractive pedogenesis, with loss of basic cations and the aluminium being the key factor in the interactions between the organic components and the minerals that define the soil properties (Macías Vázquez 2003); (3) vegetation, the prime material for the formation of the soil organic matter (SOM) and the processes induced by certain plants (Carballas and Guitián Ojea 1966; Carballas et al. 1971); and (4) time, particularly interesting in the soils of Galicia, where the lack of intense glaciations down 1,000 m of altitude has permitted the conservation of Paleosols, with *ferralic* characteristics on easily alterable materials such as basic rocks; and polycyclism, with burial processes and the new edaphic process of the regoliths giving rise to discontinue series of cycles K, is frequently found as well (Mücher et al. 1972; Macías Vázquez 2003).

The study of all the soil properties was broached by the school, and the study of the acidity of the soils, the need to lime them, the tampon power of the soil, the complex of the exchangeable cations and the lack of available Ca and Mg as well as available N and P, were extensively studied by numerous researchers (Guitían Ojea and Muñoz Taboadela 1957; Muñoz Taboadela 1965). The physical properties in particular were studied by Prof. Díaz Fierros and his colleagues (Díaz Fierros and Guitián Ojea 1968); and the mineralogy by Dr. Villar and Prof. Macías and his many colleagues (Villar and Guitián Ojea 1972; Macías et al. 1987).

Without a doubt, the soil chemistry—particularly of the inorganic elements—was one of the subjects more thoroughly researched at the school, as initiated by Guitián Ojea, with more than 274 important contributions at the national and international levels (Carballas et al. 2003). It is perhaps fitting to cite the studies on copper (Martínez Fernández 1965) and nickel (Carballas et al. 1965), because they were responsible for the Rio Tinto Patiño enterprise ask Prof. Guitián Ojea and Dr. Carballas to collaborate; by means of an innovative technique, they could establish the exact point where with only one perforation, the enterprise could initiate the exploitation of the Mine of Copper of Touro in Galicia (Guitián Ojea et al. 1975). Later on, when it was closed, Prof. Macías's group was recovering the area.

Besides the chemistry of the inorganic components, the School of Galicia also developed important contributions to the knowledge of the soil's organic components, a line of research initiated by Prof. Carballas, who completed her formation on this theme at the Centre de Pédology Biologique du C.N.R.S. in Nancy, France, with the renowned pedologist and specialist in SOM, Prof. Philipe Duchaufour, Director of the Centre and Professor at the University of Nancy I. The composition of the SOM, the structure of the humic and fulvic acids, the dynamic of the soil organic matter, etc., were lines of research developed by the Group of Soil Biochemistry, using C and N tracers, and these methods were passed on to other researchers (Carballas et al. 1967, 1971; Jacquín et al. 1978; González-Prieto et al. 1989, 1991).

In this context, an important contribution was the publication of *Techniques for Soils Analysis* that in its updated second edition was published with the collaboration of T. Carballas (Guitián Ojea and Carballas 1976); it was used at practically all the laboratories of soil analysis in Spain, whether universities, centers of the CSIC or other centers of research or technique. Very important also was the translation into Spanish of four books (Carballas 1975, 1977; Carballas and Carballas 1984, 1986) written in French by Prof. Philippe Duchaufour, made by Prof. Tarsy Carballas and her brother at the instance of Duchaufour, at a time when there were few books on this matter in Spanish and the students' knowledge of other languages was limited; these books were used as references by professors, students, and researchers in Spain and South America. A sign of the success of the Pedological School of Galicia is mentioning that at the XIII International Congress of the International Society of Soil Science (IUSS), held in Hamburg, Germany, in 1986, Prof. Tarsy Carballas was the first woman elected First Vice-Chairman of Commission II: Soil Chemistry of the IUSS, for 4 years, until the following conference in Kyoto (Japan) in 1990; her candidature was proposed by the leading scientists in SOM at that time, Professors Duchaufour (France), Flaig (Germany), and Schnitzer (Canada), by a group of scientists from the east countries, and other groups of scientists from Latin America.

The study of the biochemical and biological properties begins later, because the Biology, particularly Soil Biology, was not well developed in Spain. In the Galicia School, the doctoral thesis of María José Acea Escrich, within the Department of Soil Biochemistry of the IIAG-CSIC, could be considered the first contribution to this field. After having been at Cornell University in the USA working with Prof. Alexander, she developed many projects within the Group of Soil Biochemistry (see Sect. 3.5.3). Likewise, the doctoral thesis of Montserrat Díaz Raviña, which introduced the study of the microbial biomass, was another important contribution; after having been at Lund University in Sweden, with Professors Bååth and Frostegard, her numerous papers on the detection of metal tolerance of soil bacterial communities (Díaz-Raviña and Bååth 1996a, b, c) and on the study of the structure of the microbial community by the phospholipids fatty acids or the Biolog method, have opened a very important field in soil microbiology that was followed by other members of the school and numerous researchers at the national level (see Sect. 3.5.3).

The genesis of the soils as well as the processes of pedogenesis were important lines of research initiated by Prof. Guitián Ojea, who after intense field work at all the temperate humid zones, found interesting genetic relations among the soil types represented in the study area for each province or community (Guitián Ojea 1967); afterwards, they were included in the booklets that accompany each map. Examples of these studies were: the genesis of the Rankers, mainly the Atlantic Ranker; Podzols; Vertisols; Andosols; soils with *fragipan*; littoral and continental hydromorphic soils; estuarine soils; soils on serpentine; the mountain peats of Galicia; the soils of the main mountains of the zone, Barbanza, Capelada, O Caurel, Serras de Queixa and Invernadeiro; soils on hipermagnesic or calcareous rocks; and others (see Carballas et al. 2003).

Concerning soil cartography, according to Macías Vázquez (2003), the soils of Galicia were first represented in the soil map of the world performed by the School of Dokuchaev, presented at the First International Congress of the Soil Sciences, appearing within the forest zone of northern Europe, where the podzolized soils predominated. Later on, Huguet del Villar, in his *Map of the Iberian Peninsula* at a scale of 1:1,500,000, better located the soils of Galicia within the humiferous soils, including soils rich in humic compounds of acidic character and wide hygroturberiform areas near the Terra Chá. Finally, in 1958, in a map of the Spanish soils at scale of 1:1,300,000, produced by the Spanish Ministry of Agriculture, Galicia appears to be dominated by Brown Soils, Podzolized Brown Soils and Litosols.

Historic cartographic studies on the soils of the study zone were first conducted in the 1950s by Guerra and Monturiol (1959), specifically in the territory of Cantabria, expressed in a soil map at a 1:125,000 scale. Intense pedological studies were carried out within the framework of an ambitious project, “*Mapa de Suelos de España*,” financed by the Banco de España, at the instance of Prof. Albareda, during the 1960s (1959–1968), whose objective was to elaborate the *Soil Map of Spain*. The project, coordinated by Prof. Angel Hoyos de Castro of the University of Madrid and Director of the Instituto de Edafología y Fisiología Vegetal de Madrid (CSIC), was carried out by various groups of pedologists from the Spanish Council for Scientific Research (CSIC) and divers Spanish universities, assigning to each group the area of its influence. The soil classification used was that of Prof. Kubiena (1952), because at the time he had been working in Spain at the CSIC with Prof. Albareda for many years, and knowing the soils of each region of Spain well, he elaborated on a classification that adapted very well to the characteristics of the Spanish soils. Although the field work was carried out at a scale of 1:50,000, the maps could not be edited at that scale due to the lack of financial support; nevertheless, almost all of the cartographic material was published soon after by the Instituto Geográfico y Minero of Spain at scales of 1:200,000 and 1:400,000, but a lot of the information was lost. However, the descriptive booklets that accompany the maps were published at various periods, when each group had obtained funds from various Institutions. In general, maps and memories were published for each province of Spain; afterwards, all the maps were combined and the entire *Soil Map of Spain* was published (Guerra et al. 1968).

The cartography of the Spanish Temperate Humid Zone: Galicia, Asturias, Cantabria, and the Oscense Pyrenean, but not the Basque Country, as well as the humid areas (precipitation > 800 mm) of the Provinces of León, Zamora and Palencia, was done by the groups of the Instituto de Investigaciones Agrobiológicas de Galicia of the CSIC (IIAG-CSIC) and the Department of Pedology of the University of Santiago de Compostela (USC), all under the Direction of Prof. M. Múñoz Taboadela, and after his death by Prof. F. Guitián Ojea (CSIC; USC) (Muñoz Taboadela et al. 1966; Guitián Ojea et al. 1973, 1982b, 1985a, b, 1986, 1987; Guitián Ojea and Carballas 1982). From 1974 until 1977, within the framework of another project led by Prof. Guitián and financed by the Spanish Intergovernmental Commission, the map of the same zone was produced using the F.A.O. Classification of 1974, which was only disseminated in digital form, whereas the *Soil Map of Galicia* was published in an atlas (Guitián Ojea et al. 1982a). The key of this map is full of associations and inclusions because the field work was scanty, and in fact it is a translation from the Kubiena units to the FAO groups; nevertheless, all the information was included in the first *Soil Map of the World* (FAO-UNESCO 1974, 1981).

More recently, the Government of Galicia (*Xunta de Galicia*) has financed the digital cartography of the soils of Galicia, at a 1:50,000 scale, using the FAO classification (version 1998); the work, *Mapa de Solos de Galicia* is being done by R. Calvo de Anta and F. Macías Vázquez, Professors of Edafología y Química Agrícola of the USC, comprising the individual maps of the sheets corresponding to Galicia; each soil map (number and name of the sheet) is accompanied by the key for the soil types ordained by rock types, and by the following maps for the area: geological scheme (scale 1:200,000; IGME 1972); hypsographic scheme; slope classes (FAO); administrative division (municipalities); the soil-water balance; and the grid map of Galicia (Calvo de Anta and Macías Vazquez 2000–2005). The maps already completed can be seen at http://siam.cmati.xunta.es/mapa-de-solos. From the *Atlas de Galicia*, a very interesting, well-presented chapter on the “Soils of Galicia,” has been published by the same authors (Macías Vázquez and Calvo de Anta 2001), using the same FAO system, which comprises the full *Map of Soils of Galicia*, as well as the maps of soils on the various types of rocks represented in this region.

Apart from these particular cartographic studies, others were carried out within the framework of the Pedological School of Galicia. Some examples are: the *Itinerarios de los Suelos de Galicia* (Guitián Ojea 1974); the *Capacidad Productiva de los Suelos de Galicia. Mapa 1:200,000* (Díaz Fierros and Gil Sotres 1984); the *Atlas Geoquímico de Galicia*; and many others (See Carballas et al. 2003).

Concerning Asturias and the Basque Country, besides the information cited above, more recent research on soil mapping, mainly at 1:25,000 scales, has been done by various research groups with funds from both autonomous Communities. In the context of Asturias, between 2001 and 2008, various soil mapping studies, at a 1:25,000 scale, have been conducted by the government of the Principado de Asturias, covering about 40 % of its territory (4,000 km^2). Soil information of interest on the Asturian territory is also included in the works of Álvarez and Díaz-Fierros (1995) and Taboada et al. (1995) (see Aramburu and Bastida 1995). In the Basque Country, soil mapping includes the entire territories of Álava (Iñiguez et al. 1980), at a 1:200,000 scale, and Guipúzcoa (Diputación Foral de Gipuzkoa 1991), at a 1:25,000 scale, in the 1985−1991 time period.

3.3 Soil-Forming Factors

The pedosphere, a layer of 1–2 m deep (or even more), located on the terrestrial surface, and situated in the interfase between the lithosphere and the atmosphere, has an important role in the global C cycle and in the production of food and fibers throughout the world. Although the pedosphere interacts with the atmosphere (exchange of energy and gases), with the biosphere (biological cycles of the elements or decomposition of organic debris due to the activity of the soil fauna), with the hydrosphere (leaching of elements, hydrological cycle), and with the lithosphere (biogeochemical cycle of elements, soil formation by rock weathering), there are multiple interactions among the five spheres via diverse processes (Carballas 2004).

The soils, constituents of the edaphosphere, are dynamic complex systems that progressively acquire their properties due to the combined action of these environmental factors: parent materials, climate, vegetation, and other organisms; the soils born and develop, giving rise to systems with a dynamic equilibrium. They are not inert, but are living systems where millions of chemical and biochemical reactions take place continuously and simultaneously.

Although the soil's mineral components, mainly sand, silt and clay, are very important—especially the latter—soil organic matter (SOM) is one fundamental component of the soils that is directly related to the soils' quality. The SOM is composed, according to Schnitzer (2000), by a mixture of plant and animal residues in various stages of decomposition, humic substances synthesized microbiologically and/or chemically from the more simple organic compounds, as products of the decomposed residues, and living meso- and micro-fauna and microorganisms. These living organisms, together with the enzymes, are responsible for most of the processes occurring in the soil and therefore are responsible for the soils' functioning.

These biological organisms are the agents responsible for two of the most important processes taking place in the soil: (1) the process of mineralization, whose importance has been compared to that of photosynthesis, that produces the nutrients needed for the growth of the vegetation, as well as greenhouse gases, mainly CO_2 or NH_3, in greater or lesser quantities; and (2) the process of humification, which produces humic substances, i.e., the more stable organic compounds, related to C sequestration and then to climatic change mitigation. These two processes are of paramount importance for the survival of the living organisms and for the protection of the atmosphere. They also participate in the process of aggregation and therefore in the establishment of the soil structure, another very important soil property (Carballas 2004).

From the times of Jenny (1941), it has been accepted that the main forming factors of the soil are: (1) time; (2) parent material; (3) topography; (4) climate; and (5) organisms, i.e., vegetation and animal organisms among them the men. The topography, a term originally used by Jenny in the sense of relief or geomorphology, plays an important role in the distribution and evolution of the different types of soils.

The soils born by weathering of the rocks by climate factors (rain, air, temperature and wind), the colonization of the rocks by vegetation, mainly lichens in the first steps, deposition of plant and animal residues, and later colonization of meso- and micro-fauna and micro-biota, responsible for the biological activity that also activates the rocks' weathering. The time can lead the soil to a positive evolution and then to a dynamic equilibrium, or to a degradation of its properties. Finally, human actions can change its natural evolution; besides, this can have a strong influence, especially in agrosystems.

We will now consider these forming factors and their influence on the production of the soils of the zone under study, as well as those main factors responsible for their degradation.

3.3.1 Soil Parent Materials and Geomorphology

3.3.1.1 Rock Types

The geological substrates of the study zone are of very variable nature and, generically, can be divided into nine groups:

(a) *Granitoids*. These rocks predominate in the western third of the study zone. Following the criteria of Capdevila et al. (1973), they can be divided into two large series: alkaline granites and granitoids of two micas; and calco-alkaline granites and granitoids, with a predominance of biotite, which comprises granodiorites, quartz-diorites, etc. Moreover, in the eastern extreme of the study zone (Peñas de Aia Massif) appears a small outcrop. The granitoids of the Peñas de Aia Massif consist of two units, a peripheral one of acidic nature, and a complex central unit of a gabbro-dioritic nature.

(b) *Slates and phyllites*. These are low-degree metamorphic materials and fine mineralogical size. Although they present different parageneses, they are generally formed of quartz, muscovite and chlorite, in some cases exhibiting small quantities of sulphurs (mainly pyrites) and carbonaceous material. These materials are distributed in the western half of the study zone and in small outcrops of the eastern extreme.

(c) *Schist*. This material extends mostly to the western third of the study zone. It is mainly black schist of fine grain, gneissic schist of biotite of fine grain, micaceous granatiferous schist, and mica-schist of two micas.

(d) *Basic rocks*. These are igneous and metamorphic rocks with a low content of quartz and variable concentrations of ferromagnesian minerals and plagioclases. In this group, norites, gabbros, serpentine, eclogites, amphibolites, and some basic gneiss, which appear in the western third of the study area, are included. In the eastern third of the zone, outcrops of little relevance (of dolerites and picrites from the Cretaceous era) can be observed.

(e) *Carbonated rocks*. Limestone, dolomites, and marly-limestone predominate in the eastern third of the study zone. The limestone that outcrops in this area corresponds to a wide range of eras, from the Carboniferous to the Neogene; outstanding by its relative abundance is that of the Cretaceous age, which outcrops in the eastern third of the zone, and that of the Paleozoic, located in the central area. In the western extreme of the zone, the carbonated rocks appear intercalated between Palaeozoic slates, occupying small extensions.

(f) *Volcanic rocks*. In the eastern third of the study zone, volcanic materials (i.e., lava flows and volcano-clastic deposits) appear intercalated in the marine sedimentary rocks, and include those from alkaline basalts to trachytes, formed during the Cretaceous.

(g) *Lutites and sandstones* are formations of the Jurassic, Cretaceous and Tertiary eras, distributed in the eastern half of the study zone. They are mainly calcareous sandstones, generally intercalated between lutitic and lutitic-marly levels. In small quantities, forming small outcrops, sandstones of the Triassic (Bundtsandstein) period, and lutites, with gypsum of the Keuper, can be observed. Likewise, both extremes of the study zone exhibit outcrops of pre-Cambrian and Paleozoic sandstones (fundamentally), arkoses and greywacke, alternating with slates.

(h) *Quartzitic rocks*. These rocks predominate in the western half of the area; in this group, quartzites, quartzitic sandstones, and dykes of quartz that appear associated to slates are included.

(i) *Sediments* are materials that have settled from the Miocene epoch, associated with various sedimentary environments. This group includes fluvial and fluvial-marine deposits related to marsh zones, aeolian-coastal deposits, glacial deposits and slope depots. In the western extreme, it appears that filler materials of tectonic depressions related to lagoon sites developed during the Tertiary period.

3.3.1.2 Geological Units

These groups of rocks and sediments present a complex distribution due to both the sedimentary processes involved in their formation and the subsequent tectonic processes. Thus, from the structural viewpoint, the study zone can be divided in two large geological units, i.e., from west to east, the Iberian Massif and the Basque Cantabrian Basin (Fig. 3.2).

The Iberian Massif corresponds to the outcrops of the Precambrian and Paleozoic rocks and to the more western outcrops of the European Variscan Orogen. Various authors

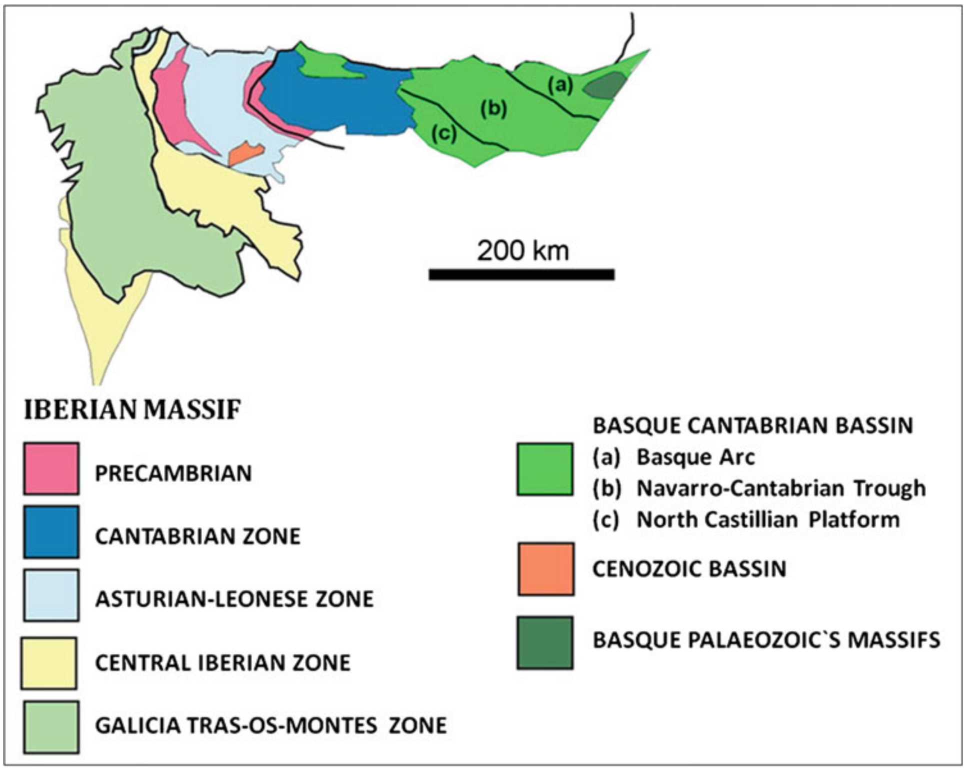


Fig. 3.2 Scheme of the distribution of the various geological units of the study zone, according to the division proposed for the Iberian Massif by Julivert et al. (1972), Farias et al. (1987), and Arenas et al. (1988), and for the Basque-Cantabrian Basin by Barnolas and Pujalte (2004)

(Julivert et al. 1972; Farias et al. 1987; Arenas et al. 1988) have proposed dividing this massif into zones, assigning the western half of the study area to the following zones: the Galicia-Trás-os-Montes Zone, the Central Iberian Zone (where the formation called Ollo de Sapo Complex was described by Parga-Pondal et al. (1964)), the West Asturian-Leonese Zone, and the Cantabrian Zone (Fig. 3.2).

The Basque-Cantabrian Basin constitutes, from the structural viewpoint, the western extension of the Pyrenean Orogen, mostly formed by materials deposited during the Mesozoic and deformed during the Alpine Cycle. It is divided by Barnolas and Pujalte (2004) into three blocks, which, from east to west, are the Basque Arc, the Navarro-Cantabrian Trough, and the North Castilian Platform (Fig. 3.2).

3.3.1.3 Geomorphology

In the study zone, two major geological units have been differentiated. One of them involves the materials affected by the Variscan Orogen and, afterwards, by the Alpine Orogeny; the other involves further materials that are almost exclusively affected by the Alpine Orogeny. Like that over the Mesozoic, most of the Iberian Massif remained emerged, and consequently supported numerous erosive cycles, thus generating extensive erosion surfaces (for instance, the surface of Chantada in Galicia) until the beginning of the Tertiary (Gutiérrez-Elorza 1994). Moreover, these zones of the Iberian Massif will suffer a structural alpine evolution with reactivation of Tardi-Hercynian faults. This way, three large morphostructural conjuncts can be differentiated. From west to east, they are: (1) the **Galaico-Leoneses Mountains** and their internal depressions; (2) the **Asturian-Cantabrian Range**; and (3) the **Basque-Cantabrian Mountains** (Fig. 3.3).

These mountain ranges descend rapidly (40–50 km) towards the north until they reach the coast, allowing to distinguish three sectors or physiographic units: (1) a superior sector in which residues of glacial and periglacial origin (Jiménez 1996; Frochoso y Castañón 1997) are conserved; (2) an intermediate sector characterized by the action of fluvial and gravitational processes; and (3) the coastline modeled by coastal processes.

The Galaico-Leonese Massif is a system of ranges and mountains located in the western extreme of the study zone, formed by rocks of the Iberian Massif. In general, the system has a bulging form, alternating horst, grabens and faults in a north-south direction. This mountainous system is formed by the southeastern Sierras of Galicia (mainly granitic) and the eastern Sierras of Galicia (mainly formed by slates and quartzites), with reliefs that amount to 2,000 m asl, constituting the natural barrier with the Spanish Meseta. The highest peak is Peña Trevinca in Galicia, at 2,127 m. In the Ancares (eastern Sierras of Galicia) appears a series of bands of slates and sandstones, quartzites, small outcrops of limestone and dolomites, and granite of two micas. The summits of these Sierras are frequently crowned by quartzites (Fig. 3.4), whereas the slopes and valleys are developed on slates, appearing as a relief of Appalachian characteristics. Some of the zones of these eastern Sierras have been affected by important glacial and periglacial episodes during

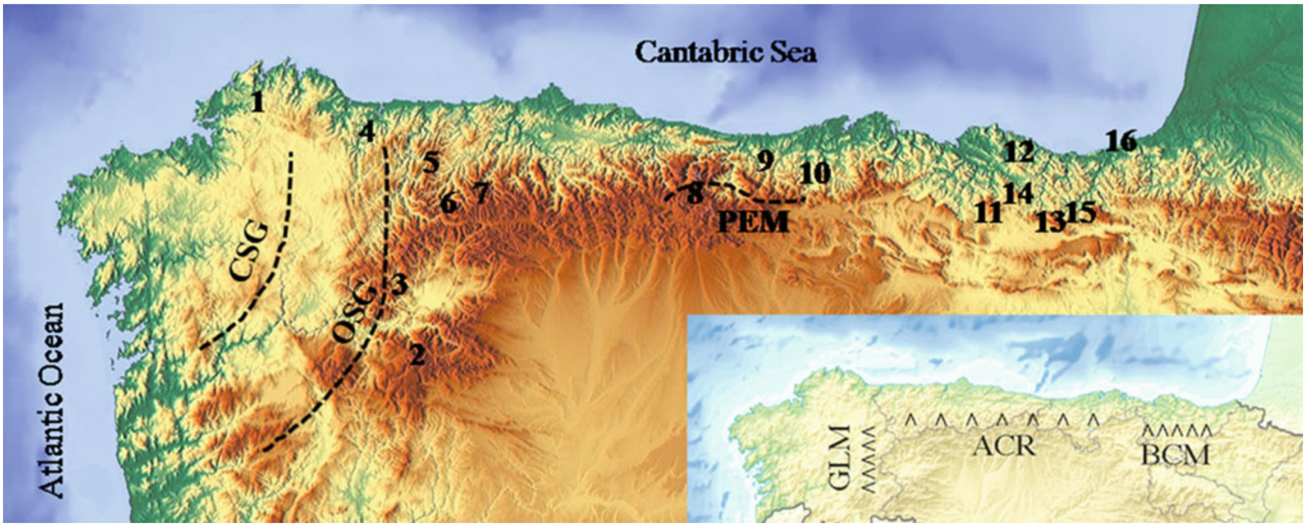


Fig. 3.3 Geographical location of the geomorphological units and some locations described in the text. *GLM* Galaico-Leonese Massif; *ACR* Asturian-Cantabrian Mountains; *BCM* Basque-Cantabrian Mountains; *CSG* Central Sierras of Galicia; *OSG* Oriental Sierras of Galicia; *PEM* Picos de Europa Mountains; *1* Sierra do Xistral; *2* Peña Trevinca; *3* Ancares; *4* Eo Valley; *5* Sierra de Bobia; *6* Sierra de Roñadoiro; *7* Sierra de La Cabra; *8* Torrecerredo peak; *9* Sierra del Escudo de Cabuérniga; *10* Sierra de La Matanza; *11* Gorbea Peak; *12* Oma Valley; *13* Aitzgorri peak; *14* Urkiola peak; *15* Arritzaga Valley; *16* Mendizorrotz-Jaizkibel Range. Background image: http://www-maps-for-free.com

Fig. 3.4 Summit of quartzites in Cabeza de Manzaneda (Sierra de Queixa). Orense, Galicia

Fig. 3.5 Summits and dolines in limestone massifs (summer). Sierra del Aramo, Central Asturias

the last Quaternary coal period (Pérez-Alberti 1982; Pérez-Alberti et al. 1992).

The Asturian-Cantabrian Range (Martín-Serrano 1994; see Gutierrez Elorza 1994) constitutes a group of mountains that connect at its western extreme with the Galaico-Leonese Massif; its eastern extreme corresponds to the Basque-Cantabrian Mountains (Fig. 3.3). The western half of the unit is formed of slates with some intercalation of quartzite (limestone towards the west), giving rise to an Appalachian relief. In this way, the Sierras formed by hard quartzite are arranged perpendicularly to the coast and parallel to one another (Bobia, Rañadoiro, Cabra), separated by long, deep valleys that developed on soft slates (Eo, Navia, Narcea, Pigüeña, Trubia). The central half presents a higher lithological variety and Appalachian relief, where the presence of limestone, sandstone, and quartzite represent the resistant elements (Solé-Sabarís and Llopis 1952). Finally, the eastern part of the Asturian-Cantabrian Range is formed mainly by Limestone (Fig. 3.5) (Caliza de Montaña Formation), highlighting the Picos de Europa Mountains, where the highest summit of the cordillera is found (Torre Cerredo, 2,650 m asl).

The cold periods of the Quaternary have retouched the relief of the high mountains in this zone. Thus, in the highest areas of the range, up to 900 m asl, there are residues of this glacial morphology, such as cuvettes of overpasses with lagoons or peats, cirques, crests, glacial valleys, moraines, and powerful fluvial-glacial deposits. Moreover, abundant periglacial and nival forms and deposits are found in abundance with block fields, talus deposits, rock glaciers, etc. In the main valleys, postglacial in mass movements can also be found. Today the dynamic of the Picos de Europa can be framed within the periglacial domain, thus the slopes lined with accumulations of debris at the foot of the rocky escarpments are frequently seen. The calcareous nature of the substrate, jointly with the elevated precipitation of the zone, has favored the presence of superimposed karst landforms.

The easternmost extreme of the study area consists of a physiographic unity that from the Bidasoa River to the Asturian-Cantabrian Range includes part of the so-called "Basque-Cantabrian Mountains" (Fig. 3.3). Within this unity, Ugarte (1994; see Gutiérrez-Elorza 1994) differentiated the Cantabrian subunit, an area occupied by the hydrographical Cantabrian basins, to which the study zone belongs. The Cantabrian subunit is characterized by the presence of header reliefs with altitudes up to 1,500 m asl in the eastern extreme, and 1,700 m in the western one. When these reliefs basically consist of limestone, the cuestas, karst landforms, and, in some summits and valleys, vestiges of the glacial activity of the Quaternary (Aralar) are frequent. Moreover, in the zones of higher altitudes with the presence of nival processes, colluviums with blocks are also frequent. When the predominant lithology consists of detrital rocks (mainly lutites, sandstone and sandy limestone), the coverings colluvial slopes are affected by gravitational processes. The valleys have a marked "V" form, strong slope breaks between the head and the rest, and little background fills in the middle parts and the head. They are torrential courses. The southern limit would correspond to the drainage divide that separates the Cantabrian watershed from the hydrographical basin of the Ebro River. Most of this divide represents a cuesta mainly generated in the Cretaceous limestone that is more resistant to the erosion than the older silic-clastics series. In this sector, the larger peaks of the Basque-Cantabrian Mountains are found (Gorbea Aitzgorri, etc.).

In this zone, the traces of the Quaternary glaciarism are centered in the Aralar Range. The best traces are in the Antziriko-Ordeka Hanging Valley or in the Arritzaga Valley. In the same sector, the periglacial processes are more generalized, making it possible to cite névé moraines (e.g., Gorbea Peak), or the traces of a nivo-karst for the conjoint of the mountains of the drainage divide. In areas of lower altitude, although the outcrops are very scarce, it has only generated regularized slopes (*grèzes litées*, solifluidal debris and talus deposits) (González-Amuchastegui 2000).

The morphology of the zone between the ranges described above and the coast varies within the study zone from west to east (Fig. 3.3). In the western extreme of the study zone, from the eastern Sierras of Galicia towards the Atlantic Ocean, a succession of the following three grand morphological units can be defined in detail (Pagés and Vidal-Romaní 1998):

Tierras Llanas of Galicia. These are wide, flat areas with an altitude between 500 and 600 m asl on average and in which there are several Tertiary basins (Monforte, Maceda, Xinzo) and important residues of the so-called "fundamental surface," an erosion surface developed during the Cretaceous; among them are the Surface of Chantada and the Terra Chá (Flat Land) (Fig. 3.6). Characteristic of this zone are fluvial valleys (Miño and Sil Rivers) with their terrace deposits.

The Central Sierras of Galicia or Dorsal Gallega. These consist of a set of reliefs with altitudes of between 750 and 1,200 m asl, composed of residues of peneplanation surfaces and residual reliefs that form the Fundamental Surface. The Central Sierras, at N 20ºE, act as a drainage divide between the Miño River and the rest of the Atlantic rivers. This relief is outlined at its northern edge by the Fundamental Erosion Surface (Martín-Serrano 1994; see Gutiérrez-Elorza 1994), and it separates the zone of the interior depressions (Tierras Llanas) from the littoral zone. These Sierras connect to the north with the North-Occidental Sierras of Galicia, which constitute the northern limit of the fosses and depressions of central Galicia. Among these mountains, highlight the Sierra do Xistral that extends towards the Cantabrian coast.

The Littoral Zone corresponds to the strip between the Central Sierras and the Atlantic Ocean. The present relief of this zone is mainly due to the action of its fluvial network, with a direct relationship to the base level. It is a zone with a stepped relief where the following residues of various planation surfaces (Pagés and Vidal-Romaní 1998) correspond to the lower altitude (180–50 m asl) of the littoral platforms (the "*rasas*").

In the central zone of the study area, the link of union of the mountainous systems that form the Asturian-Cantabrian Range and the coast is different, depending on the extreme considered, in the west or in the east. In the western half, the reliefs with south-north direction are dominant, with altitudes descending gradually until they reach the littoral platform. On the contrary, in the eastern half, there are alignments parallel to the coast, with altitudes from 500 to 1,300 m that constitute the so-called "Pre-littoral Depression." This depression, which has a mean width of 5–10 km,

Fig. 3.6 Lagoon of Cospeito in the Terra Chá (flat land). Lugo, Galicia. (*Photo* Serafín J. González Prieto, IIAG-CSIC)

Fig. 3.7 Dolina in the deep slope of the Aitzgorri Range (Cretaceous limestone). Basque Country

is formed by Cretaceous and Tertiary rocks. Between this depression and the littoral platform, there are the littoral ranges with a west-east disposition formed by Mesozoic's materials, although in the easternmost part there are outcrops of quartzite and limestone of the Palaeozoic base.

In the eastern extreme of the study zone, to the north of the mountain range formed by the Aralar, Aitzgorri (Fig. 3.7), Urkiola and Salvada Sierras, there appear various alignments in the form of an arc, of ranges parallel to the coast and to one another, controlled by tectonic structures that connect with the coast. The first alignments consist of reliefs mainly formed of lutites, sandstone and limestone; moreover, in some areas there are pillow-lavas and pyroclastic vulcanites. They are reliefs of altitudes between 500 and 1,000 m asl of loin-shaped morphology, although with strong slopes and traversed by valleys that can present alluvial fills. In zones with a predominance of calcareous rocks, the processes of karstification (i.e., the Oma Valley;

Fig. 3.8 Oma Valley; slope developed on limestone and colluvial covering. Basque Country

Fig. 3.8) are common. This band is connected to the sea in the central part of the sector, giving rise to abrupt cliffs, beaches, or estuaries (marshes of the Oka River).

Towards the west (in Cantabria), pre-littoral Sierras appear; their summits are located between 600 and 1,000 m asl, and formed by calcareous rocks. Belonging to this mountainous alignment are the Sierra del Escudo de Cabuérniga, Sierras of Mozagro, Ibio, del Valle, Matanza and Alisas, formed by clastic rocks (sandstone, conglomerates and lutites) in some cases, and by limestone in others. These Sierras connect with the coast, forming abrupt cliffs, frequently carved on Cretaceous limestone in the western extreme. In the easternmost part (Basque Country) there is a series of reliefs of lithological constitution similar to that of the band described above, although with a higher calcareous dominance and therefore with a dominance of karstic morphologies. They are very abrupt reliefs, although traversed by wide valleys carved on marls and lutites and with important alluvial deposits. Already in the coastal zone close to France, there appears a coastal range, the Mendizorrotz-Jaizkibel Range, of Tertiary sandstones and monoclinal structure, which constitute a cuesta, whose back forms the coastal cliff.

Finally, forming part of the eastern limit of the study zone, there are the Palaeozoic reliefs of the Cinco Villas Massif dominated by the granitic Peñas de Aia Massif (Fig. 3.9). The rocks of the area are mainly slate, greywackes and arenites, although the original lithology of the area is the granitoids, recognizing almost all the intermediate terms between the gabbroic and granitic extremes. In general, this area has very steep slopes (above 55 %), with convex shapes (plan and profile curvature).

In the study zone, the **coast** comprise two sections: the Atlantic Coast and the Cantabrian Coast.

The Atlantic littoral is characterized by the presence of wide valleys called "*rías*" (similar to fjords), in most of the mouths of the fluvial systems that form the drainage network of the area between the Atlantic Ocean and the Central Sierras of Galicia or Dorsal Gallega. The origin and evolution of these forms is a mainly erosive process associated with the dynamic of the fluvial network over the Cenozoic era in response to relative descents of the base level, and in which the adaptation of the fluvial network to the network of Tardi-Hercynian fracturing has played an important role (Pagés 2000). After the last Maximum Glacial, already in the Holocene, the elevation of the sea level implied the flooding of the littoral zones, transforming the mouths of the rivers in estuary-type rías and its slow sedimentary filling.

The Cantabrian coast is of a structural type, i.e., very abrupt. The main estuaries and mouths of the rivers are located only in those zones, with intense fracturing. An important and characteristic geomorphological element of

Fig. 3.9 Foreground slope developed on Paleozoic slates. Background: granite peaks of the Peñas de Aia Massif (821 m asl). Basque Country

the Cantabrian coast is the presence of platforms of marine abrasion or *rasas*, which correspond to erosive surfaces inclined towards the sea and limited inland by topographic ridges. These forms present different geneses: marine, continental, and mixed erosion (Mary 1985).

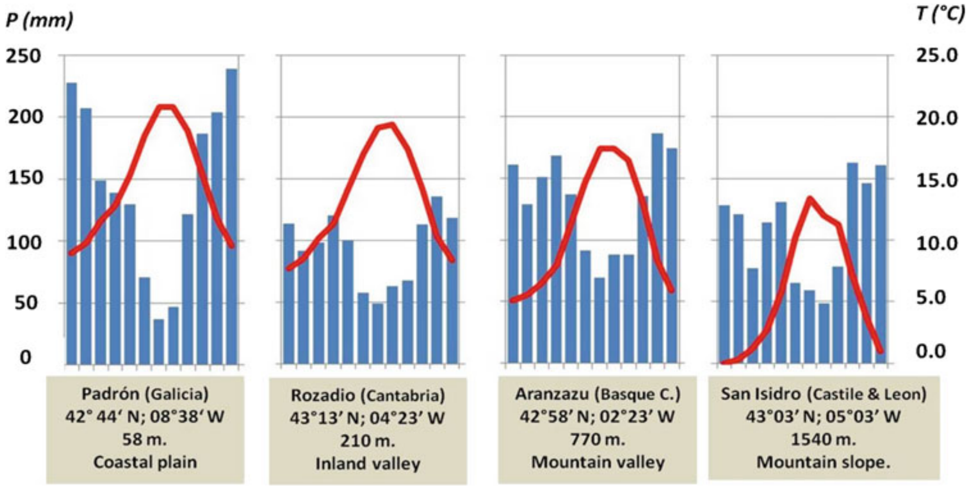
3.3.2 Climate

3.3.2.1 General Climatic Aspects of the Spanish Temperate Humid Zone

The general factor that determines the main climatic conditions of the Iberian Cantabrian area is its position at mid-latitude (42–43ºN) on the western side of the European continent, with prevailing west winds, corresponding to the northern hemisphere's circulation, and subject to cyclic oscillations (Martínez-Cortizas and Pérez-Alberti 1999). Such conditions determine a high influence of temperate and humid air masses from the Atlantic Ocean. The Atlantic depressions, with their associated fronts, affect the Cantabrian area especially during the spring, autumn and winter months, when the polar front drops to low latitudes. In the summer months, however, the polar front remains at higher latitudes and a subtropical influence occurs persistently (Felicísimo 1992).

In such conditions, moderate temperatures, and cool and very rainy winters, and temperate and relatively dry summers, constitute the basic characteristics of the climate in the Spanish Temperate Humid Zone (Fig. 3.10), in contrast to most of the regions of the planet with similar latitudes. This allows for a prolonged period of biological activity for almost the entire year, except in areas of high altitude, and particularly in the lowland coastal areas, where average

Fig. 3.10 Examples of monthly distribution of temperature and precipitation in four selected meteorological stations in the Spanish Temperate Humid Zone. Data from MAGRAMA (2013)



winter temperatures are around 9–10 °C; moreover, annual average temperatures reach 12–15 °C in most of the areas. From an edaphic point of view, such temperatures and abundant rainfall during all or most of the year clearly favor the biochemical alteration of parent materials and leaching processes in soils (Muñoz Taboadela 1965). Soil development is therefore directly related to general high values of drainage, in which case decarbonation processes and acidification are widespread (Guitián Ojea et al. 1985a).

Similar climatic conditions can be found outside Europe only in relatively small geographic areas, in equivalent latitudes such as the coastal lands on the western sides of North and South America, and in Oceania. According to the Köppen-Geiger classification, the Spanish Temperate Humid Zone corresponds to “Cfb“ (temperate without a dry season and temperate summer) and “Csb” (temperate with dry and temperate summer) climatic types (AEMET-IM 2011).

In this general context of considerable precipitation and moderate temperatures, the complexity of the relief and a wide range of altitudes (from sea level to above 2,000 m asl), involve significant climatic variations along the study zone. Moreover, the relative position of the various regions from the west coast of the Iberian Peninsula towards the bottom of the Bay of Biscay is determinant in the general distribution of the precipitation, and especially in summer, so that it generally increases from west to east across the Cantabrian area. The reason for this difference in the amount of summer rainfall lies in the distribution of the sea surface temperatures along the coast: in cold months, the sea surface temperature is relatively uniform, while in the summer a significant heating of the surface waters takes place in the Bay of Biscay; the thermal gradient generated reaches 2–3 °C between the Galician and the Basque coasts, activating the transfer of heat and humidity from the sea surface to the lower layers of the atmosphere (Felicísimo 1992). Under these conditions, a general feature in the Cantabrian area is the existence of a period, of variable duration, in which the potential evapotranspiration (ETP) exceeds the precipitation (P). Such a period coincides with one or more of the summer months, creating a potential lack of moisture in the soils, variable as a function of the soil properties.

3.3.2.2 Temperature, Precipitation, Drainage, and Moisture Deficit in the Spanish Temperate Humid Zone

Figures 3.11, 3.12, 3.13 and 3.14 summarize the precipitation and temperature data, with greater relevance from the viewpoint of the soils, taken from 54 significant weather stations (MAGRAMA 2013) for the whole Spanish Temperate Humid Zone, approximately between 1971 and 2003. In order to facilitate the interpretation of the data, the stations have been grouped according to physiographic and altitude criteria:

- Coastal areas (<100 m asl; Fig. 3.11)
- Valleys and plains in lowlands (100–400 m asl; Fig. 3.12)
- Inland valleys and mid-mountain slopes (400–800 m asl; Fig. 3.13) and
- Mountainous areas (>800 m asl; Fig. 3.14).

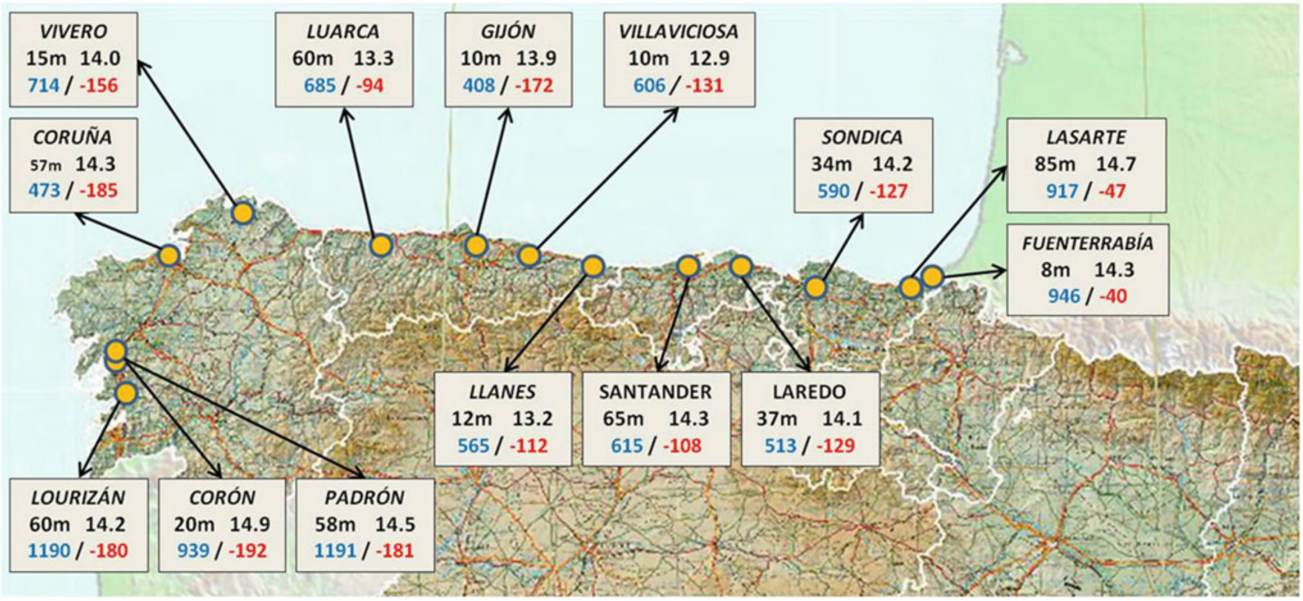


Fig. 3.11 Data from the coastal areas (altitudes below 100 m). Text boxes include: name of the station; altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values ≤ 0, *red characters*). Base map: Instituto Geográfico Nacional. IGN. Madrid, Spain

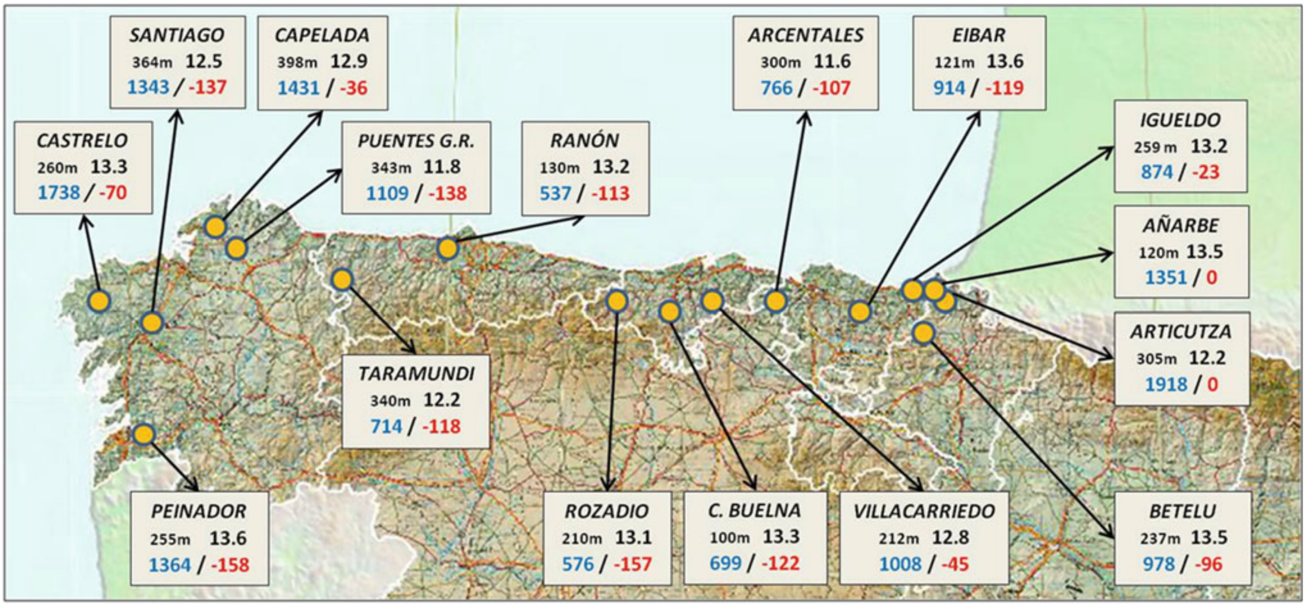


Fig. 3.12 Summarized temperature, drainage and moisture deficit data from meteorological stations in lowlands. Text boxes include: name of the station; altitude (m. asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values ≤ 0, *red characters*). Base map: Instituto Geográfico Nacional. IGN, Madrid, Spain

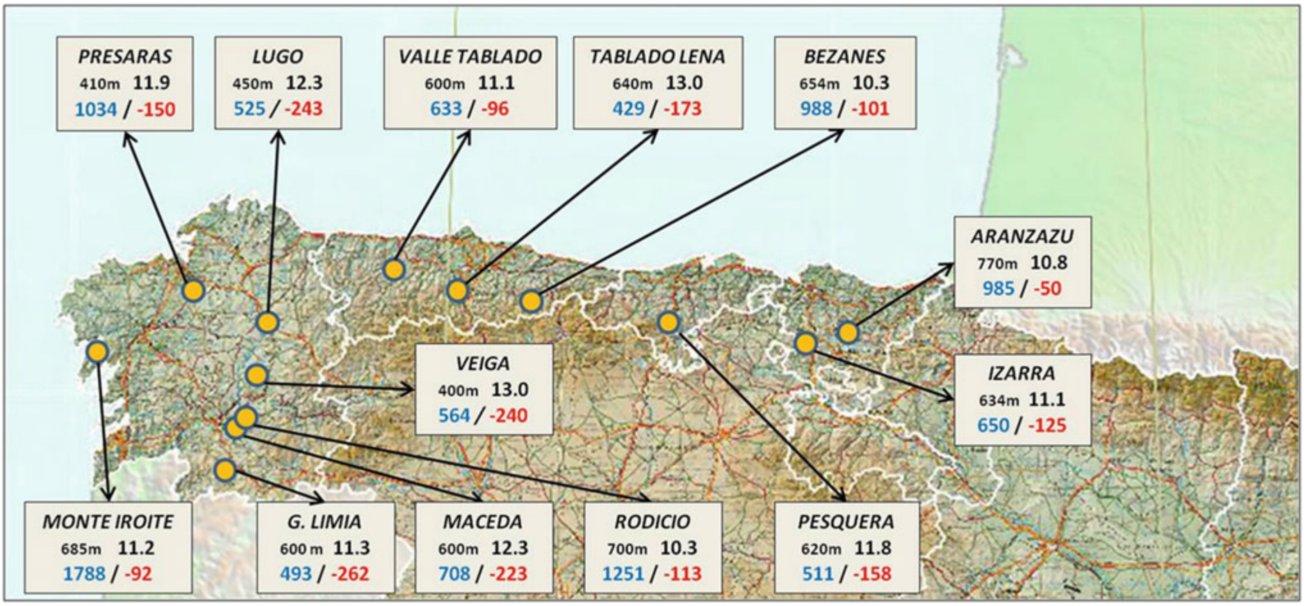


Fig. 3.13 Summarized temperature, infiltration and moisture deficit data from meteorological stations in inland valleys and slopes. Text boxes include: name of the station, altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values ≤ 0, *red characters*). Base map: Instituto Geográfico Nacional. IGN, Spain

The basic data indicated for each station include a simplified name of the station, the altitude (m asl), the average annual temperature, the average annual drainage (sum of monthly differences between precipitation and evapotranspiration, in blue), and the average summer moisture deficit (sum of differences between evapotranspiration and precipitation, values ≤ 0, in red-).

Figure 3.11 includes data from coastal areas (altitudes below 100 m), and shows high average annual temperatures (13–15 °C) and temperate winters, with no relevant

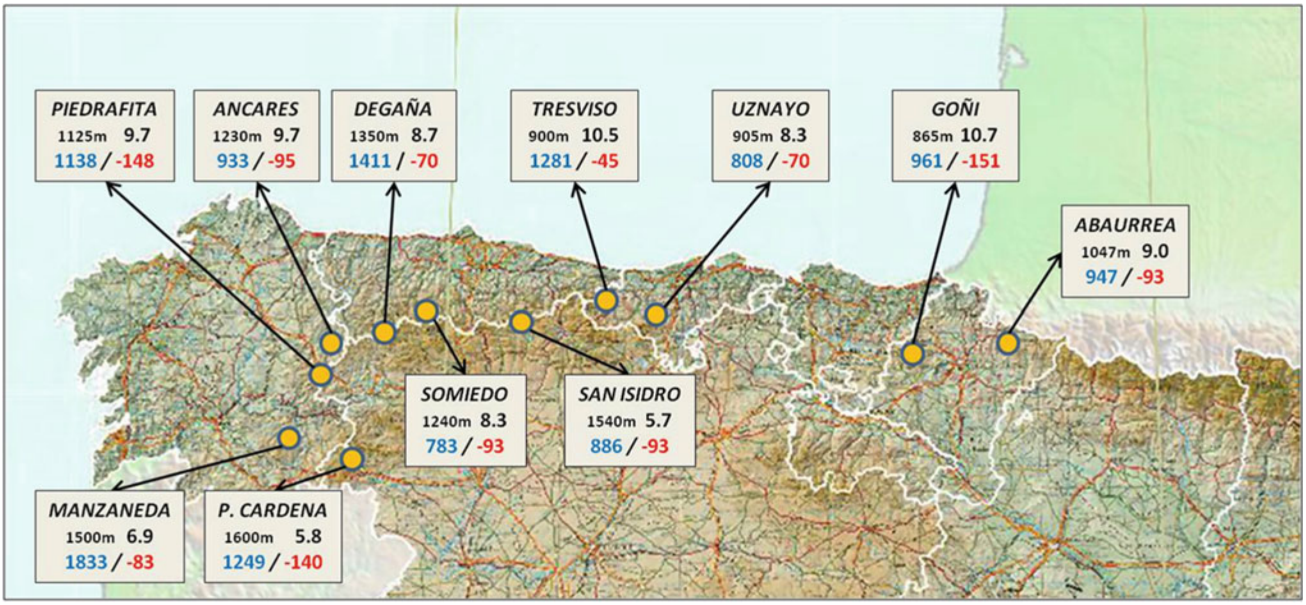


Fig. 3.14 Summarized temperature, drainage and moisture deficit data from meteorological stations in mountains. Text boxes include: name of station; altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values ≤ 0, *red characters*). Base map: Instituto Geográfico Nacional. IGN, Spain

differences in the whole area. The drainage reaches a maximum in southwest Galicia, associated with very rainy winters (around 600 mm in the December-February period), but it is significantly lower in the north-central coast and clearly increases in coastal areas in the east end of the Basque coast.

As a result of low summer precipitation on the Atlantic coast of Galicia (110–150 mm of rain in the June-August period), the potential deficit of moisture during the summer reaches a maximum in the context of the coastal and lowland areas of the Spanish Humid Zone. Such deficit decreases towards the East, through the lowlands of northern Galicia, Asturias, Cantabria and west of the Basque Country, and is reduced to a minimum in the coastal areas of the eastern Basque Country as a result of a great deal of summer precipitation (almost 300 mm). Similarly, the number of months when ETP exceeds P decreases from 4 months in the western and central parts of the region to 2 months in the eastern part.

Figure 3.12 provides information from stations in lowlands, including valleys, plains, and slopes approximately between 100 and 400 m in altitude. The temperatures show a similar behavior to that of the coastal areas, without significant disruption of the biological activity in winter (average temperatures of 7–9 °C in the December–February period).

A range of mountains a few kilometres inland constitutes a first barrier to the humid Atlantic winds and produces a clear increase in rainfall in relation to strictly coastal areas, especially significant both in Galicia and the eastern end of the Basque Country. In the case of the Galician coast, the link between the coastal plains and the mountains takes place through strong slopes that generate rapid temperature and rainfall gradients (Martínez-Cortizas and Pérez-Alberti 1999). Some stations representative of the first orographic barriers facing the Atlantic Ocean in Galicia show particularly high winter rainfall (Castrelo: 920 mm in the December–February period).

In the summer, the overall decline in rainfall is partially mitigated by the presence of these reliefs (Castrelo, 220 mm in the June-August period); however, a potential moisture deficit develops throughout the region in that period as a result of high evapotranspiration.

A clear decrease in rainfall is noticeable in the Central Cantabrian area (Rozadio, 1126 mm yr^{-1}), in which the Cantabrian Mountains are a barrier to the very humid southwesterly winds. On the other hand, only in a few lowland valleys in the eastern Cantabrian area does the precipitation exceed the evapotranspiration all year round, as a result of particularly abundant summer rainfall: Añarbe (360 mm rainfall in the June–August period), and especially Artikutza (400 mm in the same period).

Figure 3.13 shows data from stations corresponding to mid-altitudes between 400 and 800 m, where the influence of the topography is reflected both by a marked increase in rainfall in the areas most exposed to the humid Atlantic air masses, and by the opposite rainshadow effect in the areas downwind from such air masses.

Several meteorological stations in Galicia clearly show the contrast between the heavy rainfall in the coastal elevations (Monte Iroite in Barbanza: annual precipitation 2347 mm yr^{-1}) and in high valleys that open to the ocean

(Presaras, 1557 mm yr^{-1}), *versus* inland depressions (Limia, Maceda, Veiga or Lugo, 900–1100 mm yr^{-1}), while precipitation increases rapidly again in the inland ranges (Rodicio, 1771 mm yr^{-1}). In parallel to the decrease in rainfall towards inland depressions (Limia, Monforte, Terra Chá), a remarkable general decrease in the SOM content of the soils can be detected (Guitián Ojea and Carballas 1982). The rainfall gradient with respect to altitude varies greatly, depending on the topographic conditions; in the case of Asturias, this gradient is estimated at about 100 L.m^{-2} for an increase of 100 m in altitude (Felicísimo 1992).

The orientation of the inland valleys is likewise a crucial factor in the amount of precipitation and, therefore, in the potential water drainage and moisture deficit; thus, valleys facing east or north (Valles de Tablado, Lena, Pesquera, Izarra) generally receive less rainfall (950–1200 mm yr^{-1}) than those facing west or northwest (Bezanes: 1521 mm yr^{-1}; Aranzazu: 1580 mm yr^{-1}) at similar altitudes.

At these altitudes of 400–800 m, the average annual temperatures decreases 2–4 °C compared to those of the lowlands, with a cool winter period (5–7 °C December-February), which implies a variable but generally short period of limiting biological activity. Average summer temperatures generally exceed 16–17 °C.

Figure 3.14 includes data from stations in the mountainous areas of the Spanish Temperate Humid Zone (Eastern Galicia and Cantabrian Mountains, west end of the Pyrenees) above 800 m altitude. The north-facing slopes of the Cantabrian Mountains broadly define the study zone. In this range, the presence of a long period of low temperatures, implying a clear decline of biological activity in the soils, could be considered to be the most relevant climatic feature in relation to soil formation. Winter temperatures are limiting for biological activity, especially above 1,000 m, with 3–5 months of average temperatures below 5 °C; furthermore, cool summers are remarkable, with only 4 months of average temperatures higher than 10 °C.

Relief complexity is determining for the irregular distribution of precipitation. In the main ranges in southeast Galicia, rainfall generally exceeds 2000 mm yr^{-1} (Manzaneda, 2308 mm yr^{-1}), as a result of a rapid and forced ascent of very moist air masses from the southwest. Other stations in the Western Cantabrian Mountains, at a similar altitude, get around 2000 mm yr^{-1} (Degaña), but usually the highlands in the Cantabrian Mountains, with a minor influence of the wettest Atlantic air masses, show significantly lower values (1200–1400 mm yr^{-1}), accordingly to data from the available stations, as a result of the distance to the ocean, orientation, or rain shadow effect. However, there is little data available from high mountain stations, which are absent from altitudes above 1,600 m asl.

In the climatic context described above, and according to the definitions in *Soil Taxonomy* (Soil Survey Staff 2010), different soil temperature and moisture regimes are established:

(1) *Mesic* soil temperature regime is generally defined in the Spanish Humid Zone, from soils in coastal areas (bordering the *thermic* regime, especially on the Galician and Basque coasts), to inland valleys, plains and slopes at altitudes below 1,300–1,400 m asl, from which a *cryic* soil temperature regime should be considered dominant.

(2) *Udic* soil moisture regime is generally defined as characteristic of the Spanish Humid Zone; however, coastal areas and the extensive inland territories of Galicia and the western and central parts of Asturias, as a result of a significant water deficit in the summer period, are characterized by an *ustic* moisture regime (Lázaro et al. 1978).

3.3.3 Vegetation and Land Use

3.3.3.1 Climax Vegetation in the Spanish Temperate Humid Zone

There is no doubt that for the entire Spanish Temperate Humid Zone, the climax vegetation is the deciduous *Quercus* forest, both in acid and basic soils; nevertheless, taking into account that the vegetation greatly depends on climate, geological materials, geomorphology, and topography, the vegetation that covers the wide Spanish Temperate Humid Zone shows variations that depend on these factors.

Pedunculate-oak and common-beech forests are the most widely spread climax vegetation, as represented in Fig. 3.15. Oak forests, dominated by *Quercus robur L.*, are widespread in coastal areas and lowlands, either on acid soils (Galicia and western half of Asturias) or on mostly neutral or basic substrates (eastern half of Asturias, Cantabria and the Basque Country), as well as in the mid-mountain areas of Galicia. Pyrenean-oak (*Quercus pyrenaica Willd*) forests represent the transitional climax vegetation between the Atlantic and Mediterranean mountainous areas over acid soils. Common-beech forests (with *Fagus sylvatica L.*) represent the main potential formations in Cantabrian and the Basque Country Mountains, normally at altitudes over 800 m and mostly on neutral or basic soils. Birch forests (with *Betula sp.*) occupy mid-mountain slopes in acid soils. Alpine shrubs and grasslands represent the potential vegetation in the highest mountain levels. Several limestone massifs, in coastal areas, and in dry and mild inland valleys, host evergreen Atlantic holm-oak forest (with *Quercus ilex L.*).

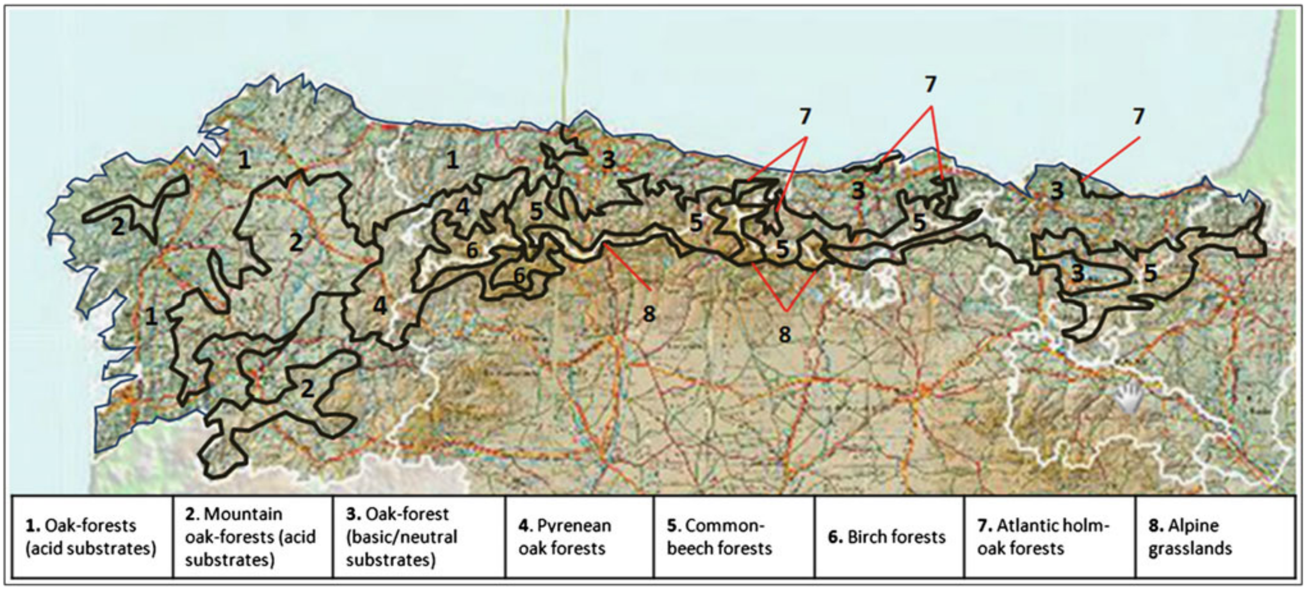


Fig. 3.15 Main climax vegetation formations in the Spanish Temperate Humid Zone. Synthesized and modified from Rivas-Martinez (1987), Spanish Potential Vegetation Map 1:400,000 scale. Base map: Instituto Geográfico Nacional. IGN, Spain

The Spanish Temperate Humid Zone is included in the Eurosiberian Region within the Holarctic or Boreal Kingdom, and roughly coincides with the Atlantic Biogeographical Region, as defined by the European Environment Agency (www.eea.europa.eu).

3.3.3.2 Actual Vegetation in the Spanish Temperate Humid Zone: Natural Forest Formations

In the entire territory, climax forests have virtually disappeared as a result of deforestation for agricultural, livestock and forestry uses, and because of forest fires. Its structure and floristic composition have been deduced from sparse fragmented forests; therefore, there is incomplete knowledge about climax vegetation (Blanco et al. 2005). Thus, except in Galicia, where oak patches are specifically maintained in thalweg ecosystems where there is usually enough humidity and deep soils, the forest stands are comparable to climax vegetation only in rocky soils, great slopes and/or soils with high acidity or other physicochemical limitations, showing, in any case, different stages of degradation. On the other hand, in Galicia, seedlings and small trees of *Quercus* sp. appear in almost all pine and eucalyptus forests and scrubs, which indicate the presence of oak forests in these areas in the past (Carballas 2003). As the evolution of the vegetation has followed different directions over time in the zone under study, it is necessary to indicate what the situation is nowadays in each area.

Regarding Galicia, due to its geographical location in an intermediate floristic zone between the Atlantic provinces of the Eurosiberian region and the Carpeto-Iberian-Leonés Provinces of the Mediterranean region, it is a country of mixtures—as a result of climate contrasts (see previous chapter). Thus, the Mediterranean character of the climate and the acidity of the soils have a decisive influence on its vegetation (Fraga Vila and Reinoso Franco 1982).

Galicia has a clear forest vocation because according to the Galician Forest Plan (Xunta de Galicia 1992), two-thirds of its surface is covered by forest ecosystems (60 % of this surface by forests and 40 % by scrubs). This plan also signals the three main masses of forests, formed by 40 % of conifers, mainly *Pinus pinaster* (75 %), *P. sylvestris* and *P. radiata*; approximately 20 % of deciduous plants, specially oak forests (*Quercus robur*, *Q. pyrenaica*); and 40 % by a mixture of *Eucalyptus* sp., and other pine and oak species.

Oak forests (Fig. 3.16) on acid substrates that represent the climax vegetation in the western part of the study area, are mainly composed in the arboreal stratum by pedunculate oak (*Quercus robur*), chestnut (*Castanea sativa*), hazelnut tree (*Corylus avellana*) and holly tree (*Ilex aquifolium*). In the undergrowth, *Rubus* sp., *Lonicera periclymenun*, gorses (*Ulex europaeus, U. nanus* and *U. gallii*) and brooms (*Cytisus* = *Sarothamnus scoparius*, *Genista florida*) form the shrub stratum; the herbaceous stratum includes *Euphorbia amigdaloides*, *Asphodelus albus*, *Anthoxantum odoratum*, *Simethis bicolor*, *Potentilla erecta*, or ferns such as *Polysthichum filix-mas*, *Pteridium aquilinum* and *Polypodium vulgare*; and the muscinal stratum, with a remarkable importance in the initial soil development, includes *Pseudoscleropodium purum*, *Thuidium tamariscinum, Hypnum cupressiforme, Rhytidiadelphus loreus*, *Polytrichastrum*

Fig. 3.16 Oak forest (climax vegetation). Sierra do Caurel, Lugo, Galicia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

Fig. 3.17 Cantabrian holm-oak forest in a limestone massif. Mañaria, Vizcaya, Basque Country

formosum and *Diplophyllum albicans* (Fraga Vila and Reinoso Franco 1982; Carballas 2003).

Generally, mountainous oak forests in a colder continental climate show a variant characterized by enrichment in species like birch (*Betula verrucosa*), holly tree (*Ilex aquifolium*) or rowan trees (*Sorbus aucuparia*) and bilberries (*Vaccinium myrtillus).* Moreover, oak forests in low valleys and coastal areas incorporate thermophyllous elements such as *Laurus nobilis*, *Rhamnus alaternus, Ruscus aculeatus* or *Hedera helix* (Blanco et al. 2005).

In Galicia, in the valleys of the Sor and Eo Rivers (Orense and southeast of Lugo Provinces), and in the southwest of the Asturias valleys (Navia and Narcea Rivers' basins), the remaining forests are dominated by *Quercus pyrenaica,* showing a transition to Mediterranean forests, predominant in the southern foothills of the Cantabrian Mountains. In southwest Galicia, *Quercus ilex* is abundant in these forests, with frequent patches of cork trees (*Quercus suber* l.), extending by the Miño River Valley and the northwest of the Province of Orense, where strawberry trees (*Arbutus unedo*)

Fig. 3.18 Chestnut forest. Viana do Bolo, Orense, Galicia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

can frequently be seen (Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b).

On limestone or calcareous mountains, with the limits strictly marked by the presence of these rocks, and in relatively dry and temperate areas are remarkable the dense formations of evergreen holm oaks in the inland valley of Cruzul and the Caurel Mountains (Province of Lugo, Galicia), the eastern coast of Asturias, the Cantabrian coastal areas and inland valleys, and the Basque Country coast (Fig. 3.17), where *Q. ilex* and the *Amelanchier ovalis*, *Crataegus monogyna*, *Lonicera etrusca*, *Lonicera xylosteum*, *Prunus spinosa*, *Rosa arvensis* or *Viburnum lantana* species are common (Guitían Ojea et al. 1982b, 1985a, b; Loidi et al. 2011).

Patches of chestnut trees are found everywhere in Galicia (Fig. 3.18). Although chestnut forests do not have a natural origin but perhaps an anthropogenic one through the cultivation or degradation of other forests, these forests are almost in climax stage, occupying the main sub-continental climate areas, particularly in some slopes of the Orense Province, in the abrupt slopes of Belesar, on soils on granite, and in the Miño River Valley, towards Chantada (Lugo Province) (Fraga Vila and Reinoso Franco 1982; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b).

Common beech (*Fagus sylvatica)* forests are widely represented in the Cantabrian Mountains, both on acid or basic substrates, especially in eastern Asturias, Cantabria and the Basque Country, being very scarce below 300–400 m. Beech distribution is closely related to summer water deficit in the temperate humid soils, so that towards the eastern Cantabrian beech area, it becomes more extended and its presence decreases in altitude. Its western boundary is located in the Galician mountainous areas of the northeast of Lugo and eastern Orense: Ancares, O Caurel, Queixa and Invernadeiro (Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b).

In Cantabria, above 1,500 m, the forest is degraded and replaced by a scrub of juniper and heath (*Juniperus communis*, *Calluna vulgaris*, *Erica vagans*) and then to alpine prairies composed of *Carex sempervirens* or *Festuca eskia* and alpine clover species of greater nutritive value. Finally, on the cliffs of the high summits, there are skeletal soils that scarcely sustain a rachitic vegetation of ferns, mosses and lichens, without any economical or edaphic value.

Oak forests in the eastern part of the Spanish Temperate Humid Zone (eastern Asturias, Cantabria, Basque Country) are commonly linked to neutral or basic substrates, and they are considered to be eutrophic or mesotrophic oak forests. Because of the high fertility of the soils associated with these forests, the original area is almost completely used for agriculture and livestock. Thus, current representations are scarce and strongly altered; however, most of the tree species considered in the potential vegetation, such as common ash (*Fraxinus excelsior*), maples (*Acer pseudoplatanus*, *A. platanoides*), and wild cherries (*Prunus avium*) are now present, with sessile oak (*Quercus petraea*) being more frequent in the highest areas, or *Q. pyrenaica* and *Q. pubescens* in transition with Mediterranean areas (Loidi et al. 2011). The eutrophic conditions of the soils and the mild climate favor a rapid mineralization of the organic matter (Blanco et al. 2005).

Oak, chestnut and beech, and deciduous natural forests in general (Fig. 3.19), produce residues that are easy to humify, and so the quality of the soil organic matter is excellent. In the western areas covered by heath, the tendency is to give

Fig. 3.19 Mixed deciduous woodlands. Quirós, Central Asturias

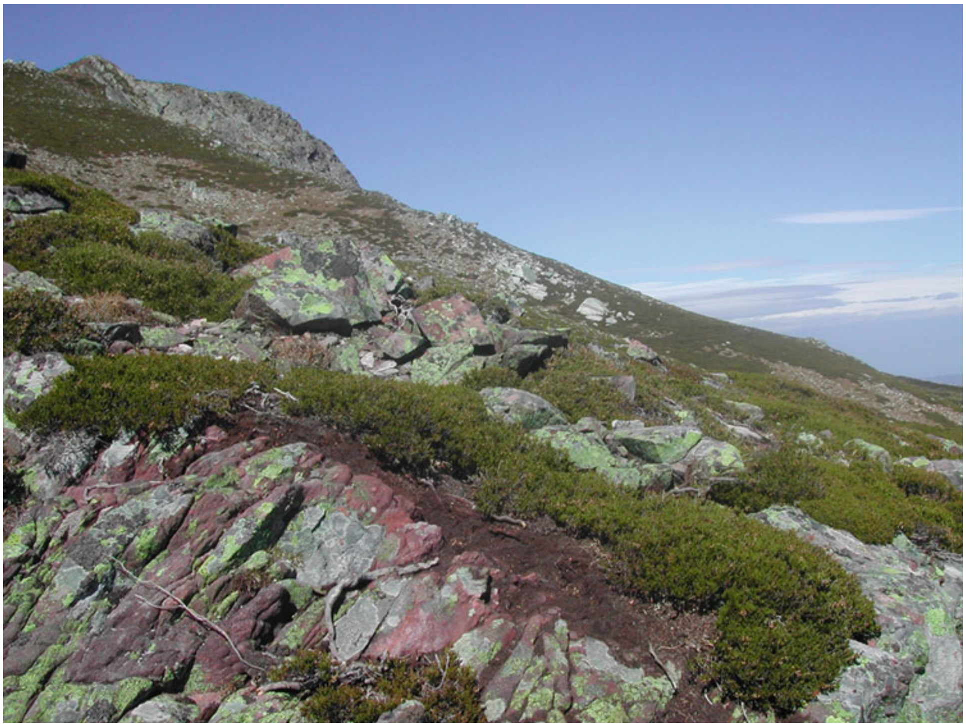


Fig. 3.20 High-mountain scrub. San Isidro, Cantabrian Cordillera. South-Central Asturias

dystrophic humus, with a high C/N ratio (higher than 20). The leaves of the oak facilitate the humification and, as a result, the soils of the oak forest used to be deep, with an A horizon from a few centimeters to −50 cm depth.

The shrub formations, to whose expansion numerous circumstances connected to human intervention have contributed, represent, in general, different degradation stages of the forest formations described above (Fig. 3.20). Usually they develop on acid soils that are poor in nutrients and frequently of small thickness, and they are very tolerant to different physical conditions, even periods of accused dryness, although they need a certain degree of humidity that they can acquire even from fog and mist in the area.

Fig. 3.21 Gorse scrubs (*Ulex* sp.) and pine forest. Spanish Temperate Humid Zone

Among the numerous types of scrubs abounding in Galicia, the western part of Asturias and the central and east Cantabrian areas, with acid soils associated with lithologies of quartzites, sandstone or lutites, the gorse scrubs stand out (Fig. 3.21); the surface covered by *Ulex europaeus*, *U. gallii* or *U. minor* predominate, although the presence of other plants, mainly *Erica* sp., *Daboecia cantabrica, Calluna vulgaris* and *Pteridium aquilinum* (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b, 1986) is also important. They are, without a doubt, the scrubs that are more subjected to human intervention, mainly because of the value of the leguminous species for the soil, and also due to frequent fires.

The heaths, where *Erica* sp. predomínate, are also of various types (Figs. 3.22 and 3.23). Those of *Erica umbellata*, *E. tetralix, E. arborea. E. australis, Pterospartum tridentatum* and *Calluna vulgaris*, among others, are associated with shallow and rich in organic matter soils, frequently coarse-textured and arid in summer. With increasing altitude, however, the amount of pastures increases because of the higher humidity, giving rise to sub-alpine pastures on flat summits that are used by the livestock in the dry season.

In the area under study, also represented are scrubs of brooms, formed by *Cytisus* sp., of high height; and scrub of clumps, mainly with *Cistus ladanifer*, *C. salviifolius* and *C. hirsutus* that developed only in the areas with Mediterranean climate, in the basins of the Sil, Bibei and Casallo Rivers, and in the Larouco range, in the limit between the Lugo and Orense Provinces (Fraga Vila and Reinoso Franco 1982; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b).

3.3.3.3 Actual Vegetation in the Spanish Temperate Humid Zone: Singular Formations on Hydromorphic, Sandy or Saline Soils

Riparian formations, both on acidic or basic soils, include species as alder (*Alnus glutinosa)*, ash tree (*Fraxinus excelsior*), and willows (*Salix atrocinerea, S. triandra, S. salviifolia*), as well as a rich herbaceous stratum with ferns as *Blechnum spicant*, *Athyrium filix-femina* and *Osmunda regalis* (Fig. 3.24). Such species are characteristic of fluvial shores, creeks, pools, small lagoon areas and hygrophilous areas and peat lands, where the common ecological condition is the continuous flooding of the plant roots (Fraga Vila and Reinoso Franco 1982). With increasing altitude, some tree species become more common, as birch (*Betula* sp.), cantabrian willow (*Salix cantabrica*), wych elm (*Ulmus glabra*) or aspen (*Populus tremula*) (Blanco et al. 2005).

The hygrophilous formations locally called "*brañas*" in Galicia, formed by the retention of waters in smooth depressions, and that cannot be considered peats due to its different origin, are frequently found in low extensions dispersed throughout the entire Galician territory, the Brañas de Brins (Figueiras, Santiago), Gándaras de Boedo (Guitiriz) or the Budiño (Porriño) and many others being the most remarkable; apart from the *Sphagnum* that grows there, in these semi-submerged scrubs, *Potamogeton polygonifolius*, *Ranunculus hololeucus, R. lenormandi*, *Parnesia palustres,* and insectivores such as *Drosera intermedia* and *D. rotundifolia* are frequently found. In the next terrain separated from the submerged area, the hydrophilic scrub initiates with

Fig. 3.22 Heath scrub (*Erica* sp., *Calluna vulgaris*). Peña Trevinca, Orense, Galicia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

Fig. 3.23 Fern and heather formations in quartzite-slate massifs. Narcea valley, western Asturias

heaths as *Erica tetralix*, *E. ciliaris* and *Calluna vulgaris*, gorses as *U. europaeus*, *U. nanus* and *U. gallii*, and *Genista angelica*, *Lotus corniculatus*, *Potentilla erecta*, and rubs as *Juncus sylvaticus* (Muñoz Taboadela et al. 1966; Fraga Vila and Reinoso Franco 1982; Guitián Ojea and Carballas 1982). These formations, together with the real peats, reach their greatest size in mid-mountainous areas of Galicia, with the typologies of blanket bogs, fens or raised bogs (Martínez-Cortizas and García-Rodeja 2001). In Asturias (Cudillero, Borbolla, Cué), Cantabria (Liébana), and the Basque Country (Ordunte, Gorbeia), there are small peat areas of diverse origin (Aseginolaza et al. 1988) where *Eriophorum* sp. and *Carex* sp. are frequently found; particularly in the Basque Country, peatlands are very rare and appear over 700 m asl on flat hilltops. Mosses, mainly *Sphagnum* sp., represent an important part of the biomass of these formations.

Sandy areas in dune formations show an arenicolous halophyte vegetation type, represented by marine grass (*Agropyrum junceum*) and beach grass (*Ammophila

Fig. 3.24 Riparian formation. Limia River shore, Orense, Galicia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

arenaria), which are developed jointly with *Cakile maritima*, *Salsola kali*, *Honckenya peploides* and other species. Differences in sand movements and direct sea influence, saline spray, soil salinity, organic matter and nutrients, calcium carbonate content and pH, determine the distribution of the species in the dunes.

Extended dunes are present on the Galician coast, with *Agropyrum junceiforme*, together with *Euphorbia paralias*, *E. portlandica*, *E. peplis, Eryngium maritimum*, *Cakile maritima* or *Convolvulus soldanella* in the base, whereas their summits are dominated by *Ammophila arenaria,* besides *Pancratium maritimum* and *Medicago maritima*. As they are mobile dunes, the areas of vegetation can easily change. In the secondary dunes or dead dunes that are formed by fine sands fixed by the vegetation, there are mosses and lichens—mainly *Tortula ruraliformis, Polystrichum poliferum* and *Cladonia foliacea*. Most species are annual, with halophyte and nitratophyte characteristics as a result of local large amounts of nitrates due to the decomposition of detritus (Fraga Vila and Reinoso Franco 1982). Cantabria has the largest dune field of the Cantabrian coast (*Liencres*). *Atriplex prostrata*, *Cakile maritima*, *Euphorbia*

Fig. 3.25 General view of tidal wetlands. Marsh in the estuary of the Mandeo River, Betanzos, A Coruña, Galicia (*Photo* Ana Cabaneiro Albaladejo, IIAG-CSIC)

peplis, *E. paralias, Honckenya peploides*, *Calystegia soldanella*, *Eryngium maritimum*, or *Salsola kali* are characteristic of dunes in the Basque Country (Loidi et al. 2011).

On the cliffs, which are subject to a constant abrasive and desiccant action, there are halophyte associations that are influenced by the nature of the rock; the vegetal cover, such as maritime fennel and plantago, covers wide surfaces of the soil. *Crishmum maritimum*, *Armeria pubigera,* and *Armeria maritima,* are abundant (Fraga Vila and Reinoso Franco 1982). All these plants, with their deep roots, penetrate the rocks and produce their disaggregation.

Tidal wetlands, such as salt marshes and estuaries, are frequently found in the coastal areas of the Spanish Temperate Humid Zone (Fig. 3.25). Tidal and alluvial dynamics determine soil texture and salinity as the main factors affecting flora and vegetation. On the Atlantic coast of Galicia, in the estuaries locally known as "*rías*," where the fresh water is widely mixed with the salty water, the vegetation is mainly composed of *Juncus maritimus*, *Agrostis solonifera*, *Statice limonium* and *Plantago maritima* (Fraga Vila and Reinoso Franco 1982). In these marshes, two important formations of sedimentary origin (Fluvisols), influenced by the tides, can be differentiated: the Sapropel soils (Kubiena 1952; Cabaneiro Albaladejo 1979), located in the intertidal zone and therefore submerged in the sea and merging only in the low tides, and the Marsh soils (Kubiena 1952), where the tides arrive only sporadically and in various degrees of terrification. The same formations can be observed in Cantabria (marshes of San Vicente de la Barquera; bays of Santander and Santoña) (Muñoz Taboadela et al. 1966; Guitián Ojea et al. 1982b, 1985a, 1986).

3.3.3.4 Land Use: Some Aspects of Agricultural, Livestock and Forest Uses in the Spanish Temperate Humid Zone

The anthropogenic action shows its activity with variable intensity. As was mentioned above, the most fertile soils in the entire humid zone have been dedicated to general agricultural use, predominantly the use of areas of smooth topography, such as valleys, fluvial meadows, and flat surfaces. Climatic and topographic factors determine that the intensity of the anthropogenic action generally decreases from the coastal areas towards inland, with increasing slope and altitude, and imply the relatively low percentage of the surface for agricultural use, compared to other regions of the Iberian Peninsula. As a whole, natural vegetation formations of the Iberian Peninsula have experienced a remarkable development in recent decades, as observed through successive forest inventories (MAGRAMA 2011).

In Galicia, the surface dedicated to agriculture represents only 25 % of the total surface. Although in the past, in all small villages farmers cultivated horticultural plants, cereals and potatoes on small plots for their own consumption, the abandonment of rural farms has completely changed these habits. Nowadays the farming economy focuses on the production of milk and its derivatives, mainly cheese, good veal and pork, and cultures of particular value. Therefore, the agricultural production is based on a number of species that extend its culture over most parts of the country, mainly cereals: maize (*Zea mays*), graminaea from South America that was introduced in Galicia in 1604 and occupies most of the extension, using mainly hybrid seeds; rye (*Secale cereale*) in less extension and in regression; and wheat (*Triticum aestivum*) in minor extension but increasing; and herbaceous plants: potatoes (*Solanum tuberosum*), the most divulged cultivation because it is cultivated everywhere although it does not occupy the highest surface; and oats (*Avena sativa, A. strigosa*). Other cultures are *Brassica napus* and its reputed varieties for consumption, locally called "*grelos*," *Lolium multiflorum*, *Trifolium incarnatum* and other leguminous plants for forage. All these plants are well adapted to the Atlantic climate and the acid soils (Lloveras Vilamanyá and Alonso Rosano 1982).

The viticulture in Galicia goes back to the Roman period. The vine (*Vitis vinifera*) culture is localized in areas of low altitude, depressions, or riversides of the rivers, in the southern area of the Lugo and Orense Provinces, where the influence of the Mediterranean climate permits this culture even in the very high slopes of the fluvial shores of the Miño, Sil and Bivei Rivers, protected from the dominant winds; therefore, the winter temperatures are smooth, and in summer the heat is more intense than in the elevated zones, thus obtaining a higher thermic integral, necessary for the maturation of the grapes. The human action has built narrow terraces in a series of gradins, taking advantage of the underlying rocks, granite and schist, transforming the initial Ranker soils (Kubiena 1952) into a deeply anthropogenic soil without differentiation of horizons, due to the tenacious and frequent works carried out on them, thus eliminating any vegetation other than the vine (Fig. 3.26). The vineyards occupy a large extension (more than 32,000 ha) spread over the four provinces, in Betanzos; Valdeorras; Valleys of Quiroga, O Rosal and Verín; the riversides of the Bivey, Miño, Sil, Avia (Ribeiro) and Ulla Rivers; Condado de Salvatierra, and O Salnés, each zone almost giving rise to a variety of wines (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1986; Lloveras Vilamanyá and Alonso Rosano 1982).

In Asturias, 37 % of the total regional surface is intended for permanent pastureland, compared to 32 % of wooded forest use, while only 2 % of the area consists of croplands (Gobierno de Asturias 2008). On calcareous soils, there are generally prairies in the valleys and subalpine pastures in the high areas. The wide extension of the prairies in Asturias was determined by four main factors: (1) humid climate regime all year round, without summer dryness; (2) soils with a great

Fig. 3.26 Vineyards in terraces. Riverside of the Miño River. Lugo-Orense, Galicia (*Photo* Rogelio Pérez Moreira, USC)

capacity of water retention, mainly Luvisols (Terra Fusca, Kubiena 1952); (3) anthropogenic factors derived from the scarcity of agricultural manpower, displaced in favor of the industries; and 4) the presence of natural subalpine pastures, whose livestock exploitation is unique, possibly due to its climatic conditions (Guitián Ojea et al. 1985b).

In Cantabria, human activities have imposed great modifications in the distribution of the vegetation. Thus, the coastal area has very poor natural vegetation, because this zone constitute the center of the agricultural activity; even so, there are some typical ecological domains directly related to the climax of the region. After this is another, much more extended and complex area that arrives to 500 m in altitude, a zone that is the most "humanized" in the Province of Santander and therefore presents a landscape with the less natural vegetation. However, where deforestation provoked the degradation of natural forest and its substitution by gorses and heather, today very abundant, the planting of Australian eucalyptus and Monterrey pine have been successively introduced; they are now the most widespread vegetation in the Cantabrian littoral zone. Finally, the semi-natural prairies appear, but when they are badly managed, they degenerate and the scrub of heath and furze occupy the area. The oak forest used to subsist associate with the prairies (Guitián Ojea et al. 1985a).

In the Basque Country, forests and forest plantations occupy almost 60 % of the land, while grassland is spread over another 30 %. Data from 2007 (EUSTAT) for Guipúzcoa and Vizcaya, territories fully included in the humid zone, indicated that only 2 % of the surface is for crops, and 25 % is designated for pasturelands, compared to 31 % for forestry use.

Eucalyptus globulus plantations are widespread in the temperate humid zone; specifically, the expansion of *Eucalyptus* sp. has been considered spectacular despite the increase in timber harvesting of that species (MAGRAMA 2011). *Eucalyptus globulus* is the most extensive forest cultivation in coastal and lowland areas from Galicia (Lugo and A Coruña, and in most parts of the Pontevedra Province) to the Basque Country. In eucalyptus cultivations, the undergrowth is a very poor scrub with few species, favoring erosive processes mainly due to the rain; this impoverishment of species is attributed to some essences, rich in terpenes, with antiseptic action that contributes to soil sterilization and the diminution of microbial activity, with the consequent decrease of soil organic matter (Lloveras Vilamanyá and Alonso Rosano 1982).

Plantations of *Pinus pinaster* in Galicia occupy diverse extensions and a band along the coast from the north to the south, growing on both poor and good filtration soils on acid rocks, looking for the climatic regime of the Atlantic coast, i.e., temperate and rainy. In the same way, *Pinus radiata* is much in use on the coast, alone or mixed with *P. pinaster,* and less used in inland surfaces (Sánchez Rodríguez et al. 2002; González Prieto and Villar 2003). Forests of *Pinus sylvestris* are mainly observed in Galicia, in the high areas of the Provinces of Lugo and Orense (Lloveras Vilamanyá and Alonso Rosano 1982), being scarcely present in Asturias.

In the Basque Country, some plantations with *P. pinaster,* substituted for *P. radiata,* can be observed on shallow, stony, and acid soils; other species, such as *Pseudotsuga menziesii* or *Larix* sp. are used in colder areas at higher altitudes. All these plantations are intensively managed, and in the case of *P. radiata,* this means 2–3 intermediate thinnings and a final clear-felling at age 25–40 years, with stem-only harvesting. Fertilizers are very rarely used, and high rates of nutrient export result from this land use. The mechanical site preparation techniques used in some cases after clear-felling result not only in significant increases in the loss of nutrients, but also in other processes of soil degradation, such as high rates of soil loss and compaction (Merino and Edeso 1999; Olarieta et al. 1999, 2006; Merino et al. 2005).

According to data from EUSTAT (2007) in the Basque Country, it is worth noting the predominance of *P. radiata*

Fig. 3.27 Anthropogenic action: mosaic of pastures and thin forest masses (bocage). Riosa, Central Asturias

on eucalyptus and other species in forest cultivation in coastal areas and lowlands, occupying *P. radiata*, 150,000 ha, against 10,000 ha of eucalyptus.

Both forests and shrublands played an important role in the agrarian economy in the past, not only in terms of firewood and timber, but also as the main sources of fertilizer in historical times and up to the 1960s, as litter and organic horizons were collected from forests, and bracken and gorse were harvested as bedding material for animals and then spread onto arable land and grassland (Carballas 2003). In some areas, shrublands were used under a slash-and-burn agricultural system that produced significant processes of soil degradation (Soto et al. 1995). From eastern Asturias to the Basque Country, liming materials are abundant, as limestone is a widespread rock, but they were only used for crops and, more sparingly, for grassland. The same occurred in Galicia, with liming material coming from limestone quarries (Guitián Ojea and Muñoz Taboadela 1957). This polarization of soil fertility between arable land and grassland on the one hand, and forests and shrubland on the other, is still evident today. Small lime fragments frequently appear on the subsurfaces of plots that were used for agriculture in the past but are now used for forest plantations, which commonly do not receive any fertilization. These plots also show significantly higher concentrations of the main nutrients. A similar situation has been described in other areas of Europe and Africa.

The prairies of natural origin occupy small surfaces and are generally being substituted by those semi-naturals, due to the anthropogenic activity that tends to favor the development of the herbaceous plants and eliminate the scrub plants. The best prairies are located in the fond of the valleys, fluvial shores, and gentle slopes, on terrain of good quality and with considerable humidity (Fig. 3.27).

The use of fire is a common practice, especially in acid soils, oriented towards the use of pasture in large areas of heaths and other acidophilus bushes. Controlled fires take place during the periods of low or no risk of fires; however, fortuitously or intentionally, almost all the soils in the mountains have repeatedly supported the fire action that destroys the SOM, particularly in peats and other Fluvisols (Anmoor soils; Kubiena 1952) down to −30 cm in depth in these cases, giving rise to large quantities of ashes that can change the soil pH and diminish the dystrophy of the upper horizons; this is how for the raising of ownerless animals or the stockbreeders and proprietors of hunting reserves transform shrublands into grasslands (Carballas 2003).

The anthropogenic soils that are those in which human activities have acted intensively modifying the general formation processes, constitute an independent group in which the natural soil is considered as parent material subject to evolution by the action of the cultures, fertilizers, amendments, forest fells, fires, etc. This process, called “meta-edaphogenesis” by Yaalon and Yaron (1966), differs from the soil formation factors by the rapidity of its actuation and its reversibility.

Top-quality prairies are those with green herbs, mainly perennial species, with rhizomes or stolons able to easily propagation of vegetative form permitting thus surviving to the frequent cuttings; they are not pastured and are reaped periodically each time the herb reaches a sufficient height. Frequently, some species are introduced in order to improve the pasture. The typical reaping prairies are of secondary quality or of dry herbs and are considered dry prairies, although generally they are developed on soils with abundant humidity; these prairies are reaped in July or August and then grazed on by the livestock until the end of the winter or early spring, when they are closed again until the following summer. The prairies of inferior quality are always pastured by the livestock all year round; their composition in species is even more reduced. Nowadays, in most of the exploitations, the herb is used for silage in periods of maximum production, thus disposing of forage in periods of scarcity of green herbs (Lloveras Vilamanyá and Alonso Rosano 1982).

In some parts of Galicia, pastures under brooms (*Cytisus*, *Genista* and other *Fabaceae* genus) are maintained by farmers because of their higher productivity in the dry season, with a humus of better quality and a considerable supply of N due to the leguminous and its debris. In the high mountains, such as Cabeza de Manzaneda, the bilberries (*Vaccinium myrtillus*), characteristic of humid soils of high acidity that form raw or dystrophic forms, typical of podzolized organic soils, are abundant. In the mountainous areas, the livestock exploitation profits from the subalpine pastures on organic soils, frequently hydromorphes (Guitián Ojea and Carballas 1982).

In the Basque Country, farms are mostly small, usually less than 50 ha with a mean size of about 10 ha (almost the same occurs in Galicia, where the territory is also divided in small parcels) and worked on part-time. The land used for arable purposes is less than 1 ha per farm, mostly just as vegetable gardens. Full-time, mainly arable farms are very rare and concentrate on horticulture and fruit production. In these cases, they use less than 5 ha for this purpose on slopes of less than 10 %, while the rest of the farmland is used for forest plantations. Animal farms are the most frequent full-time enterprise, and use slopes up to 47 % for cutting and/or grazing, slopes up to 58 % for grazing, and slopes steeper than this for forest plantations. Stocking rates in dairy and beef farms are 2–3 LU/ha, while in sheep farms are 0.8–1 LU/ha. Some land owners may have all their land in forest plantations, but even in this case, the size of these holdings is less than 10 ha; the species most frequently used in these plantations is *Pinus radiata*, which spreads over 50–60 % of the total forest area, and *Eucalyptus globulus* (Olarieta, J.R., personal communication).

3.4 Main Factors of Soil Degradation

The main factors contributing to soil degradation in this wide territory that are also common to the study zone are:

(1) Erosion processes mainly due to the frequent rains and a general landscape that comprises a coastal zone with steep cliffs and the mountainous inland zone with deep and abrupt slopes (Diaz-Fierros et al. 1982); and
(2) Forest fires 40 years ago that increased at such abnormal rates that they merit additional explanations, bringing about serious processes of post-fire erosion.

3.4.1 Forest Fires

The above-cited *Plan Forestal de Galicia*, elaborated by the Galician government (*Xunta de Galicia*) in 1992, signals as a "priority objective of any forest policy in Galicia the eradication of the forest fires . . ." Galicia, with a total surface of 29,430 km^2, has approximately two million hectares, which is two thirds of its territorial surface, with forest vocation, favored by its climatology with abundant rain (600–3,000 mm annual precipitation) and only sporadic periods of severe and prolonged dryness. Forests, plentiful scrubs, and herbaceous plants would cover our mountains, constituting a great ecological and economical richness by itself, but also by their role in the protection of the soil against erosion, which like that accounted for low levels of risk (Díaz Fierros et al. 1982). However, since around 1968, wildfires have been increasing gradually at previously unknown rates (more than 250,000 forest fires were recorded between 1968 and 2012), converting them in real catastrophes not only by the surface affected (1,711,000 ha) but mainly by the quality of the mountains affected (700,000 ha of arboreal surface). Forests, shrubs, and all types of vegetal cover affected by the fires have been destroyed, recurrently in many cases; the soils have been degraded in more or less degree and on top of that, the most negative impact of the fire arises—the post-fire erosion, resulting in high-risk levels in some cases, causing the loss of uncalculated amounts of soil, and even appearing rock outcrops (Carballas 1994, 2003, 2007, 2014).

To better comprise the magnitude of the problem in Galicia, which, together with northern Portugal, are the European zones with the highest number of fires per ha or inhabitant, although Galicia represents only 6 % of Spain's surface, for instance, from 1968 until 2012 it had 55 % of the fires in all of Spain, and representing 16 % of its forest surface, the surface affected by forest fires represented 25 % of that of all Spain and 26 % of its arboreal surface.

To both prevent and fight against this ecological, environmental, economic, and social catastrophe, the Spanish government has reacted by elaborating the INFO and PLADI Plans for forest fire prevention and extinction for each Community, but not for the management of the affected areas, such as the immediate protection of the burnt soils and

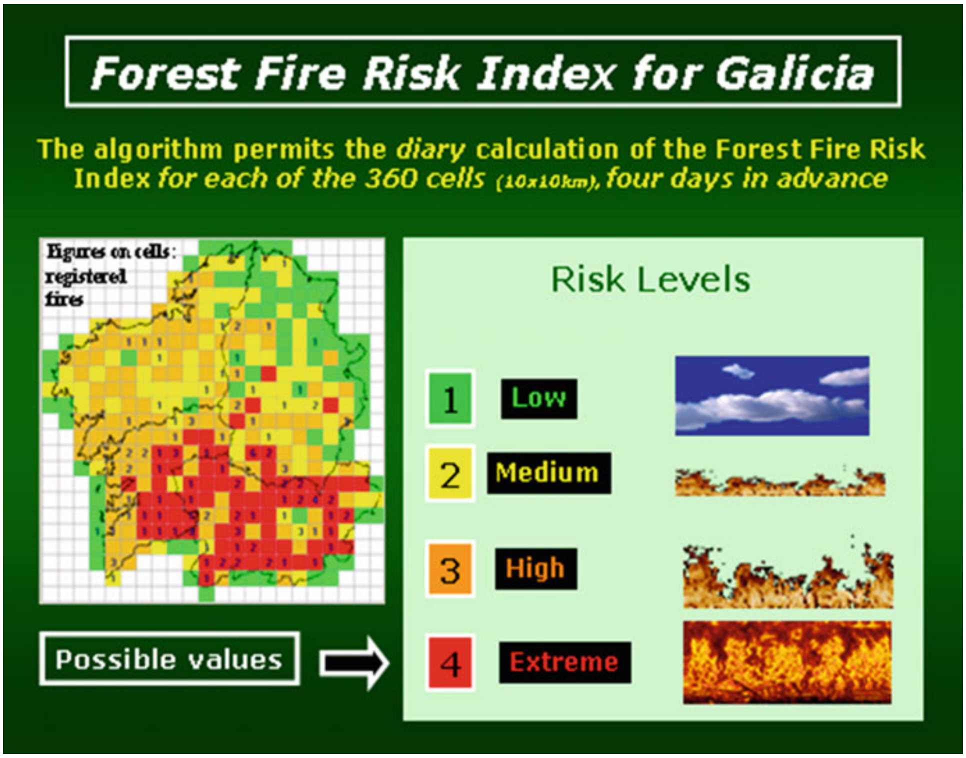


Fig. 3.28 Fire prevention. Statistical Forest Fire Risk Index that predicts the areas with risk of fire four or more days in advance (*Photo* THOR Group, USC, CSIC, UVigo, UAC)

restoration of the forest ecosystems affected by the fire—that is, recovery of the soil and rehabilitation of the vegetation (Carballas 2003, 2014). At the same time, numerous researchers have dedicated their efforts to the study of the various aspects of this subject: effects of fire on all components of the environment; measures for the control of soil erosion processes; management of forest ecosystem restoration; and even a handbook on stabilization activities in an emergency and rehabilitation of burnt forest areas in Galicia (Vega et al. 2013).

On the other hand, taking advantage of the new technologies, computer tools have been developed using statistical models, knowledge based systems, artificial intelligence, teledetection, and others, to elaborate risk indices to predict, in both at short and long term, the areas at risk of fires; the temporal location and the first days of the periods with more density of fires (forest fire peaks); systems that predict the fires' behavior and spreading; systems for the management of the humans and material, terrestrial or aerial resources for fire extinguishment; and systems for the management of the burnt areas until restoration, etc. (Alonso-Betanzos et al. 2003; Varela et al. 2006; Paz Andrade et al. 2010; Carballas et al. 2011; Carballas 2014) (Fig. 3.28). All this with the aim of supplying the governments with ample scientific information to help them make decisions regarding the reduction of forest fires to only sporadic and controllable ones and, therefore, to allow them to accomplish the main objective of the forest police: "to pretend a balance between the ambient functions of the mountains and the obtaining of satisfactory economical profits".

Similarly, forest fires in Asturias are considered to be one of the main environmental problems and a grave menace for one of the better conserved zones of biodiversity in Europe: their forest and forest resources and the ecosystems depending on them; the levels of environmental quality; and the live form of the Asturian people. The degradation of the soils derived from the progressive loss of SOM, structure and fertility, which can be very difficult or even impossible to recover, as well as the acceleration of erosion and the general degeneration of forest and landscape as a result of the forest fires and their frequent recurrence, particularly in the south of the western quarters of this Community, are probably the main environmental problem of this province. Between 1990 and 2012 the number of fires recorded were 34,077, affecting 2,180 km^2 of surface, of which 41,735 ha were arboreal vegetation. Since 1994, 38.19 % of the territory has been affected at least once by fire, and some areas have been burned six times in 10 years. The measures taken by the Government of the Principado de Asturias, mainly the annual Plan INFOPA, have improved the statistical parameters concerning the effectiveness of fire extinguishment, because the 25,534 ha of surface burned between 2002 and 2003 has gone down to 12,283 ha between 2004 and 2005;

in the same way, the mean value of the burnt surface per fire has been reduced from more than 7.0 ha to less than 3.0 ha, respectively, in the same periods (Álvarez García 2007).

To a much lesser extent, Cantabria had 9,344 forest fires recorded between 1990 and 2012, and 104,812 ha of burnt surface, 14,265 ha being of arboreal vegetation. The Basque Country suffered the same problem but at a lesser magnitude. Other regions of Spain, as well as other countries in the European community, such as France, Greece, Italy, and Portugal are also being affected by the forest fires.

3.4.1.1 Causes of Forest Fires

To find the reason for this sudden increase in the number of forest fires, historic antecedents and current causes should be considered.

Fire was always a work tool used by the farmers of the study zone, particularly the superficial burning of mountain vegetation to cultivate cereals, profiting from the ephemeral increase of chemical fertility as a result of the accumulation of ashes and, therefore, of nutrients from the burnt vegetation; in addition, worthless weeds and shrubs, with low nourishment value, are controlled. They also used the fire for burning the residues of the farm.

The climax Galician forest, a deciduous oak forest (*Quercus robur*) with its cortege of other deciduous species and its particular undergrowth, was the object of various deforestations, as the result of a high demand for wood for the army—to build ships, beams for the railways, and to produce vegetal carbon (charcoal) for the local forges or iron and steel foundries, even firewood for the tanneries, or simply deforestation due to the increase of extensive agriculture to match the increase in population. This caused the expansion of the scrub, mainly gorse (*Ulex* sp.) and heather (*Pteridium* sp.). On the other hand, the wood and the shrub material were used and consumed as combustible material for domestic uses and the scrub plants for bedding of the livestock with the aim of producing manure, which was the better and unique fertilizer for the agricultural soils. Besides that, the scrub, as well as its undergrowth, was pastured; for this, the gorse was extensively sowed by the farmers from the eighteenth century until the 1950s. The degradation of the forests due to deforestation was counteracted, in the 1950s, by a massive reforestation not only of mono-specific communities of pines and eucalyptus, two productive species of rapid growth, but also by pyrophyte species that favored forest fires and rarely with autochthonous species, usually slow-growing oak species.

The control of the vegetation managed by its domestic use and the production of manure was restrained at this period by diverse causes: the use of other fossil combustibles for the heating; the introduction into the market and the massive use of mineral fertilizers to the detriment of organic manures; the diminution of the extensive livestock; and the proliferation of industrial stables to raise livestock. All these factors decreased the pasture demand and the bedding system, and in turn produced another type of organic fertilizer —the slurry. The result of all this is the human abandonment of the mountains, their exploitation and care, and, consequently, the accumulation of enormous amounts of plant materials (biomass), some of them highly combustible, which favored the proliferation of forest fires.

Based on these historic facts, it is necessary to find the immediate reasons for the fires. Although meteorology (maximum temperature, relative humidity, precipitation, and wind speed and direction) has a great influence on the potential risk and propagation of the fires, it is not a direct cause—except for lightning. The same can be said of population distribution; according to the latest statistics, of the possible causes of fires—lightning, negligence (fires produced by farmers and stockbreeders, tourists, etc., that burn out of control), and intentionality (preparation of grasslands; transformation of scrubs in grassland; burning of scrubs in game reserves to produce herbs; extension of the horses free living; extermination of insects; quarrels between neighbors, etc.)—and other unknown reasons, intentionality, together with negligence, now account for more than 95 % of the fires. Therefore, it is obligatory to conclude that men and their socio-economic activities are always behind the fires and that their effects should be considered to be anthropogenic impacts (Carballas 2003, 2007, 2014).

3.4.1.2 Soils and Forest Fires

One of the main problems concerning forest fires is that society, and even the institutions responsible for firefighting, apparently ignore the fact that all the forest ecosystems are formed by the soil and the vegetation, two interdependent natural resources. The soils are the physical support of the vegetation and supply the plants with the water and nutrients needed for their growth: without soils, there is no vegetation. In turn, soils cannot develop without vegetation because the plant debris is the prime material of the SOM, a fundamental soil component directly related to soil quality; besides, the vegetation cover protects the soil against the direct impact of the rain and the plant roots fix the soil, thus protecting it from aerial and pluvial erosion processes. Moreover, the vegetation is a renewable resource, whereas the soil is not, because the formation of soil can take thousands of years. In spite of this, the society and even the governments are only concerned with the destruction of vegetation and do not see the degradation of the soil, mainly due to the burning of the SOM; and therefore, measures for the immediate protection of bare soil and the recovery of the burnt soil are not applied (Carballas 2014).

The destruction or diminution of the SOM by the fires, modifying its chemical and microbiological composition, negatively affects almost all the soils' properties, decreasing the soils' quality and altering its functioning (Figs. 3.29 and

Fig. 3.29 Soil affected by a severe wildfire: ash layer. Cabeza de Manzaneda, Orense, Galicia

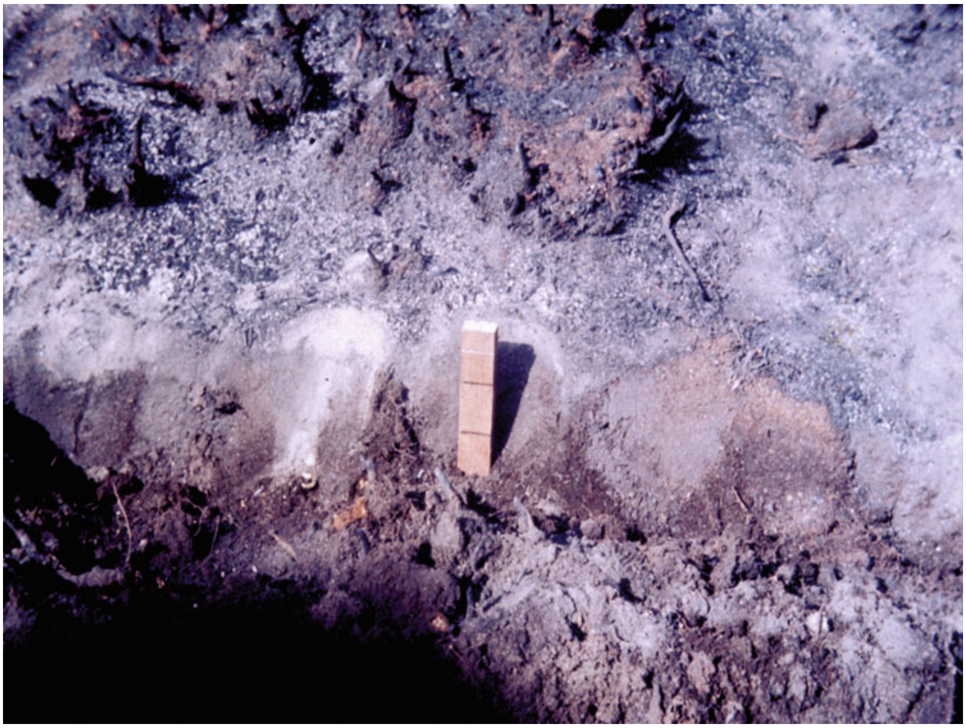


Fig. 3.30 Soil affected by a severe wildfire: detail. Cabeza de Manzaneda, Orense, Galicia

3.30). (Saá et al. 1993; Carballas et al. l994; Salgado et al. 1995; Acea and Carballas 1996; Carballas 1997; Prieto Fernández et al. 1998, 2004; Carballas et al. 2009a).

The destruction of the aggregates can diminish the porosity and then the infiltration of water in the soil, thus increasing the runoff and favoring the soil erosion and its catastrophic effects on other ecosystems (Figs. 3.31, 3.32, 3.33 and 3.34) (Carballas 2003, 2014; Villar et al. 2004a).

The fires destroy the more labile forms of C and N (hydro-soluble C and N and microbial biomass) as well as

Fig. 3.31 Soil erosion caused by post-fire erosion processes after a severe forest wildfire (Galicia 2006)

Fig. 3.32 Beach covered by sediments from the Xiabre Mountain (Pontevedra, Galicia, 2006), affected by a severe wildfire and post-fire erosion due to torrential rains after the fire

other compounds that are less labile, such as carbohydrates, lipids, and unhumified OM, and increase the most recalcitrant to microbial attack like lignin, humine, humic acids, organo-Al complexes and residual N, which are the major and more stable pool of the SOM, thus decreasing the mineralization speed of the organic C and N compounds and the liberation of nutrients for plant growth and therefore the formation of the vegetation cover (Vázquez et al. 1993; Fernández et al. 1997, 2001; Castro et al. 2006; Carballas et al. 2009a; Martín et al. 2012).

The micro-biota is destroyed by the fire but is rapidly recovered; however, the changes induced by the fire in the

Fig. 3.33 Beach covered by dead bivalves due to waters and sediments from a severe wildfire that has changed the salinity of the sea water (Galicia, 2006)

Fig. 3.34 Post-fire erosion after a controlled fire to transform a scrubland into grassland (Lugo, Galicia)

mass, activity, and diversity of the microbial population very much alter the normal soil functioning. The microbial biomass could never be recovered or would take some years after the fire, most likely due to the slow recovery of the fungi that contribute more to the biomass than bacteria. The impact of the fire on soils, including post-fire erosion, is particularly accused during the first year and then it tends to be attenuated; however, the recovery of some properties affected by the fire, even in the absence of soil erosion and without destruction of the total SOM, is not produced until 5–10 years after the fire, when the regeneration of the vegetation cover has been produced.

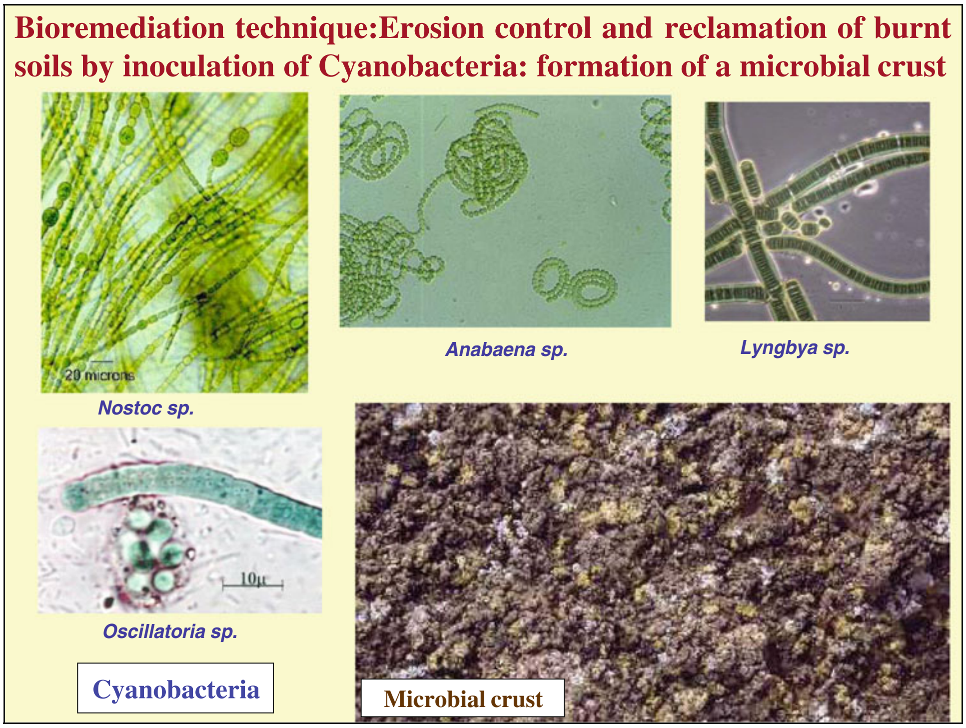
Fig. 3.35 Natural mulching that protects the burnt bare soil against post-fire erosion (Pontevedra, Galicia)

Fig. 3.36 Field experiment for evaluating two bioremediation techniques, seeding and mulching (straw) for burnt soil protection, erosion control (by geo-textile fences) and ecosystem rehabilitation (Orense, Galicia)

Consequently, the protection/recovery of the burnt soils, applying measures (mainly bioremediation techniques such as seeding or diverse organic mulching that promotes the regeneration of the microbial population and activity), the rehabilitation of the biological cycle of nutrients, the recovery of the vegetation and thus the content in SOM, are obligatory for avoiding the irreversible loss of soil and the rock outcrops (Figs. 3.35, 3.36, 3.37 and 3.38). In this way, forest ecosystems could again develop their potential richness and ecological functions, mainly the protection of waters and atmosphere and conservation of the diversity (Acea et al. 2003; Vázquez et al. 1996; Villar et al. 1998, 2004b; Carballas 2006, 2014; Castro et al. 2007; González-Prieto et al. 2008; Carballas et al. 2009b; Díaz-Raviña et al. 2010, 2012; Fontúrbel et al. 2012).

Fig. 3.37 Bioremediation techniques: straw application to burnt soil

Fig. 3.38 Bioremediation technique for erosion control and reclamation of burnt soils: inoculation of cyanobacteria (*Photo* María José Acea Escrich, IIAG-CSIC)



3.5 Major Soil Types in the Spanish Temperate Humid Zone

The study of the taxonomy, classification, and cartography of the soils of various countries over time has given rise to different soil classification models, all them looking for the best way to reflect the field's morphological observations and the analytical characteristics of the different soils in one system that permit pedologists to visualize a given type of soil without visiting its field profile; furthermore, they look for the system that reflects the relationships among the types of soil, whether genetic, topographic, or other. Consequently, almost every nation has built its own soil classification that is very well adapted to its soils—hence, the soil classifications of Kubiena for Spain and Germany, the French or the Italian soil classifications, the Soil Taxonomy of the USA, the various versions of the FAO soil classification, etc. Of course, in this way each nation has solved its own problem, but the main problem, which is to be able to compare the soils of two or more countries, necessitates knowing the classifications of both countries—whether their own classifications of each country or simply two different systems—has not yet been resolved.

The *World Reference Base (WRB) for Soil Resources 2006*, first updated in 2007 (IUSS Working Group WRB 2007), aims to solve this problem because it "is not meant to substitute for national classification systems but rather to serve as a common denominator for communication at an international level". This is the main reason for using this Soil Classification System in this chapter. Another reason is that although the first cartographic studies of the soils of the area were made using the *Soil Classification of Kubiena* (1952), since it matched the characteristics of the study zone, the more recent cartography was done using the FAO Soil Classification in the 1974 and 1998 versions. For some of the authors of these studies, the FAO classification was very familiar because on two occasions, 1981 and 1991, at the instance of the President of the Spanish Society of Soil Science, Prof. Roquero, and later on of Prof. Dudal (FAO), respectively, the two books, *Soil Classification FAO* and *Soil Map of the World-Revised Legend* were translated into Spanish by Carballas and other scientists, the last Spanish version being presented at the 14th International Congress of Soil Science of the IUSS held in Kyoto, Japan.

3.5.1 Reference Soil Groups (RSGs) and Second-Level Units of the WRB in the Study Zone

Following the rules of the WRB for soil classification, the Reference Soil Groups (RSGs—higher categorical level) and the second-level units (prefix and suffix qualifiers) for each RSG of the WRB (IUSS Working Group WRB 2006) of the soils identified in the Spanish Temperate Humid Zone, are listed in Table 3.1. From a total of 32 RGSs, 18 are found in the study area, indicating a high degree of soil diversity associated with a wide variety of soil forming factors.

Taking into account that there are pedologists who use the Soil Taxonomy, and that most of the soils of the study zone have a mesic temperature regime and an udic or ustic moisture regime (as established earlier), tentative correlations between the RGSs of the WRB (2006) and the SOIL ORDERS of the Soil Taxonomy (Soil Survey Staff 2010) are schematically collected in Table 3.2. Moreover, within each of the sections referring to the different RSGs, some comments will be included regarding these tentative correlations. It is necessary to emphasize that such equivalences are approximate, since although much of the diagnostic horizons, features or properties have a similar basis, there are significant qualitative and quantitative differences in their definition that prevent a direct correlation between both classifications.

3.5.2 Characteristics and Distribution of the Main Types of Soils Identified in the Zone

3.5.2.1 Histosols

The Histosols (from the Greek "*histos*," meaning "fabric"), characterized by an *histic* horizon (*H*), are soils formed by organic material in conditions of poor aeration generally due to its saturation with water in most years because the water level reaches or surpasses the soil surface. Consequently, the biological activity is limited and the processes of mineralization and humification of these materials are very low, the organic matter decomposes very slowly and accumulates until reaching a thickness of 100 cm or more.

In the study area, two types of Histosols, those commonly called peats, where only marshy vegetation such as mosses, mainly *Sphagnum sp.*, and herbs as *Carex* sp. and *Eriophorum* sp. can live, are well represented: Fibric Limnic Histosol, where *Sphagnum* predominates; and Ombric Sapric Histosol, where the predominant organic material consists of recognizable plant tissues. These formations spread in small patches in cold areas of high precipitation and low evapotranspiration, on acid rocks, occupying altogether a significant surface in the zone, mainly in Galicia, where there can be differenciated peats located in the central depressions (Terra Cha, Guitiriz, etc.) and in the mountain summits (Martínez-Cortizas and García-Rodeja 2001), or in areas of slope change (Montes del Buyo in Vivero, occupying the largest extension, Sierras Faladoira, Ancares, O Xistral) (Figs. 3.39 and 3.40). On calcareous rocks, the Ombric Sapric Histosol (Calcareous, Eutric) can also be found in the eastern zone of Asturias and in Cantabria. Also occupying small areas spread by the territory, Ombric Histosols (Dystric) are quite common near the peats or the Galician *brañas* (Fig. 3.41) (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b, 1986).

These soils are characterized by a high content of organic matter in the entire profile, acid pH and generally, except those developed on calcareous rocks, a low percentage of base saturation of the CEC, where the H^+ predominates due to the high concentration of organic acids and the high content of exchangeable Al^{3+} as can usually be found in soils developed on granites and other acid rocks (Table 3.3; see Appendix page 120).

According to the Soil Taxonomy, these soils are essentially equivalent to the homonymous order Histosols; besides, both units of the WRB can be correlated, in general

Table 3.1 Reference soil groups (RSGs) and categorical details identified from the WRB (2006) for the soils of the Spanish Temperate Humid Zone

Simplified concepts associated to Reference Soil Groups (Concepts based on WRB 2006)		**IUSS-WRB (2006)**	**Second-level units**	
		REFERENCE SOIL GROUPS (RSGs)	**Prefix qualifiers**	**Suffix qualifiers**
Soils with thick organic layers		***HISTOSOLS***	*Fibric-Limnic, Ombric-Sapric, Ombric*	*Calcaric, Dystric, Eutric* (and their combinations)
Soils with strong human influence	With long and intensive agricultural use	***ANTHROSOLS***	*Hortic, Escalic*	Mainly *Dystric* and *Eutric*
	Containing significant amount of artefacts	***TECHNOSOLS***	*Urbic, Garbic, Spolic*	–
Soils with limited rooting	Shallow or extremely gravelly soils	***LEPTOSOLS***	*Lithic, Rendzic, Andic, Mollic, Umbric, Cambic, Haplic*	*Calcaric, Humic, Dystric, Eutric, Oxyaquic, Skeletic* (and their combinations)
Soils influenced by water	Alternating wet-dry conditions; rich in swelling clays	***VERTISOLS***	*Mazic*	*Calcaric, Humic, Hypereutric* (and their combinations)
	Floodplains, tidal marshes	***FLUVISOLS***	*Salic, Tidalic, Gleyic, Mollic, Umbric, Haplic*	*Thionic, Anthric, Calcaric, Oxyaquic, Humic, Dystric, Eutric, Arenic* (and their combinations)
	Groundwater-affected soils	***GLEYSOLS***	*Histic, Mollic, Umbric, Haplic*	*Calcaric, Humic, Alumic, Dystric, Eutric, Silty, Clayic* (and their combinations)
Soils set by Fe/Al chemistry	With allophones or Al-humus complexes	***ANDOSOLS***	*Aluandic* *Leptic-Aluandic, Umbric-Aluandic, Umbric-Melanic*	*Anthric, Calcaric, Dystric, Eutric, Thixotropic, Clayic*
	Cheluviation and chilluviation	***PODZOLS***	*Gleyic-Placic, Umbric-Orsteinic, Albic, Umbric, Stagnic, Haplic.*	–
Soils with stagnating water	Submitted to stagnating water; with structural and/or moderate textural contrasts	***STAGNOSOLS***	*Mollic,Umbric, Haplic*	*Calcaric, Alumic, Dystric, Eutric, Siltic, Clayic* (and their combinations)
Accumulation of organic matter; high base status	Transition to more humid climate	***PHAEOZEMS***	*Rendzic, Leptic, Haplic*	*Anthric, Calcaric, Clayic* (and their combinations)
Soils with a clay-enriched subsoil	Low base status; high activity clays	***ALISOLS***	*Leptic-Cutanic-Umbric, Leptic-Umbric, Gleyic, Haplic*	*Anthric, Alumic, Humic, Clayic* (and their combinations)
	Low base status; low activity clays	***ACRISOLS***	*Haplic*	*Hyperdystric*
	High base status; high activity clays	***LUVISOLS***	*Cutanic, Leptic-Cutanic, Haplic-Cutanic, Andic, Haplic*	*Anthric, Manganiferric, Humic, Hypereutric, Oxyaquic, Profondic, Siltic, Clayic* (and their combinations)
Relatively young soils or soils with little or no profile development	With an acidic dark topsoil	***UMBRISOLS***	*Leptic, Leptic-Endogleyic, Endogleyic, Andic, Mollic, Cambic, Cambic-Mollic, Haplic*	*Anthric, Humic, Alumic, Hyperdystric, Endoeutric, Pachic, Skeletic, Siltic, Clayic* (and their combinations)
	Sandy soils	***ARENOSOLS***	*Protic, Haplic*	*Calcaric, Dystric*
	Moderately developed soils	***CAMBISOLS***	*Leptic, Endogleyic, Andic, Haplic*	*Calcaric, Alumic, Humic, Dystric, Eutric, Oxyaquic, Siltic, Clayic, Escalic* (and their combinations)
	Soils with no significant profile development	***REGOSOLS***	*Leptic, Endogleyic, Haplic*	*Calcaric, Humic, Dystric, Eutric, Skeletic, Siltic, Clayic* (and their combinations)

Table 3.2 Tentative correlations between the WRB (2006) and the Soil Taxonomy (2010) soil classifications for studying the soils of the Spanish Temperate Humid Zone

Simplified concepts associated to reference Soil Groups	**IUSS-WRB (2006)**	**USDA-Soil Taxonomy (2010)**
Concepts based on WRB 2006	**REFERENCE SOIL GROUPS (RSGs)**	**SOIL ORDERS** and more significative lower categories (fully or partially correlated)
Soils with thick organic layers	**HISTOSOLS**	**HISTOSOLS** (*Fibrists* and *Saprists* suborders)
Soils with strong human influence	**ANTHROSOLS**	**INCEPTISOLS** (*Plagganthrepts* and *Haplanthrepts* great groups) **ENTISOLS** (*Udarents*, *Ustarents*, *Udorthents* or *Ustorthents* great groups)
	TECHNOSOLS	**ENTISOLS** (*Udorthents* and *Ustorthents* great groups)
Soils with limited rooting	**LEPTOSOLS**	**ENTISOLS** (*Lithic* subgroups of: *Udorthents* and *Ustorthents* great groups; locally, *Xerorthents* great group) **INCEPTISOLS** (*Lithic* subgroups of: *Udepts* and *Ustepts* suborders; locally, *Xerepts* suborder) **MOLLISOLS** (*Lithic* subgroups of: *Rendolls*, *Udolls* and *Ustolls* suborders)
Soils influenced by water	**VERTISOLS**	**VERTISOLS** (*Uderts* and *Usterts* suborders)
	FLUVISOLS	**ENTISOLS** (*Udifluvents* and *Ustifluvents* great groups)
	GLEYSOLS	**ENTISOLS** (*Aquents* suborder) **INCEPTISOLS** (*Aquepts* suborder) **MOLLISOLS** (*Aquolls* suborder)
Soils set by Fe/Al chemistry	**ANDOSOLS**	**ANDISOLS** (*Udands* and *Ustands* suborders)
	PODZOLS	**SPODOSOLS** (*Humods* and *Orthods* suborders)
Soils with stagnating water	**STAGNOSOLS**	**ALFISOLS** (*Epiaqualfs* great group) **ULTISOLS** (*Epiaquults* great group) **INCEPTISOLS** (*Epiaquepts* great group)
Accumulation of organic matter, high base status	**PHAEOZEMS** Phaeozems	**MOLLISOLS** (*Udolls* and *Ustolls* suborders, mainly *Hapludolls*, *Haplustolls*, *Argiudolls* and *Argiustolls* great groups)
Soils with a clay-enriched subsoil	**ALISOLS**	**ULTISOLS** (*Udults* and *Ustults* suborders) **ALFISOLS** (*Udalfs* and *Ustalfs* suborders) **INCEPTISOLS** (*Dystrudepts* and *Dystrustepts* great groups)
	ACRISOLS	
	LUVISOLS	**ALFISOLS** (*Hapludalfs, Paleudalfs, Haplustalfs and Paleustalfs* great groups) **INCEPTISOLS** (*Eutrudepts* and *Haplustepts* great groups)
Relatively young soils or soils with little or no profile development	**UMBRISOLS**	**INCEPTISOLS** (*Humudepts* and *Humustepts* great groups)
	ARENOSOLS	**ENTISOLS** (*Udipsamments* and *Ustipsamments* great groups)
	CAMBISOLS	**INCEPTISOLS** (*Dystrudepts*, *Eutrudepts*, *Dystrustepts* and *Haplustepts.* Locally, *Dystroxerepts and Haploxerepts* great groups)
	REGOSOLS	**ENTISOLS** (*Udorthents* and *Ustorthents* great groups. Locally, *Xerorthents* great group)

terms, with Fibrist and Saprist suborders of the Soil Taxonomy.

3.5.2.2 Anthrosols

The Anthrosols are soils derived from the anthropogenic action on natural soils, mainly cultivation, mixing organic and mineral horizons, adding organic (mainly dung, poultry manure, slurry and other wastes) and mineral fertilizers, calcareous amendments to change soil pH in acid soils and even earth from other soils, thus creating a mineral surface horizon (*hortic* horizon) generally of more than 30 cm thick (Hortic Anthrosol). These soils occupy in the study zone most of the areas that are dedicated to the traditional agriculture, generally using the plough to till the earth for the various cultures. In general, they expand by areas of smooth topography, such as valleys, fluvial meadows, and flat surfaces, with well drainage or easy irrigation, slow slopes, and even the flat summits of mountains, mainly for transforming scrublands into grasslands (Galicia and the Basque Country), in which case controlled forest fires are frequently used to eliminate the plants of the scrubs (Figs. 3.42 and 3.43), and by the *rasa* in the coast (Asturias and Cantabria) (Fig. 3.44).

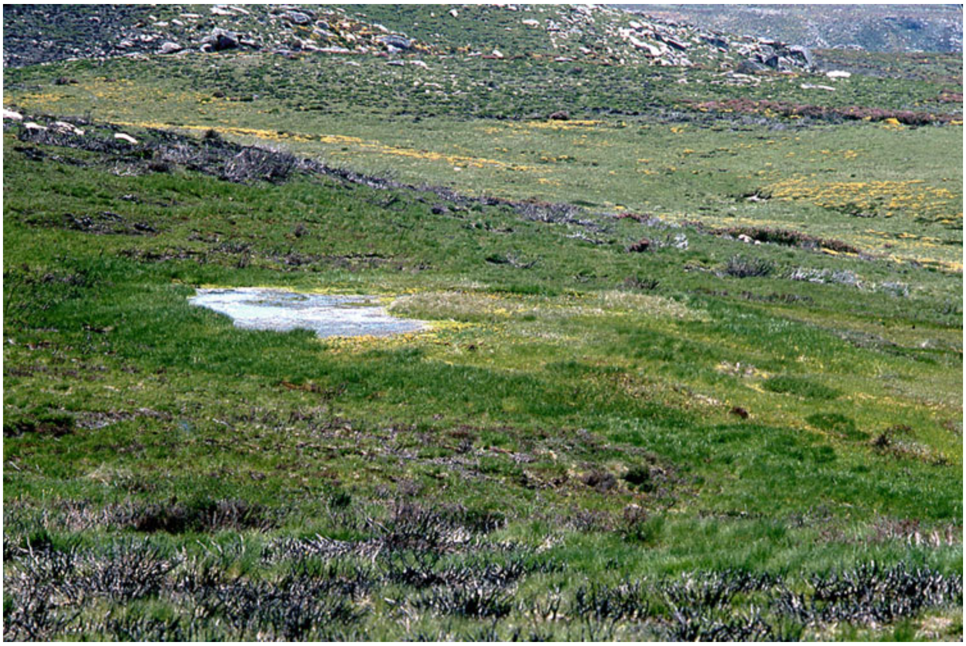


Fig. 3.39 Landscape of Fibric Limnic Histosol (Dystric). Sierra do Xistral, Galicia

Fig. 3.40 Ombric Sapric Histosol (Dystric). A Coruña, Galicia

In the abrupt slopes of the Miño, Sil and Bivei River shores (Galicia), the human activity has built narrow terraces in a series of gradins, transforming the natural soils into deep anthropogenic soils without differentiation of horizons and artificial elevation of the soil surface by the addition and mixing of earth of the same slope, rich in organic matter (Escalic Anthrosol) (see Fig. 3.26), and where the vine is cultivated or in the abandoned vineyards, other adapted cultures have been developed.

The Soil Taxonomy (2010) has accommodated the anthropogenic impacts on the various taxonomic levels and, specifically, with different diagnostic horizons and features as anthropic and plaggen epipedons, agric subsurface horizon, aquic conditions (anthric saturation), or densic materials (Wilding and Ahrens 2002). Depending on the differences in the definition of the diagnostic horizons between the WRB (*hortic, irragric, plaggic, terric*) and the Soil Taxonomy (*plaggen, anthropic*), the Anthrosols are roughly correlated to the anthrepts suborder in terms of the Soil Taxonomy system; additionally, many of them correspond to the Udarents, Ustarents, Udorthents or Ustorthents groups of Entisols.

3.5.2.3 Technosols

This type of soil is derived mainly from: (1) the accumulation of all kinds of urban organic wastes, such as urban refuse (Garbic Technosols); (2) artefacts and waste products of the diverse human activities (Urbic Technosols); and (3) dumps of mines and stone quarries (Spolic Technosols). The three types of Technosols are represented in Galicia and

Fig. 3.41 Ombric Histosol (Dystric). Sierra del Faro, Lugo, Galicia

Fig. 3.42 Anthropogenic action: grassland in the Sierra do Caurel, Lugo, Galícia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

in some cases (dumps of the ancient Mine of Cu, in Touro, and Mine of lignite in As Pontes, both in A Coruña), they have been rehabilitated, and in other cases, especially dumps of urban refuses have been revegetated (Leirós et al. 1993). Spolic Technosols derived from dumps of iron and steel industries as well as dumps from limestone, quartzite and particularly from the big exploitations of granite and slates in Porriño (Pontevedra) and O Barco (Orense), respectively, are spread all over the territory of Galicia (Macias Vázquez and Calvo de Anta 2001). The same classes of Technosols are frequently observed in other areas of the study zone.

No specific characteristics or horizons are defined in the Soil Taxonomy (2010) mainly in similar terms, other than those related to WRB's Technosols (especially 20 % or more of artefacts and other man-made elements), so there is no proper correlation between both classification systems in relation to these types of soils. In any case, the order Entisols (Udorthents and Ustorthents great groups) allows the

Fig. 3.43 Anthropogenic action: landslides in clayey soils under pastures. Eastern Guipúzcoa, Basque Country

Fig. 3.44 Anthropogenic action: intense cultivation in coastal areas (coastal *rasas*). Cabo de Peñas, North-Central Asturias

inclusion of Technosols at least partially. For mapping purposes, soils characterized as Technosols could be included in "miscellaneous areas," defined as areas having essentially no soil, some of them as a result of human activities, including dumps, scoria lands, slickens, or urban lands (Van Wambeke and Forbes 1986).

3.5.2.4 Leptosols

Leptosols (from the Greek "*leptos*," meaning "thin") are soils with mainly an AR profile, where the A horizon has a depth less than 25 cm on a continuous rock or a cemented layer. They are young soils, scarcely developed due to erosion or being the result of erosive processes of other soils, appearing frequently over all the territory, on all types of slow-weathering acid materials (granite, gneiss, quartzite, slates, schist rich in quartz, etc.), and usually located on flat summits or edges of the abrupt slopes of high mountains.

In general, due to its depth, arboreal vegetation, except for pines, have limitations to grow on them, usually being developed under diverse types of scrubs, prairies, and pastures suitable for livestock. Climatic conditions can also limit their evolution when they are located in humid and cold areas; they usually have good drainage, but those situated in the eastern part of the zone can become dry in summer. Numerous varieties of Leptosols can be found in the study zone. Lithic Leptosol is found when the rock starts within −10 cm of the soil surface or is located in the middle of rocky outcrops. On acid rocks, like those mentioned above, and sandstones, phyllites, lutites and volcanic rocks, they present an *umbric* horizon (*Umbric Leptosols*), whereas on calcareous rocks they may have a *mollic* horizon (Mollic Leptosols; Rendzic Leptosols), and on basic rocks (amphibolites, gabbros) they frequently present *andic* properties (Andic Leptosols). They can present a high percentage of gravels, in which case they have a *skeletic* character.

In the Basque Country, Leptosols developed from lutites (mostly classified as Haplic Leptosols), have higher pH values when used for grassland or arable (5–7) land than those for forestry (4–4.5) with high clay contents (30–43 %), and they frequently show *oxyaquic* features. The Leptosols developed from volcanic rocks are mostly classified as Umbric or Mollic Leptosols, because although they show a characteristic strong, fine, granular structure similar to that of the Andosols of the region, they may not have some of the characteristic *andic* properties, particularly when they have been, or still are, used for agriculture; in that case, they have a higher pH and base saturation and lower content of organic matter than when they remain forested. The Leptosol expand on the western mountains and the eastern sierras of the western part (Galicia and Asturias), and in the eastern part (Cantabria and the Basque Country) of the study zone, on acid rocks, whereas on calcareous rocks they occupy wide extensions in the eastern part of Asturias and Cantabria.

Table 3.4 (see Appendix page 121) shows the main characteristics of profiles located in the study area. On acid rocks these soils show sandy or sandy loam texture, very low in clay except on lutites, low pH, high content in SOM with a C/N ratio varying between 9 and 29, low base saturation, and high content in exchangeable aluminium (Al^{3+}), as well as in Al and iron (Fe) hydroxides (Figs. 3.45 and 3.46). By contrast, on limestone or dolomites, with or without active $CaCO_3$, the pH has variable values and the content of clay is higher (Fig. 3.47). In some Rendzic Leptosols, the concentration of Fe and Al hydroxides is high, favoring the decarbonation of these soils.

The main requirement of the Leptosols RSG (presence of coherent rock within 25 cm of the soil's surface), is partially covered by the Soil Taxonomy in defining "lithic" subgroups within various soil orders. Generally, the lithic contact is a diagnostic characteristic at the subgroup level if it is within 50 cm of the soil surface. Thus, a general correlation between both classification systems in the context of the Spanish Temperate Humid Zone, considers as Leptosols some soils classified in the lithic subgroups within Udorthents and Ustorthents great groups in Entisols; Udepts and Ustepts suborders in Inceptisols; and within Rendolls, Udolls and Ustolls suborders in Mollisols. Especially in southeast Galicia, and on the southern boundary of the study area, the presence of soils with *xeric* moisture regime should be noted, especially when dealing with very shallow soils: *lithic* subgroups of Xerorthents and Xerepts.

Fig. 3.45 Lithic Leptosol (Humic, Dystric) on quartzite. Pola de Allande, Asturias

Fig. 3.46 Haplic Leptosol (Humic, Dystric) on carboniferous schist. Guntín, Lugo, Galicia

Fig. 3.47 Rendzic Leptosol (Calcaric, Humic, Eutric) on limestone. Espinama, Cantabria

3.5.2.5 Vertisols

Vertisols are soils characterized by a “*vertic*” horizon (from the Latin “*vertere*,” meaning “to turn”) that is a clayed horizon with at least 30 % of clay in a thickness of 15 cm or more, a hard to very hard consistency and cracks of 1 cm or more wide when dry. These soils are scarcely represented in the study area; however, due to their singularity, three Mazic Vertisols (called Pelosols in Kubiena’s classification) from Galicia, Asturias and Cantabria, are included in Table 3.5 (see Appendix page 122) (Guitián Ojea et al. 1971, 1982b, 1985a, b). These are soils characterized by the lack of evolution of the profile due to the very compact clayed mineral horizon that prevent the movement of the water in the profile. Consequently, there is no differentiation in horizons and the parent material mostly conserves the characteristics of the clayed depot. The profile has a thin A horizon with variable SOM content over the mineral horizon, which presents well-developed cubic or prismatic structures, in summer forming very hard blocks that are very difficult to destroy, and wide retraction cracks that permit separating prismatic units from the profile (Figs. 3.48a–c and 3.49). These cracks are the only way to conduct the water down the profile; moreover, through these cracks there is illuviation of clay and organic matter colloids, located only in the superficial faces of the prismatic blocks, thus avoiding the loss of these colloids. In the humid periods, the water provokes a wide expansion of the clay, the cracks disappear, and the soil, saturated in water, constitutes a plastic mass of uniform aspect, reaching its total impermeability. As a result of the alternating phases of expansion and retraction of the

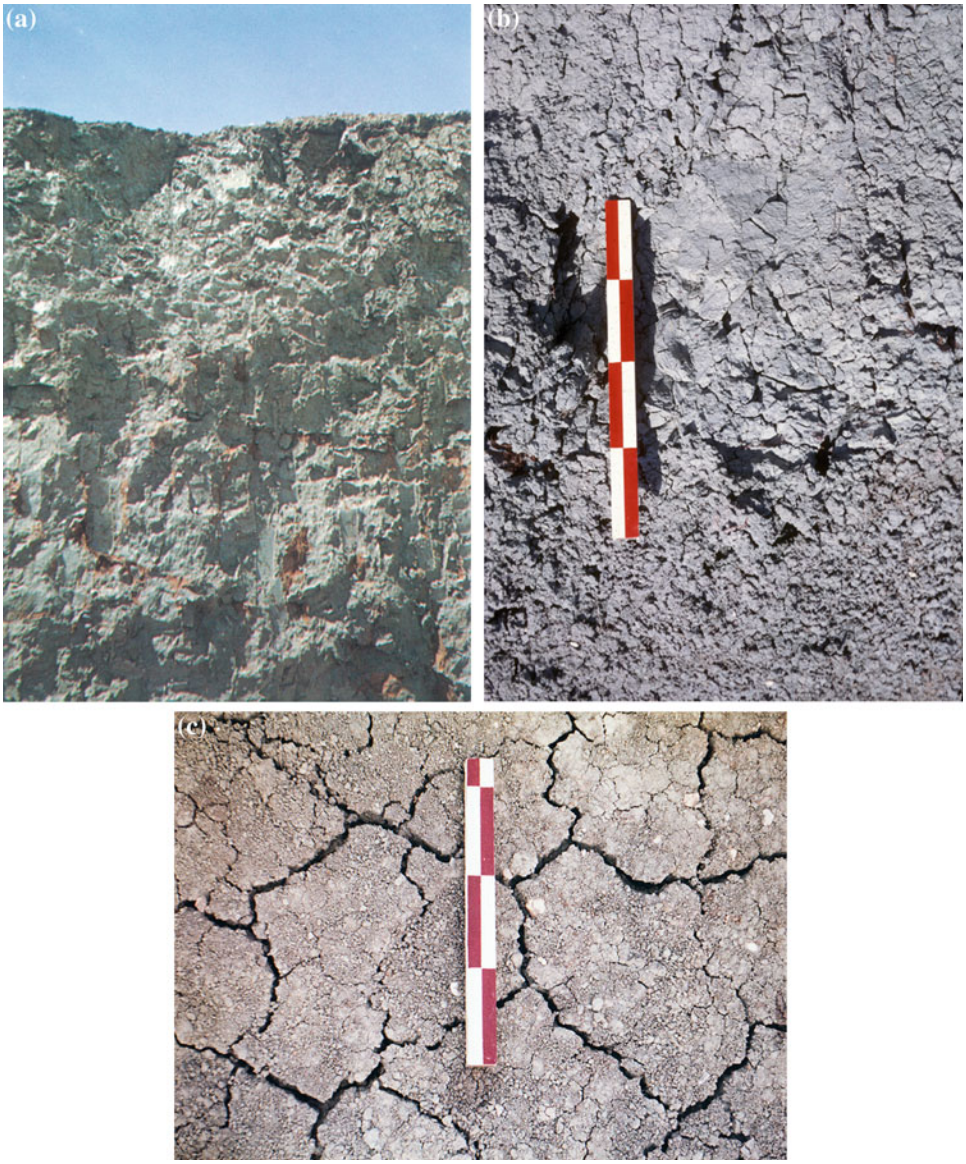


Fig. 3.48 Macic Vertisol (Humic, Hypereutric) on clay sediments: **a** profile; **b** self-mulching and slickensides; and **c** vertical view of the polygonal cracks in the soil surface. Cospeito, Terra Chá, Lugo, Galicia

clay, *slickensides* that can be easily observed are formed. In the non-calcareous Vertisols, the clay minerals are mostly kaolinite and illite, while in the calcareous ones, chlorite and vermiculite are mainly found, together with kaolinite; in the profile Figs. 3.49 and 3.50, the attapulgite predominates. The lack of expansive capacity in the clay minerals of the acid soil is counterbalanced by a higher percentage of clay in this soil. The soils always show *self-mulching* in the surface—that is, tendency to form small granular aggregates from the large structural blocks of the whole mass and sometimes, but not always, they present *gilgai* microrelief.

The WRB's soil reference group of Vertisols have virtually the same requirements as the homonymous order in the Soil Taxonomy, in terms of such key features as clay content, presence of wedge-shaped aggregates and slickensides, or thickness. In the context of the Spanish Humid Zone, the study Vertisols can be considered within the Usterts and Uderts suborders.

3.5.2.6 Fluvisols

Fluvisols (from the Latin "*fluvius*," meaning "river") are soils formed by *fluvic* material, that is, fluviatile, marine, or lacustrine sediments, these materials being received now or in the past; characteristic of this type of soil is the stratification of the sedimentary materials and then homogeneity of the profile or the irregular decreasing of the organic matter and other soil properties. In the study zone, they are represented by formations developed in the coastal marshes and estuaries of the rivers, and in the fluvial valleys. In the areas influenced by the tides, two subtypes have been defined: Salic Tidalic Fluvisol (Thionic) (Sapropel soil in Kubiena's classification) when it is permanently affected by the tides

Fig. 3.49 Mazic Vertisol (Humic, Hypereutric) on clay (attapulgite) sediments. Depression of Roupar, Lugo, Galicia

Fig. 3.50 Ferruginous separations in the Mazic Vertisol of Roupar (*Photo* María Teresa Barral Silva 1987)

and therefore with reduction conditions and production of H_2S that precipitates as iron sulphide (Figs. 3.51 and 3.52); and Salic Tidalic Fluvisol (Arenic) (Marsh soil in Kubiena's classification) when it is sporadically affected by the tides, which occurs mainly in the period of high tides, and shows a higher degree of evolution to terrestrial soils (Fig. 3.53) (Cabaneiro Albaladejo 1979; González-Prieto et al. 1989). These soils, colonized by halophytic plants, are particularly abundant in the *rías* of Galicia (Catoira, Cedeira, Mera, and others), in the estuary of the Saja River near San Vicente de la Barquera and the Bays of Santander and Santoña (Cantabria), and the Bay of Biscay (Basque Country) (Muñoz Taboadela et al. 1966; Leirós de la Peña and Guitián Ojea 1981a, b; Guitián Ojea et al. 1982b, 1985a, 1986).

Very much extended in the whole study zone are the soils developed from fluviatile and lacustrine sediments and located mainly in alluvial plains and fluvial valleys (Fig. 3.54), with [(Gleyic Fluvisols, Gleyic Mollic Fluvisols, Haplic Fluvisols (Oxyaquic)] or without (Umbric Fluvisols, Mollic Fluvisols, Haplic Fluvisols) reducing conditions in some parts of the profile, sometimes relating to the presence of the water table at shallow depths. These soils are mostly

Fig. 3.51 Salic Tidalic Fluvisol (Thionic, Humic, Dystric). Estuary of the Eume River, Ría de Puentedeume, A Coruña (*Photo* Ana Cabaneiro, IIAG-CSIC)

Fig. 3.52 Tidalic Fluvisol (Humic, Dystric). Estuary of the Eume River, Ría de Puentedeume, A Coruña. Galicia (*Photo* Ana Cabaneiro Albaladejo, IIAG-CSIC)

used as arable land or grassland (Figs. 3.55 and 3.56), in which case as a result of fertilization practices they can be in the Eutric or even Calcaric class (Fig. 3.57), and are rarely used for forest plantations.

The characteristics of these soils in the study zone are shown in Table 3.6 (see Appendix page 123). The pH value of the surface mineral horizon varies mainly between 5 and 8, and the SOM content between 2 and 11 %. These soils frequently have high values of bulk density, both in the surface (1.4–1.7 g cm^{-3}) and subsurface mineral horizons (1.6–1.7 g cm^{-3}), even if they have been under forest plantations for the past 40 years. The main minerals in the clay fraction are kaolinite, illite and vermiculite.

Characteristics associated with soils developed under alluvial deposition are considered in the Soil Taxonomy on different taxonomic levels, on the basis of an irregular decrease in organic matter with depth and gentle slopes. In the case of Entisols, such characters are defined at suborder level in Fluvents (with no significant reducing conditions, Udifluvents and Ustifluvents great groups), and are defined at the great group level in Aquents (Fluvaquents, with significant reducing conditions) and Wassents (Fluviwassents, in areas with permanent high water potential). In tidal areas, various taxa within the Entisols order are established, on the basis of the presence of sulphidic materials combined with fluventic properties (i.e., Sulfic Fluvaquents and Sulfic

Fig. 3.53 Salic Tidalic Fluvisol (Humic, Eutric, Arenic). Estuary of the Umia River, Ría de Arosa, Cambados, Pontevedra, Galicia (Photo from Ana Cabaneiro Albaladejo, IIAG-CSIC)

Fig. 3.54 Haplic Fluvisol (Humic, Dystric). Alluvial terrace of the Mero River. La Coruña, Galicia

Fluviwassents subgroups). Furthermore, fluventic characteristics are defined in low taxonomic categories (subgroups) within various soil orders, as Fluventic and Fluvaquentic subgroups in numerous great groups of Inceptisols and Mollisols.

3.5.2.7 Gleysols

Gleysol*s* (from the Russian "*gley*," meaning pasty soil mass due to excessive water) are soils characterized by a permanent but oscillatory water level that only exceptionally reaches the organic surface horizon of variable thickness. Under the organic horizon, which can be *umbric* (Umbric Gleysols), *mollic* (Mollic Gleysols), or even *histic* (Histic Gleysols), a mineral horizon, 25 cm or more thick, is developed that presents in some parts reducing conditions and a gleyed color pattern throughout the horizon. Usually this horizon is differentiated in a brown oxidation horizon due to the oxidized iron compounds, followed by a reduction horizon of gray, green or blue color, generally of high thickness, where the iron compounds are in ferrous forms, that is in reduced forms like other elements such as manganese (Mn) and even N and S. This sub-horizon is permanently water saturated, indicating the lowest depth of the water table; here, the ferrous iron, Fe^{2+}, soluble in water, is mobilized during the humid season, being transported to the oxidation horizon where it is irreversibly deposited in insoluble ferric forms during the periods of aeration in the dry season (Figs. 3.58, 3.59 and 3.60).

Fig. 3.55 Haplic Fluvisols under grasslands in Cornellana, Narcea River, Western Asturias

Fig. 3.56 Haplic Fluvisol (Anthric, Humic, Dystric). Alluvial terrace on gneiss. Sás de Penelas, Orense, Galicia

These soils are developed on acid and basic geological materials in areas of flat topography and difficult drainage, and they are usually, but not always, rich in clay or fine mineral fractions, related to clayed sediments, and in SOM. They can be used to cultivate cereals but are frequently under permanent grassland due to the presence of the water table that guarantees enough humidity in the soil surface even in the dry seasons. The Gleysols are present in the study zone in variable extent, but generally in small patches (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b, 1986); their main characteristics are shown in Table 3.7 (see Appendix page 125).

Similar diagnostic properties to those defining the Gleysols RSG are basically considered within all of the Soil

Fig. 3.57 Haplic Fluvisol (Humic, Eutric). Cares River alluvial plain, Mier, Eastern Asturias

Fig. 3.58 Umbric Gleysol (Humic, Dystric) on sandstone. La Espina, Asturias

Fig. 3.59 Umbric Gleysol (Humic, Alumic, Eutric) on amphybolite. Monte Castelo, La Coruña, Galicia

Fig. 3.60 Umbric Gleysol (Humic, Dystric) on sediments of the Antela lagoon. Ginzo de Limia, Orense, Galicia

Taxonomy's mineral soil orders described at the Spanish Humid Temperate Zone, thus establishing high taxonomic categories as soil suborders: Aqualfs, Aquands, Aquents, Aquepts, Aquolls, Aquods or Aquults, and also applied to lower categories (great groups and subgroups). Nevertheless, significant differences are evident between the specific requirements for the WRB's Gleysols and for the different suborders according to Soil Taxonomy, thus impeding an accurate correlation between the two systems. The former include diagnostic properties such as "reducing conditions" and "gleyic color patterns" that can be defined with few field and laboratory criteria, while the latter include numerous and complex definitions gathered in "aquic conditions," and other complementary requirements. Some common criteria may, however, be established in determining the presence of Fe^{2+} (use of alpha, alpha-dipyridyl field test, measures of grayish-greenish colors), as indicators of reducing/ redoximorphic soil features.

3.5.2.8 Andosols

The Andosols (from the Japanese "*an*," meaning "dark," and "*do*," meaning "soil") are soils containing layers 30 cm or more thick, starting within 25 cm of the soil surface, with *andic* properties. These properties that are commonly derived from moderate weathering of pyroclastic deposits can be also developed from other silicate-rich materials under acid weathering in humid climates (García-Rodeja et al. 1984, 1987; Verde et al. 2005). They present high concentrations of Fe and Al oxides and stable organo-mineral complexes or short-range-order minerals such as allophanes; usually, they have a high content in very dark organic matter, low bulk density, fluffy structure, and silty loam or finer texture, showing thixotropic conditions and hydrophobia after drying processes or periods of dryness, high variations of the cation exchange capacity depending on pH, and high phosphate retention capacity. These specific properties are recognized by the Basque farmers with various names in Basque (e.g., *txindurri lurre*, which means *ant-soils*, and may reflect their high porosity), or related to plants that live on them (e.g., *kiru lurre*, which refers to the legume, *Adenocarpus complicatus* (*L.) Gay*, that grows spontaneously on these soils).

From the viewpoint of fertility, the capacity to form complexes immobilizes two of the main nutrients: nitrogen (N), forming very stable complexes, thus diminishing the available N; and phosphorus (P), provoking the immobilization not only of the available P of the soil, but also that of the fertilizers (Trasar-Cepeda et al. 1990). Due to this, natural vegetation on these soils that have *andic* properties from the soil surface is generally skeletal or degraded bushes. Nevertheless, their high values of total (60–70 %) and aeration (30–40 %) porosity make these soils particularly suitable for fruit orchards. Similarly, the growth of *Pinus radiata* shows a very specific behavior, as it does not decrease significantly with altitudes up to 600 m, but is particularly sensitive to summer drought and to the degradation of the soil's physical properties (Olarieta et al. 2006).

Agricultural practices, such as tillage, liming or fertilization, tend to suppress the *andic* soil properties (Verde et al. 2005); these practices are also reflected in other properties, and thus in the surface mineral horizons of forest plantations, the pH varies in the 4–5 range, except in those plots that have been used for agriculture at some point in history, where it may reach values of 7. Quartz is the predominant mineral in the clay fraction of Andosols on volcanic rocks, but vermiculite appears as one of the main minerals in the clay fraction of these soils, which is not the case in soils from all other parent materials; illite and chlorite are the other main minerals present in that clay fraction.

Soils with *andic* properties are found in the eastern part of the study zone, the Basque Country, on volcanic rocks, mainly Leptic Aluandic Andosols (Dystric) and Umbric Aluandic Andosols.

In the western extreme, Galicia, on various acid rocks and some basic rocks, a thoroughly researched Umbric Melanic Andosol (Dystric, Thixotropic) (called *Atlantic Ranker* in Kubiena's classification), is expanded in small patches in diverse areas (Fig. 3.61) (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1968a, Guitián Ojea et al. 1982b, 1986; Carballas et al. 1983b).

This particular Andosol, found in Galicia, shows a high concentration of Fe and Al hydroxides, organo-Fe and particularly organo-Al complexes and amorphous minerals (allophanes) (Carballas et al. 1983a). They have a low bulk density (0.7–0.9 g cm^{-1}), sandy texture (Carballas et al. 1984), and the clay fraction, always in the minority, is formed by degraded micas and vermiculite, together with small quantities of phyllosilicates 1:1 and gibbsite (Carballas et al. 1986). The black SOM has a high percentage of humification that predominates over biodegradation, thus favoring the accumulation of organic matter and producing humic substances, fulvic and humic acids, already from the surface of the profile, with a low FA/HA ratio; there are no illuviation processes of these elements and complexes due to the high stability of the organo-Al complexes (Carballas et al. 1979, 1983a; Jacquín et al. 1978; Acea and Carballas 1987). They always show signs of fire (carbon), and from detailed analyses of all the soil components, including micro-morphological analysis, it was concluded that they were formed by the accumulation of organic and mineral materials from soils located in the upper part of the slope, which are the result of edaphogenetic processes, and deposited in areas where the slope is smooth or at the bottom of the slope, where they have followed their evolution likely in other climatic conditions (Carballas 1982; Kaal et al. 2008).

Due to the abundance of Al in the soils of the zone, particularly in the soils of Galicia, almost all the soils with abundance of SOM have a positive reaction to the NaF independently of the parent material, frequently showing *andic* properties, accentuated in soils over basic or ultrabasic rocks (Fig. 3.62) (García-Rodeja et al. 1984, 1987; Macías Vázquez et al. 2013).

Fig. 3.61 Umbric Melanic Andosol (Dystric, Thixotropic) on granite of two micas. Monte Xiabre, Pontevedra, Galicia

Fig. 3.62 Genesis of an Andosol on a ferrallitic soil on metabasic rocks; the polycyclisme is observed by the presence of a stone line. Ultrabasic Complex of Capelada-Cabo Ortegal, La Coruña, Galícia

Table 3.8 (see Appendix page 126) shows the main characteristics of some Andosol profiles.

Andic properties are defined in a substantially common way in both WRB and Soil Taxonomy classification systems, in terms of high Al+Fe content (oxalate extracted), low bulk density, high phosphate retention capacity, and organic carbon content (less than 25 %). Within the context of the Spanish Temperate Humid Zone, soils with such properties can be classified within the *Andisols* order of Soil Taxonomy and, specifically, in Udands and Ustands suborders.

3.5.2.9 Podzols

The name Podzols (from the Russian "*pod*," meaning "below," and "*zola*," meaning "ash") refers to white horizons like the *albic* horizons. However, in the BWR these soils are characterized by the presence of a *spodic* horizon (from the Greek "*spodos*," meaning wood ash). These soils are formed by the illuviation of amorphous substances composed of SOM, Fe and Al from the superficial alluvial horizon (*Ae* or *E*), that like that losses these colloids and then becomes white or gray, which is the color of the minerals of the coarse particles that remain there (mainly quartz), forming an *albic* horizon. Below this horizon, a brownish-black to reddish-brown *spodic* horizon (*Bs*) is developed, due to the illuvial materials, organic matter, Fe and Al, deposited there because they become insoluble; in this horizon, a Bh horizon can be differentiated by the accumulation of the alluvial organic matter, and a *Bs* horizon rich in sesquioxides of Fe and Al. Over the *albic* horizon

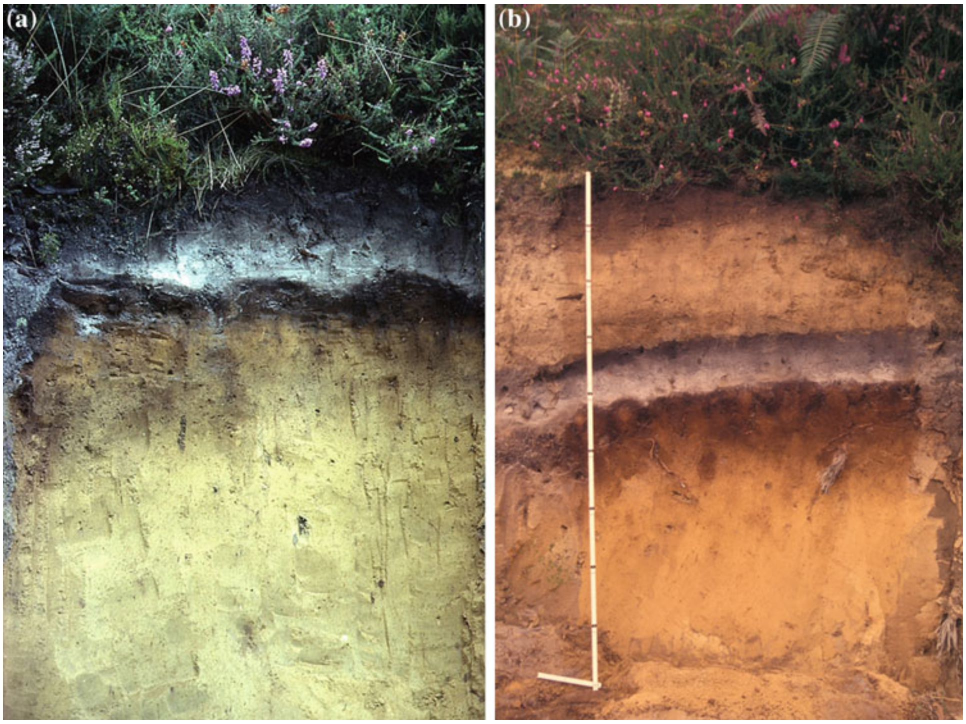


Fig. 3.63 Haplic Podzol on sandstone (**a**); Haplic Podzol buried by a Haplic Cambisol (Humic, Alumic, Dystric) (**b**). Ferreira del Valle de Oro, Lugo, Galicia

Fig. 3.64 Haplic Podzol on sandstones. Erandio, Vizcaya, Basque Country

Fig. 3.65 Umbric Podzol on quartzites. El Barquero, La Coruña, Galicia

they usually have an organic horizon that is not very thick, but they can also exhibit an *umbric* horizon. In the study zone, Haplic, Gleyic, Stagnic, or Umbric Podzols have been identified (Figs. 3.63a, 3.64, 3.65, 3.66 and 3.67). In some cases, the separation of Fe is so net that an enduring, cemented horizon (Placic Podzol) or a petrified horizon (*orstein*) (Orsteinic Podzol) is formed (Guitián Ojea and Carballas 1968b; Macías et al. 1987).

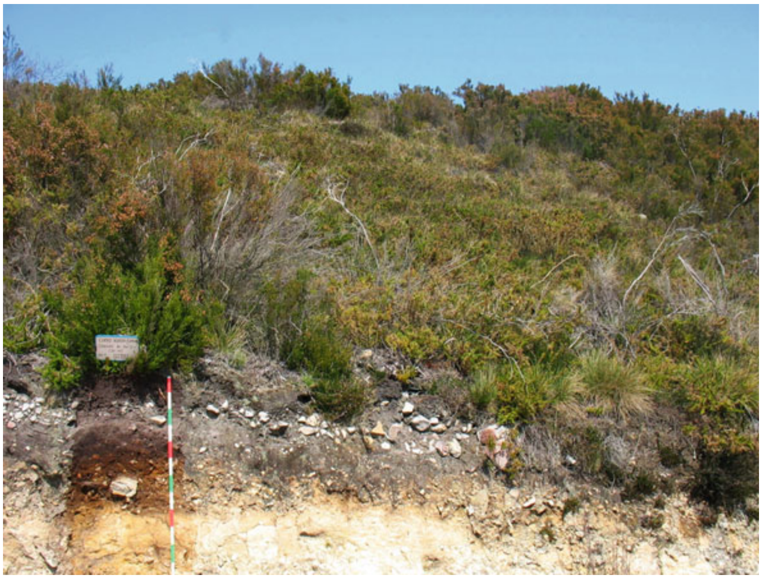


Fig. 3.66 Umbric Podzol in quartzite colluvium, under characteristic vegetation: shrubland with heaths (*Erica sp.*) and gorses (*Ulex sp.*). Onís, Eastern Asturias

Fig. 3.67 Umbric Podzol on altered schist very rich in quartzite. Sanfitoiro, Orense, Galicia

The composition of the vegetal residues that the different arboreal and busted species supply to the soil varies greatly, influencing the form of humus produced, and conditioning the mobilization of Fe and Al oxides and clays, which mainly occurs by the water extracts of *Erica* sp. plants. In fact, in previous studies (Carballas and Guitián Ojea 1966) of the podzolizant action of water extracts of various vegetal debris (especially leaves), as well as their mineral composition and their variation when they are incorporated into the soil, it was concluded that the mixed forest of deciduous leaves contributes to the creation of eutrophic soils of *mull* humus, whereas *Erica* sp. are characterized by its podzolizant power. Nevertheless, these soils that develop in humid and coal areas, under heaths, where *Erica* sp. predominates, or gorse scrubs, can be found only in areas with very acidic geological materials poor in bases—mainly sandstones and quartzite—under all types of scrubs, alone or reforested with pines, being these types of rocks the main formation factor for Podzols. Consequently, despite the potential capacity of the study zone for this type of soil, they occupy a small surface (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1982b, 1985a, b, 1986). They are sandy textured, with acid pH, poor in basic cations, and have low fertility.

Table 3.9 (see Appendix page 127) shows the main characteristics of some profiles of Podzols, and Fig. 3.63a shows the Profile 1131 described in the table, whereas Fig. 3.63b shows the same Podzol profile buried by a Haplic Cambisol (Humic, Alumic, Dystric) developed over the Podzol of Fig. 3.63a as parent material, from materials coming down the slope of the mountain, which has been developed under pedogenetic processes in different climatic conditions (Abadín et al. 1998).

The diagnostic criteria of a *spodic* horizon, according to the WRB, coincide with the definition of the homonymous horizon in the Soil Taxonomy, except for minor aspects. Thus, the correlation between the WRB's Podzols and the Spodosols order of the Soil Taxonomy is practically direct, depending on the characteristics delimited by the moisture regimes. In the area of the Spanish Temperate Humid Zone, the study soils correspond to Humods and Orthods suborders of the Soil Taxonomy, whereas Podzols with placic and

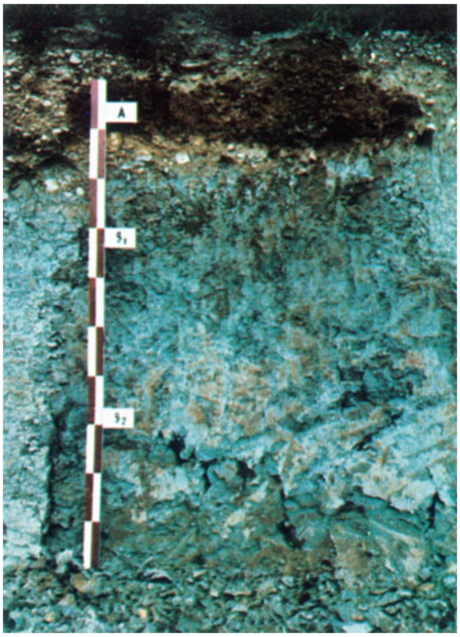


Fig. 3.68 Haplic Stagnosol (Dystric, Clayic) on clayed tertiary sediments. Terra Chá, Lugo, Galicia

ortsteinic qualifiers correspond approximately to Placohumods and Placorthods great groups.

3.5.2.10 Stagnosols

These soils are characterized by the presence of reducing conditions for some times over the year, in some parts within −50 cm of the mineral soil surface, and consequently a *stagnic* color pattern (from the Latin "*stagnare*", meaning "to stagnate") in half of more of the soil volume. The Stagnosols are typical of humid temperate zones, usually with clay loam or clay textures, compact, and characterized by an alternating oscillation of stagnancy due to their scarce interne permeability. In the dry periods, the upper mineral soil layers are free of water. The *A* horizon, which could be an *umbric* or *mollic* horizon, although it usually does not have the necessary thickness, is followed by a mineral horizon of gray to green, with some ochre or dark brown spots, developed over a more compact and impermeable horizon than the preceding one with nodules and mottled in various greens, blues, etc., colors that resemble some kinds of marble (Fig. 3.68). This relative impermeability with regard to the upper mineral horizon, provokes the accumulation of water in the latter horizon, which did not find free drainage. This stagnant layer (*nappe perchée*, in the French soil classifications) is the necessary condition for the formation of the Stagnosols. During the dry period, this layer disappears almost totally by evaporation and the soil surface becomes dry (Guitián Ojea et al. 1982b).

Fig. 3.69 Haplic Stagnosol (Humic, Dystric) on recent sediments. Niñodaguia, Orense, Galicia

Stagnosols are widely spread over the study zone, in valleys originated by erosion of soils mainly developed on acid and basic rocks, producing clayed sediments and Haplic or Umbric Stagnosol (Alumic, Dystric, Clayic) or on calcaric rocks, giving rise to Haplic Stagnosol (Calcaric, Eutric, Clayic) or other classes (Figs. 3.69 and 3.70). (Muñoz Taboadela et al. 1966; Guitián Ojea and Carballas 1982; Guitián Ojea et al. 1985a, b). Table 3.10 (see Appendix page 129) shows the main characteristics of some Stagnosol profiles.

Diagnostic properties that define Stagnosols are considered within different Soil Taxonomy Orders; in the study area, they correspond to soils with conditions similar to "episaturation," based on a "water table perched on top of a relatively impermeable layer." These are soils with remarkable hydromorphic features, contrasted horizons, clay-textured, and without an ***albic*** horizon: Alfisols (Epiaqualfs great group), Ultisols (Epiaquults great group), and Inceptisols (Epiaquepts great group).

3.5.2.11 Phaeozems

The Phaeozems (from the Greek "*phaios*" meaning "dark" and the Russian "*zemlja*" meaning "earth") are characterized by the presence of a *mollic* horizon (from the Latin "mollis" meaning "soft") and a base saturation of the CEC of 50 % or

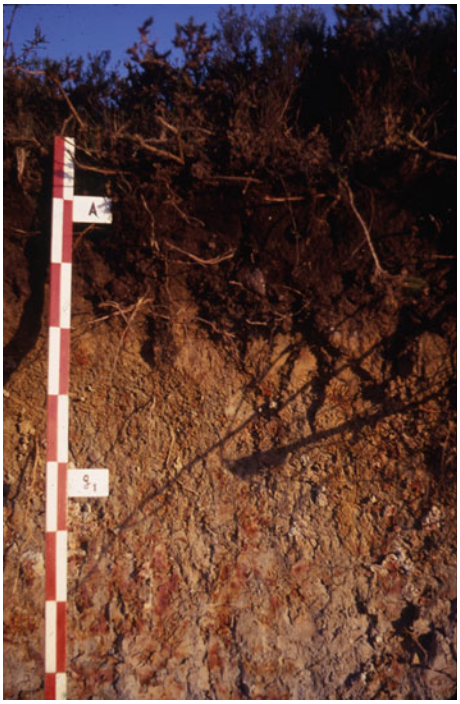


Fig. 3.70 Haplic Stagnosol (Humic, Dystric) on schist. La Castellana, A Coruña, Galicia

more, saturated by basic cations. In the study zone they are scarce due to the high precipitation that can provoke the leaching of the basic cations with the infiltration water and the decrease of the pH, in which case the *mollic* horizon tended towards an *umbric* horizon. However, small patches of recently developed Phaeozems can be found in Galicia, over ultrabasic rocks (Leptic Phaeozems) such as serpentines, rich in magnesium (Fig. 3.71) (Macias Vázquez et al. 2013), and on some calcareous rocks such as limestone, dolomites and others, Leptic or Haplic Phaeozems (Calcaric, Clayic) (Fig. 3.72), and under grassland on the latter rocks, Phaeozems (Anthric, Calcaric) in Asturias, Cantabria, and the Basque Country. Most of them have a clay texture, high pH (6–8), and SOM content ranging from 2 to 10 %.

Table 3.11 (see Appendix page 130) shows the main characteristics of some profiles of Phaeozems.

The requirements of a *mollic* horizon, according to WRB, are significantly equivalent to those that define the homonymous horizon of the Soil Taxonomy. A high base saturation of the exchange complex throughout a large soil thickness is also a common requirement between Phaeozems and the Mollisols order of the Soil Taxonomy, although the latter is somewhat more demanding on the thickness in which this high saturation occurs. Likewise, the absence of a *calcic* horizon in the Phaeozems that characterizes the RSGs of Chernozems and Kastanozems should be noted. Consequently, and taking into account the context of the Spanish Humid Zone, a proper correlation between the Phaeozems and the Udolls and Ustolls suborders within Mollisols, and specifically, with Hapludolls, Argiudolls, Paleudolls, Haplustolls, Argiustolls, and Paleustolls great groups of the Soil Taxonomy, can be established.

3.5.2.12 Alisols and Acrisols

The Alisols (from the Latin "*alumen,*" meaning "alum") and the Acrisols (from the Latin "*acer,*" meaning "very acidic") are both characterized by a subsurface *argic* horizon (from

Fig. 3.71 Leptic Phaeozem on serpentinic microkarst. Sierra de La Capelada, A Coruña, Galicia

Fig. 3.72 Haplic Phaeozem (Calcaric, Clayic) on limestone. Santander, Cantabria

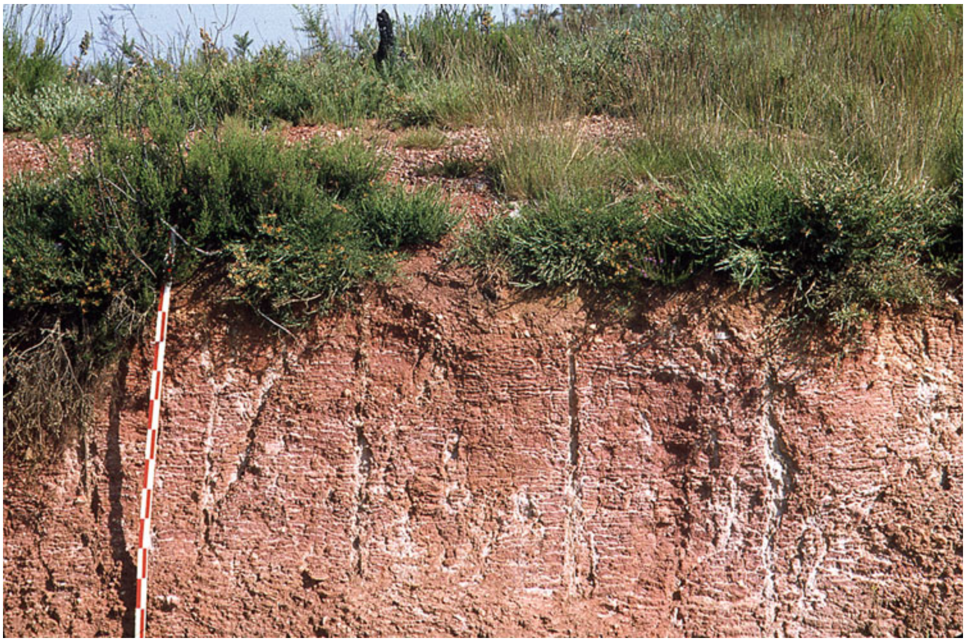
the Latin "*argilla*" meaning white clay), whose main characteristic is a distinct higher clay content than the overlying horizon; this textural differentiation is due to various causes, mainly illuvial processes. Such *argic* horizons must have a base saturation of less than 50 %, in most parts between −50 and −100 cm. The properties that distinguish both soil reference groups are based on the cationic exchange capacity (CEC) referring to the clay fraction. Thus, in the case of Alisols, the CEC has to be at least 24 $\text{cmol}_c\ \text{kg}^{-1}$ clay, while Acrisols show lower values as a consequence of dominating low-activity clays. The Alisols mainly develop on basic rocks, while the Acrisols generally develop on acid rocks or ancient sediments.

In the study zone, the Alisols are scarcely represented, and commonly developed on acid rocks, while the Acrisols are even more restricted, which justifies presenting both soil groups in the same table. They can be found spread in small patches in the territory on various types of rocks, as can be seen in Table 3.12 (see Appendix page 131), where six profiles, five Alisols and only one Acrisol were included.

In the Basque Country, they have been found on dolerite and classified as Leptic Umbric Cutanic Alisols (Humic), showing in some cases an *A-Bw-Bt* profile with a *cambic* horizon overlying the *argic* horizon; although the clay content does not change significantly with depth and it is always in the 30–40 % range, clay coatings are prominent in the *Bt* horizons; the pH values decrease with depth in the mineral surface horizon in soils that were used for agriculture in the past, while they increase at depth in soils never cultivated.

The other profiles are developed on acid rocks, exhibit a clear *Bt* horizon and leaching of basic cations, mainly Ca, and show a base saturation of less than 50 % in most parts between −50 and −100 cm. Leptic Umbric Cutanic, Haplic, Leptic Umbric, and Umbric Gleyic Alisols, as well as Haplic Acrisols (Fig. 3.73), in the Humic or Clayic clases, have been differentiated (Iñiguez et al. 1980; Guitián Ojea et al. 1982b).

Fig. 3.73 Haplic Acrisol (Humic, Eutric, Clayic) on tertiary sediments. Puertomarín, Lugo, Galicia



Concerning the definition of "*Argic*" (WRB) and "*Argillic*" (Soil Taxonomy) diagnostic horizons, regarding Alisols and Acrisols, a different criterion in considering the evidence of clay illuviation must be taken into account. Such a feature is considered optional in the WRB, but is mandatory in the definition of *argillic* horizons in the Soil Taxonomy, which characterizes Alfisol and Ultisol orders. Such differences imply that some of the *argic* horizons should be characterized as *cambic* horizons according to the Soil Taxonomy. Another significant difference refers to the degree of base saturation; for both Alisols and Acrisols, the required percentage of base saturation is lower than 50 %, whereas Alfisols and Ultisols differ by a percentage higher or lower, respectively, than 35 %. Therefore, and considering the moisture regimes defined in the Spanish Humid Zone, a proper correlation between both Alisols and Acrisols and the next Soil Taxonomy orders: Ultisols (Udults and Ustults suborders), Alfisols (Udalfs and Ustalfs suborders), and Inceptisols (Dystrudepts and Dystrustepts suborders) can be established.

3.5.2.13 Luvisols

Luvisols (from the Latin "*luere,*" meaning "to wash") also have an *argic* horizon (*Bt*) with a CEC of 24 cmol $kg^{-1}clay^{-1}$ or more throughout or to a depth of −50 cm below its upper limit, but there are no limitations concerning the base saturation. They have higher clay content in the subsoil than in the topsoil, mainly due to clay migration, high-activity clays throughout the *argic* horizon, and a high base saturation at certain depths, without marked leaching of base cations or advanced weathering of high-activity clays. Highly leached Luvisols might have an *albic* eluviation horizon (*Ae*) between the surface horizon and an *argic* subsurface horizon (*Bt*).

These soils are commonly associated with calcareous material and are widespread in the eastern area of Asturias, Cantabria and the Basque Country (Table 3.13; see Appendix page 132). Most Luvisols developed on limestone (*Terra fusca* and *Terra rossa* in Kubiena's classification) (Guerra y Monturiol 1959; Guerra et al. 1968; Iñiguez et al. 1980; Guitián Ojea et al. 1985a, b) are classified in the Haplic Luvisols (Humic, Clayic) (Fig. 3.74) or Leptic Luvisols (Humic, Clayic) (Figs. 3.75 and 3.76) classes, but they can also present clay coatings in the *argic* horizon and are mostly classified as Leptic Cutanic Luvisols (Humic).

In the Basque Country, they appear in pockets on very steep slopes in a complex pattern at a very short distance with limestone outcrops, Leptosols and Cambisols, and are mostly used for forest plantations, rough grazing, or to support native *Quercus ilex* forests. Very deep Cutanic Vertic Luvisols (Humic) develop in dolines, and these are the only areas in this landscape that may be used for agriculture nowadays. These soils have the highest pH values in the region. Surface mineral horizons in plots that have not been used for agriculture have pH values mostly in the 5.6–6.2 range, but may be as low as 4.2–4.6; otherwise, pH values increase from 7.0 on the surface to 8.4 on horizons close to the underlying limestone. Organic matter concentration in the surface mineral horizons is 3.5–6.9 % and rarely exceeds 8.6 %. Bulk density and packing density of *Bt* horizons, as well as porosity, suggest that these horizons provide very poor conditions for root development; this is

Fig. 3.74 Outcrops and Haplic Luvisol on limestone. Tielve, Picos de Europa. Eastern Asturias

Fig. 3.75 Leptic Luvisol (Humic, Clayic) on limestone. Suances, Santander, Cantabria

emphasized by the small amounts of organic carbon accumulated, being the *Bt* horizon in the soil surface or not. These soils have few rock fragments throughout the profile and belong to the Siltic or Clayic classes, as the silt content is 40–60 % and that of clay is mostly 25–50 % but may reach 60 %. Illite is the dominant mineral in the clay fraction; there are also significant proportions of quartz, and not so much chlorite. Some Luvisols have developed from volcanic rocks (dolerite), and are classified as Leptic Cutanic Luvisols (Manganiferric, Humic); these soils have a narrow range of pH values, 5–6, clay content, 30–40 %, and organic matter concentration in the surface mineral horizons of 3.5–6.0 % (Olarieta, J.R., personal communication).

Fig. 3.76 Leptic Luvisol (Humic, Clayic) on limestone. Vizcaya, Basque Country. (*Photo* Guerra et al. 1968)

As mentioned above (4.2.12), and according to Soil Taxonomy, Alfisols are characterized by an *argillic* diagnostic horizon in which the base saturation of the exchange complex is more than 35 %. Therefore, soils characterized within the RSG of Luvisols, with evidence of clay illuviation, may be virtually associated with Alfisols within the Soil Taxonomy. Luvisols with no evidence of clay illuviation must be generally considered as Inceptisols characterized by a *cambic* horizon. In the context of the Spanish Temperate Humid Zone, Luvisols can thus be classified in the Alfisols (mainly Hapludalfs, Paleudalfs, Haplustalfs and Paleustalfs suborders) and the Inceptisols (Eutrudepts and Haplustepts suborders) orders.

3.5.2.14 Umbrisols

The Umbrisols are characterized by a dark-colored surface horizon, which can be an *umbric* horizon (from the Latin "*umbra,*" meaning "shade") with low base saturation (less than 50 %), or a well-structured *mollic* horizon (from the Latín "*mollis,*" meaning "soft") with high base saturation (50 % or more), and a moderate to high content of organic matter in both cases; the upper limit varies between 20 and 30 % of SOM. These soils are spread by all the territory of the Spanish Temperate Humid Zone on all types of rocks, usually under scrubs with or without *Pinus sp*. or *Eucalyptus globulus* trees, and are located at varying altitudes, from 100

Fig. 3.77 Leptic Umbrisol (Humic, Hyperdystric) on granite. Codeso, A Coruña, Galicia

to more than 1,000 m asl. They are soils affected by anthropogenic action in most cases, particularly in those located in flat areas, smooth depressions, and fluvial valleys, as well as in the coastal *rasas*, for cultivation, and in the flat summits and smooth slopes of high mountains for permanent prairies or pastures, i.e., for grassland.

The Umbrisols that developed on acid rocks predominate in the western area of the study zone, mainly in Galicia and the western part of Asturias, where Leptic Umbrisols, Cambic Umbrisols and Endogleyed Umbrisols, in the Humic, Alumic and Hyperdystric clases, are majority (Figs. 3.77, 3.78 and 3.79). They present a wide range of pH, 4.0–6.5, and SOM content, 2–33 %, generally very low base saturation, and a high content in exchangeable Al and sandy-loam texture. In the soils of Galicia with high content in SOM but very low content of available Ca and Mg, the large amount of Al provokes the immobilization of N and P, diminishing the fertility of these soils. On basic rocks, they can present *andic* properties, and be classified as Andic Umbrisol, in the Humic, Alumic and Dystric classes (Figs. 3.80 and 3.81).

In Cantabria and the Basque Country, some Mollic Umbrisol, in the Humic, Eutric and Clayic classes with high pH and base saturation, can be found. Moreover, in the Basque Country, there are Umbrisols on volcanic rocks, lutites, sandstones and conglomerates, which are more frequently developed at altitudes below 600 m asl. Those that develop from volcanic rocks are classified as Leptic Umbrisols and belong to the Humic class; their pH increases from 4.0–5.1 in the surface mineral horizon to 4.7–5.3, with

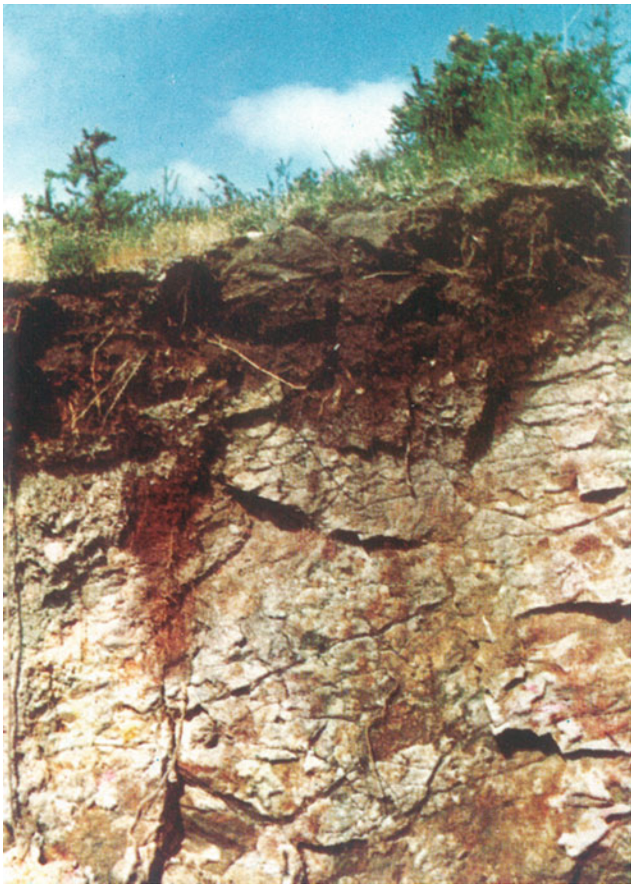


Fig. 3.78 Leptic Umbrisol (Humic, Hyperdystric) on phyllites. Grandas de Salime, Oviedo, Asturias

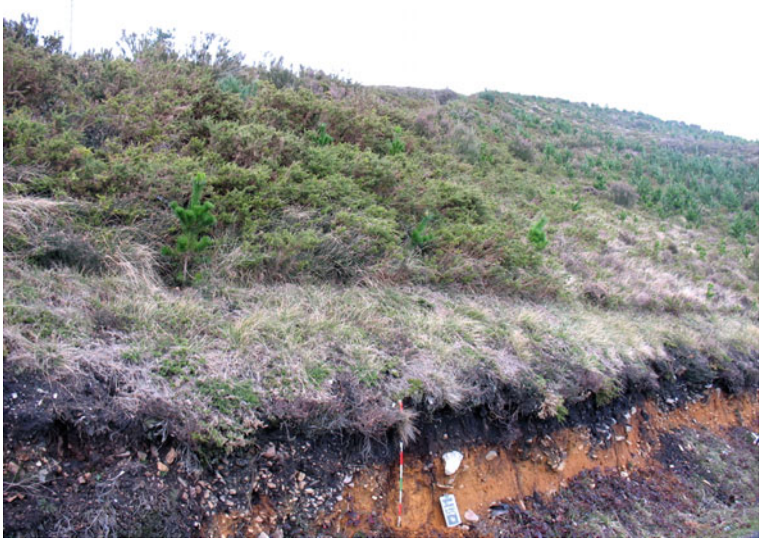


Fig. 3.79 Haplic Umbrisols in quartzite colluvium. Pola de Allande, Western Asturias

Fig. 3.80 Andic Umbrisol (Humic, Alumic) on amphibolites. Mellid, La Coruña, Galicia

Al saturation values below 15 %. The Umbrisols that developed from lutites, sandstones and conglomerates are mostly Leptic Umbrisols and rarely Haplic Umbrisols; they generally belong to the Humic class, while those developed from conglomerates also have a skeletic character. The pH values in the surface mineral horizon vary depending on the land use, but may be as low as 4.0 in shrublands and forest plantations, and the organic matter concentration in these horizons reaches up to 6.0 % (Olarieta J.R., personal communication). Table 3.14 (see Appendix page 134) shows the main characteristics of some profiles of Umbrisols.

The requirements of an *umbric* horizon in the WRB are significantly comparable, in basic terms, to those defining the homonymous horizon of the Soil Taxonomy; however, in other cases, slight variations concerning the thickness requirements have to be considered. While the Umbrisols include the possible presence of a *mollic* horizon, these soils lack a high content of bases in the whole profile, which excludes them as Mollisols. Likewise, the absence of subsurface horizons other than *cambic*, in general allow its correlation with the Inceptisols order of the Soil Taxonomy. Taking into account the soil moisture regimes defined in the Spanish Temperate Humid Zone, an adequate correlation between the WRB's Umbrisols and the Humudepts and Humustepts great groups within the Inceptisols order of the Soil Taxonomy can be established.

Fig. 3.81 Andic Umbrisol (Humic, Dystric) on amphibolite. La Capelada, La Coruña, Galicia

Fig. 3.82 Protic Arenosol (Dystric). Dunes in Ponteceso Beach. La Coruña, Galicia (*Photo* Serafín J. González Prieto, IIAG-CSIC)

3.5.2.15 Arenosols

The Arenosols (from the Latin "*arena*," meaning "sand") are mainly characterized by the texture that can be loamy sand or coarser and by the percentage of gravels, less than 40 % in volume. This type of soil is only found in the numerous beaches and dunes that are spread along the 2,400 km of coast bathed by the Atlantic Ocean and the Cantabrian Sea that limit by the west and the north, respectively, the study zone. In general, Protic Arenosols and Haplic Arenosols, Dystric or Calcaric, are present in the beaches and in the dunes, respectively (Fig. 3.82).

The taxonomic criteria related to poorly evolved and sandy-textured soils are covered in the Soil Taxonomy within the Entisols order, particularly in the suborder Psamments. Considering the dominant regimes of soil moisture in the Spanish Humid Zone, the WRB's Arenosols can be properly associated with the Udipsamments and Ustipsamments great groups of the Soil Taxonomy.

3.5.2.16 Cambisols

The Cambisols are characterized by a subsurface *cambic* horizon (from the Italian "*cambiare*," meaning "to change")

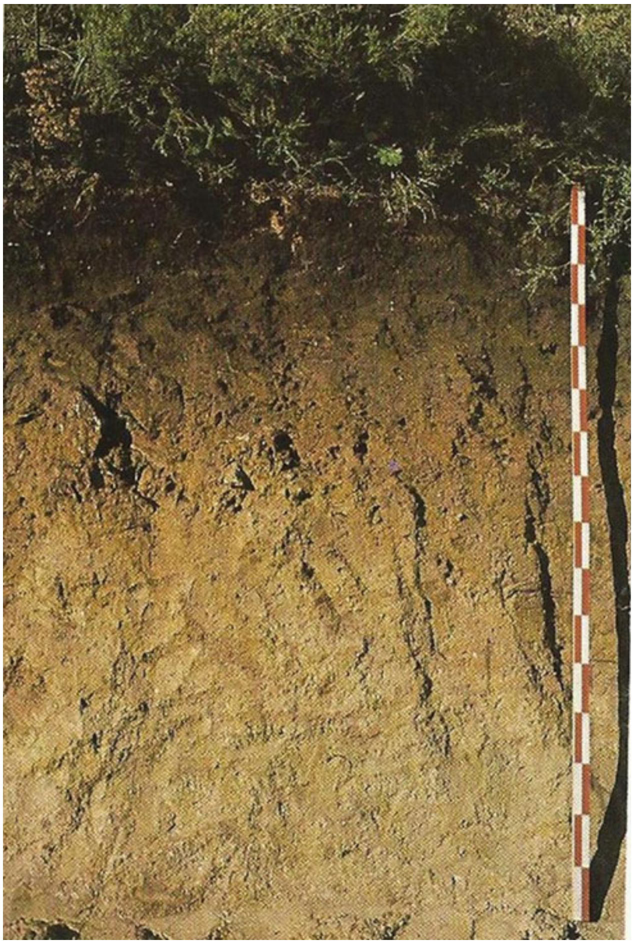


Fig. 3.83 Leptic Cambisol (Humic, Dystric) on porphydic granite. Chantada, Lugo, Galicia

of 15 cm or more, with evidence of alteration compared with the underlying horizon; besides, it cannot be part of a plough layer, and it does not consist of organic material. Cambisols, together with Umbrisols, Regosols, and Leptosols, and their numerous classes, are the soils that cover most of the surface of the study zone. They develop from all types of parent materials, whether acid, such as granite, slates, sandstone, acid or basic schist, phyllites, lutites, volcanic rocks and basic and ultrabasic rocks, or calcareous materials such as limestone, marly limestones and dolerites. In the western area of the study zone (Galicia) and the western area of Asturias, the Cambisols on acid rocks predominate, whereas in the eastern area of Asturias and in Cantabria as well as in the Basque Country, the Cambisols on calcareous rocks dominate the landscape; finally, in the eastern extreme of the study zone, the Basque Country, Cambisols on volcanic rocks can be found.

In most of the Cambisols, the *cambic* horizon (*Bw*) is well developed, with a thickness between 15 and 135 cm, and with an overlying organic *A* horizon of 5–20 cm deep, whose content in organic matter varies between 2.9 and 22.2 %. The pH varies from 4.0 to 6.7 on acid rocks and from 5.8 to 8.0 on calcareous rocks, with the base saturation varying in the ranges of 2–40 % and 27–100 %, respectively. On acid rocks, the exchangeable Al can reach 100 cmol kg^{-1} soil. The texture varies from sand to clay loam and the structure in the *Bw* horizon, mainly granular and prismatic columnar in soils developed on acid rocks, is subangular polyhedron in Cambisols on calcareous rocks. Consequently, with these characteristics, Leptic or Haplic Cambisols (Alumic, Humic, Dystric) are in the majority on acid parent materials (Figs. 3.83 and 3.84) and Leptic or Haplic Cambisols (Humic, Eutric) predominate on calcareous rocks (Figs. 3.85, 3.86 and 3.87), whereas on basic rocks, Leptic or Andic Cambisols (Alumic, Humic, Dystric) are produced (Figs. 3.88, 3.89 and 3.90).

Fig. 3.84 Haplic Cambisol (Humic, Dystric) on rasa deposits (sand, quartzite, slates). Tol, Western Asturias

The Cambisols developed from marly limestone appear mostly on steep slopes and, therefore, are rarely used for agriculture nowadays; they are Leptic Cambisols in most cases. The most distinctive feature of these soils is the presence of silt coatings in the *cambic* horizon, and, in some cases, they have developed *oxyaquic* conditions. The pH of

Fig. 3.85 Leptic Cambisol (Calcaric, Humic, Eutric) on limestone. Álava, Basque Country (*Photo* Iñiguez et al., 1980)

these soils increases with depth, from 4 in the surface horizon to 8 in the deep horizons; these values are related to the present and past land use of the plot, never dropping below 5 if they are used for grassland, whereas in forest plantations, pH is 5.5–7.5 if they were used for grassland or agriculture in the past, but only 4–5 otherwise. Therefore, they are mostly in the Dystric or Eutric classes, but rarely in the Alumic class. Illite is the main mineral in the clay fraction, and quartz and chlorite appears in significant amounts, particularly the latter in the subsurface horizons.

The Cambisols that developed from volcanic rocks are usually Leptic Cambisols (Humic); their pH increases from 4.0–4.5 in the surface to 4.5–5.2 in the *cambic* horizon. All these soils maintain a strong, fine, granular or subangular structure and a dark color (with a hue of 7.5 YR or 10 YR, and value and chroma of 3/3 to 4/4) throughout the profile, and belong to the Humic class, with Al saturation values below 15 %.

Finally, Haplic Cambisols, and in some cases Endogleyic Cambisols, have been developed from fluvial sediments; these soils show a decreasing concentration of organic matter in depth, from values of 1.7–2.5 % in the surface horizons to 0.13–0.19 % at a depth of −70 cm, and their structure shows weak development in the *cambic* horizons. The pH values increase with depth from 6.0–7.5 to 7.0–8.2, and small fragments of lime frequently appear at the base of the surface horizon and in the *cambic* horizon (Olarieta J.R., personal communication). The main characteristics of some profiles of Cambisols are shown in Table 3.15 (see Appendix page 136).

The requirements of the WRB for the definition of Cambisols exhibit remarkable coincidences with the corresponding definition of the order Inceptisols of the Soil Taxonomy. In the context of the Spanish Temperate Humid Zone, among the various diagnostic horizons that characterize both Cambisols and Inceptisols, the *cambic* horizon is

Fig. 3.86 Haplic Cambisol (Calcaric, Humic, Eutric) on metamorphic limestone. Becerreá, Lugo, Galicia

Fig. 3.87 Leptic Cambisol (Humic, Eutric) on alluvial-colluvial deposits from limestone. Tielve, Eastern Asturias

the one that occurs most frequently. Likewise, the definition of *cambic* horizon in both systems is coincidental in key aspects such as thickness, texture, soil structure, and properties that exclude the presence of other horizons. As a general rule, soils classified as Cambisols can be included within the Inceptisols order, whose definition is significantly wider, and, more specifically, in the next great groups: Dystrudepts, Eutrudepts, Dystrustepts, and Haplustepts. Local conditions of increased summer dryness in the southern part of the study area can be associated with Inceptisols with *xeric* soil moisture regime: Dystroxerepts and Haploxerepts suborders.

3.5.2.17 Regosols

The Regosols (from the Greek "*rhegos*," meaning "blanket") are mineral soils without any diagnostic horizon, very weakly developed on unconsolidated material of fine grain, usually in arid lands or mountainous areas, and mainly used for extensive grazing or under forest. In the study area, they are quite widespread, on all types of acid rocks associated with erosion processes in mountainous areas mainly in the last Quaternary glacial period and the intense deforestation due to fire. In Galicia, Asturias and Cantabria, they are mostly Leptic Regosols with sandy textures and pH in the range of 4.0–6.5, a variable content in SOM (1–16 %), and base saturation (4–63 %), predominating the Humic and Dystric classes (Figs. 3.91, 3.92, and 3.93). In some areas, like the western part of the study zone, these soils appear in the landscape associated with Leptosols. Those developed on calcaric materials are Haplic or Leptic Regosols, mainly in the Humic and Eutric classes (Fig. 3.94).

Fig. 3.88 Leptic Cambisol (Alumic, Humic, Dystric) on amphybolite. A Coruña, Galicia

In the Basque Country, these soils are widespread and have developed from lutites, marls and marly limestones, sandstones, conglomerates, and volcanic rocks and their colluvium. Most of the former soils are classified in the Eutric class, and some in the Calcaric class, with small fragments of lime at the bottom of the mineral surface horizon or in the subsurface horizon, in plots that, in some cases, have not received any liming for a few decades.

Lutites, mixed with sandstones to varying degrees, are the most common parent material and are associated with various geomorphological positions, from steep slopes to rounded crests. Most of these soils show little horizon evolution and are classified as Leptic Regosols; they have an *AC*

Fig. 3.89 Andic Cambisol (Humic, Dystric) on amphibolite. La Capelada, La Coruña, Galicia

Fig. 3.90 Andic Cambisol (Humic, Dystric) on amphybolite. Mellid, Galicia

profile with a depth of 20–40 cm to the bedrock, and the pH values are in the 5.1–8.2 range under grassland or arable, but it is only 3.6–4.9 in forest plantations that have not been previously used for agriculture, and the SOM concentration is mostly in the range of 4–6 %. They have few rock fragments and a sand content lower than 30 % in most cases; therefore, they can be classified in the Humic, Dystric or Eutric classes, and frequently belong to the Siltic class but rarely to the Clayic class. Soil management not only affects the chemical properties of these soils, but it is also the major determinant of their physical properties, such as bulk density and porosity with a more intense effect than soil texture (Olarieta et al. 1999). Various degrees of drainage problems appear in these soils, with redoximorphic features frequently within the surface 15 cm of soil, but they are not necessarily associated with flatter slopes or finer textures, whereas in other instances these features appear in the subsurface horizons (Endogleyic Regosols). The clay fraction is completely dominated by illite and quartz in various proportions (Table 3.16; see Appendix page 138).

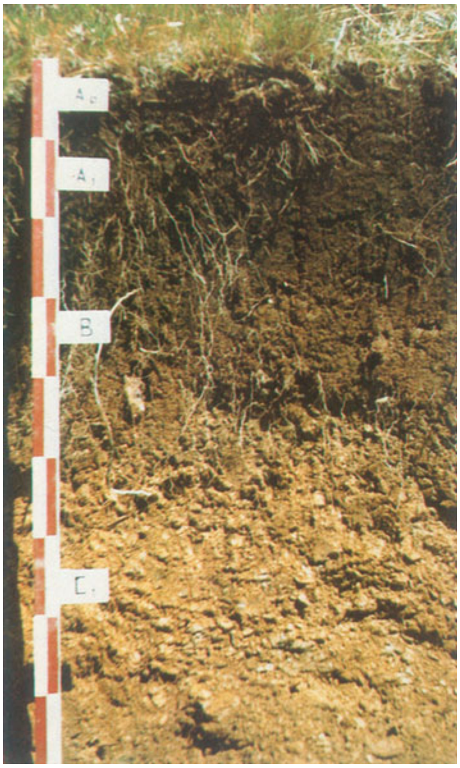


Fig. 3.91 Leptic Regosol (Humic, Dystric) on schist. Santander, Cantabria

Fig. 3.93 Leptic Regosol (Humic, Dystric) on granite of two micas and coluvium of quartz. Alto do Rodicio, Orense, Galicia

Soils developed from marls and marly limestones are frequently classified as Leptic Regosols. Their pH values range from 5.6 to 7.2 when used for arable or grassland, from 4.8 to 5.6 when at present used for forestry but formerly for grassland or arable, and from 3.8 to 4.8 when they have only been under forestry or shrubland. They frequently fit in the Siltic or Clayic classes, as their sand content is mostly below 24 % and may be as low as 5 %. Table 3.16 shows the main characteristics of some profiles of Regosols.

Fig. 3.92 Leptic Regosol (Dystric) on altered granite. Alto de Cerango, Orense, Galicia

Fig. 3.94 Haplic Regosol (Humic, Eutric), in calcaric sandstone colluvium. Bezanes, Eastern Asturias

The key to the reference soil groups of the WRB considers the Regosols as the RSG comprising those soils that cannot be included in other groups. Therefore, they are under "definition by exclusion" criteria, like the way that Soil Taxonomy deals with the Entisols order. Thus, a suitable correlation between Regosols and Entisols can be established, considering, however, that the latter constitute a broader concept, so that soils classified as Regosols can be generally integrated in the Entisols order in terms of Soil Taxonomy. With the base of the dominant soil moisture regimes in the study area, Regosols will be included in Udorthents and Ustorthents great groups. Locally, summer dryness conditions in the southern part of the study area determine their belonging to the Xerorthents great group.

3.5.3 Main Biochemical and Biological Characteristics of the Soils of the Zone

Although the study of the biological properties of the soils began much later than that of the physical and chemical properties due to the retard in the knowledge of the Biology, and even recognizing the spectacular experimental advances in recent years, the understanding of soil biology has not yet reached the level of the other fields of the Soil Science. Within the biology of the soils, it is essential that there be more microbiology studies, due to the importance of the soil processes determined by the microorganisms, such as biodegradation, mineralization and humification of the SOM, weathering of rocks and minerals, soil structure formation, atmospheric N fixation, etc.

The soils of the Spanish Temperate Humid Zone generally have a high SOM content, mainly due to the incorporation of large quantities of vegetal and animal debris that favor the development of the microbial population whose activity should be also favored by the climatic conditions of this area. Consequently, the edaphogenesis of most of these soils will be influenced by the evolution of the organic matter that, among other factors, will depend on the activity of the microbial population.

3.5.3.1 Microbial Population

Studies of the surface horizons of soil profiles representative of the study zone (Leptosols, Andosols, Podzols, Phaeozems, Luvisols, Umbrisols, Cambisols, and Regosols) and of the whole profiles in the case of a Podzol and an Andosol, have led to a general knowledge of the microbial population, taxonomic and physiological groups, involved in the C, N and S cycles, of this area (Acea and Carballas 1986a, b, 1987, 1990). The total microbial population is in the range of 10^5–10^8 microorganisms g^{-1} soil, dominating the bacteria on the other taxonomic groups; actinomycetes, whose density varies between 10^3 and 10^6 followed in numerical importance to bacteria; fungi were in the range of 10^2–10^5; and algae is the group of lower density.

The higher density of all the microbial groups of the C-cycle corresponds to the pectinolytics, which are followed in importance by the amilolytics, while the aerobic cellulolytics' value is much lower and the number of anaerobic cellulolytics is even lower. Within the microorganisms of the N-cycle, highlighted by its abundance of proteolytics and ammonifiers, whereas the number of nitrifiers, both ammonium oxidizers and nitrite oxidizers, is very low, and the same occurs with the denitrifiers and the N_2-fixers, both aerobic and anaerobic, which have very reduced values. Among the microorganisms of the S-cycle, the anaerobic mineralizers of the organic S and the sulphate reducers dominate, whereas the sulphide reducers as well as the elementary S oxidizers do not appear in most soil samples analyzed.

The microorganisms that exhibit the lower density in the soils present very high coefficients of variation that indicate not only the presence of unfavorable environmental factors, but also its high sensibility to environmental changes. The coefficients of variation of the better-represented groups (ammonifiers, proteolytics, pectinolytics and amilolytics) are very low. Except for fungi, which are negatively correlated with certain other groups (especially algae), all the other microbial groups are either not correlated or positively correlated with each other, and in most cases the correlation coefficients are significantly high, which indicates a certain stability in the relationships among soil microbiota as well as a certain biological stability in them.

Texture is the soil property with the greatest influence on the microbial population, although it is less favorable for coarse particles size. Surprisingly, there is no correlation between the microbiota and the SOM content; nevertheless, it is very elevate when the quality of the organic matter is high. The C/N is negatively correlated with all the microbial groups except fungi, which justify the use of this ratio as an indicator of soil biological activity. The base saturation degree of the exchange complex is the third most important soil property among the factors that influence microbial development; exchangeable Ca^{2+} and Mg^{2+} show the major influence, whereas Al^{3+} shows a bad influence on the microbiota. The increase of pH shows a favorable tendency; by contrast, the lack or scarcity of soil humidity has a negative effect on all the microbial groups. Besides, the microorganisms presenting a higher dependency of the soil's physical or chemical characteristics are those pertaining to the N-cycling, following by those of the C-cycling and, finally, those of the S-cycling.

Both microbial density and functionality decrease with the depth of the profile, likely due to the decrease of SOM content that generally occurs in most profiles; this is supported by the fact that the microbial density can be higher in deeper horizons than at the surface (Alexander 1977). The climatic factors greatly affect the development of the microbial population, increasing its density and functional diversity in winter, which seems to indicate that humidity is a more limiting factor than temperature. There is also a certain influence of the parent material on the microbial population, associating the soils on limestone to the N-cycle, the soils on basic rocks to the S-cycle, and the soils on acid rocks to the C-cycle.

In the study soils, there is a clear dominance of the potential ammonification process on nitrification, which seems to indicate a ralentization of the mineralization at the nitrification stage. There is also an unbalance between nitrification and denitrification in most of the study soil samples.

The microbial population of the Haplic Podzol (Profile 1131; Table 3.9) study was the most empowered, both in numbers and functionality; although it decreased with depth, the E horizon exhibited a microbial population richer than that corresponding to *albic* horizons, highlighting the high number of algae. The A horizon of the buried Podzol (see-Sect. 3.5.2.9) had an extraordinarily poor microbial population that justify its consideration as a fossil horizon, although it does show some microbial activity.

The soils on limestone or calcareous material, such as Rendzic Leptosols, Phaeozems, and Luvisols, present high microbial density and elevated functional potentiality. The other soils that developed on acid and basic rocks are situated between the Podzol and the calcareous soils, presenting certain homogeneity, in concordance with the type of humus and other characteristics, similar in all the soils. Nevertheless, there are differences with regard to the metabolic and functional potentiality of the microbial population, much more concordant with the C/N ratio than with the type of humus.

The Andosol on granite (Profile 1317, Table 3.8) presents a relatively high nitrification/ammonification ratio and a high number of cellulolytics; its microbial population did not decrease with depth, but exhibited a maximum in the A_3 horizon, their behavior pattern being similar to that of a polycyclic soil concerning the distribution of the microbiota in depth.

The study profiles of Umbrisols and Cambisols developed on granite have a relatively high microbial density but a low potential functionality, heavily dominating ammonification on nitrification. The soils developed on micaceous and basic schist and on serpentines have a relatively low microbial population, which is attributed, in the first case, to the presence of vegetation near the climax because its functional diversity is high, in the second case to the climatic regime of these soils, and in the third case, to the particular conditions of its exchange complex and to the presence of micro-elements such as nickel (Ni) (Carballas et al. 1965).

The Leptosol on gabbro—with a microbial density a little higher than the soils on schist and serpentines—shows a higher functional potential and an elevated nitrification/ammonification ratio, although the oxidation of nitrites is relatively slow.

As for the seasonal variation, the highest microbial density is in the spring and early autumn, being in the latter period the most elevated functional potentiality.

The microorganisms, besides accomplishing fundamental functions in the soils, when they dye represent a way and a very important source of nutrients for the plants' growth because, on the one hand, they are the more labile fraction of the SOM, and on the other, they have a very short turnover time. Therefore, it is fundamental to quantify the microbial biomass in order to understand the SOM dynamic and to evaluate the ecological meaning of the microorganisms in the edaphic ambient.

In the study zone, the soils exhibit high levels of microbial biomass −1,101 kg C ha^{-1} on average—although this value represents a low percentage of the total soil C, being the SOM content, the texture and the soil humidity the factors that influence this biological parameter more (Díaz-Raviña et al. 1993a). Moreover, various studies show that the microorganisms immobilize important quantities of N, P, K, and Ca, and that the contribution of the microbial biomass to the pool of available elements for plants, although in large measure determined by the season of the year, is elevated for N, important for K, P and Mg, and not significant for Na (Díaz-Raviña et al. 1989, 1993b, 1995).

The soils of the study zone present a low metabolic activity that seems to depend more on the quality and nature of the organic matter than on its quantity (Díaz-Raviña et al. 1988).

Nowadays the studies are focused on a new aspect of the microbial biomass—that is, the structure or diversity of the microbial community by means of the analysis of molecular bio-tracers such as the fatty acids of the phospholipids (PLFA) that permit knowing not only the total microbial biomass, but also that of specific groups, such as bacteria and fungi, etc. (Mahía et al. 2011). The results are very helpful in evaluating diverse processes of degradation and practices for soil conservation and, therefore, in making decisions on the management of agricultural and forest soils of the temperate humid zone (Barreiro et al. 2010).

3.5.3.2 Composition of the Organic C, N and P Compounds

Nitrogen is one of the most abundant nutrients in the study zone, particularly in Galicia; however, it is frequently one of the limiting factors for plant growth; this is because nearly 98 % of the total soil N is in organic forms and therefore not directly available for plants, but it is needed for these forms to be mineralized by the microbial population. The same occurs with the pool of the organic C, formed by labile and resistant compounds to the microbial attack, and that of the organic P. Consequently, the C, N and P mineralization capacity is an important biochemical property because organic C is a source of energy for microorganisms, and organic N and P are sources of nutrients for plants and microorganisms. Besides, P is another limiting factor due to its rapid immobilization by Al.

The composition of the organic pools of C, N and P in soils of the Temperate Humid Zone of northwestern Spain has been identified. The organic C pool consists of (1) labile compounds, among them hydrosoluble C or dissolved organic C (DOC); microbial C that represents 1–5 % of the soil organic C (SOC) and 2 % of the total C; amino acids and amino sugars; carbohydrates, with a turnover of decades that represent 5–25 % of the SOC and about 2 % of the total C and that play an important role in the formation of aggregates and then in soil structure; (2) less labile forms, such as lipids; (3) more stable organic compounds, such as unhumified and humified (fulvic and humic acids) organic matter; and (4) compounds recalcitrant to the microbial attack, such as some cellulosic compounds, humines and lignine (Fernández et al. 2001; Martín et al. 2011).

The organic N pool was studied by González-Prieto and Carballas (1988, 1991), using their own method of successive acid hydrolysis with HCl of various concentrations at various temperatures, and by Prieto Fernández and Carballas (2000), identifying: (1) labile N forms, such as solubilized ammoniacal N, amino-acids and amino-sugars, amides and total hydrolysable N; (2) less labile forms, such as hydrolysable unknown N; and (3) forms recalcitrant to the microbial attack, such as non-hydrolysable N or residual N. Finally, Trasar-Cepeda et al. (1989, 1990) have studied the numerous P forms.

3.5.3.3 Metabolic Activity of the Microorganisms

As indicated above, the metabolic activity in the study zone is low. Although the metabolic activities of the microorganisms mainly depend on the composition of the microbial population, they also depend on the characteristics of the substrate (González-Prieto et al. 1991). Nevertheless, from the results of two ambitious studies (González-Prieto et al. 1992, 1996) whose aim was to study the N mineralization capacity and the factors that influence this process in: (1) 41 temperate humid-zone soils developed on acid igneous rocks, acid and basic sediments, acid metamorphic rocks, basic and ultrabasic rocks, and limestone; and (2) a large variety (112 soils) of native (35 under forest, 22 bushland) and agricultural (32 under pasture, 33 cultivated) soils representing several climatic zones in Galicia, various types of acid, basic, ultrabasic and calcareous parent materials and soils such as Rankers and Rendzines (Leptosols), Fluvisols, Andosols, Podzols, Luvisols, Cambisols and Regosols (FAO 1974), some facts could be generalized.

The net N mineralization rate is in the 0.30–5.32 % range of the total N, being both the net N mineralization and net N mineralization rate significantly higher in forest soils than in soils under shrubs or in agricultural soils. The net N mineralization rate of pasture and cultivated soils is similar to that of bush soils, but the available inorganic N is lower. Ammonification largely predominates over the nitrification process, except in some agricultural soils. On the other hand, net N mineralization predominates over net N immobilization, which is more frequent in agricultural soils than in native soils. This behavior could be explained by the composition of the microbial population, with an abundance of ammonifiers and scarcity of nitrifiers and denitrifiers as well.

The main soil factors affecting the organic N dynamics were identified by statistical analyses. Thus, the net N mineralization rate varies according to soil parent materials in this order:

Soils over acid rocks > soils over sediments > soils over basic rocks or limestone.

Moreover, the highest net N mineralization and available inorganic N are found in soils developed on acid rocks. The highest N mineralization capacity is found in soils with low C and N contents, particularly in native soils, in which N mineralization increases as the C/N ratio increases. The N mineralization is higher in soils with low pH and base saturation than in soils with high pH and base saturation values, which sometimes favor N immobilization. Soils with a content of Al hydroxides > 1 % show lower net N mineralization rates than soils with Al hydroxide contents < 1 %, although net N mineralization and available inorganic N does not differ between these groups. Finally, the net N mineralization rate in silty soils is significantly lower than in sandy and clayic soils, although soil texture explains only a low percentage of the differences in N mineralization between soils.

As in the case of organic N, the soils of the study zone exhibit low potential activity for mineralization of the organic C, whose habitual percentage of total C mineralized (coefficient of C mineralization) is in the 2.8–3.2 % range of the total C, the variability being mainly due to differences in the SOM quality and, to a smaller extent, to differences in the SOM content.

Consequently, the accumulation of SOM (organic C and N compounds) seems to be due to poor mineralization, which was caused (in decreasing order of importance), by the low quality of the SOM, high exchangeable H^+ levels, high Al and Fe hydroxides contents and, to a lesser extent although more markedly in cropped soils, by a silty clay texture and exchangeable Al^{3+}.

The pattern of the mineralization kinetics of the organic C and N, rapid rhythm until week 4 or 6 and slower afterwards, fitted the equations of first (for C and N) or second order (for C) that permit knowing the values of the C and N potentially mineralizable and the mineralization speed of the labile and the recalcitrant pools of C and N, as well as the mean live, which is the time needed for the mineralization of half the C or N potentially mineralizable, that in the case of N is in the range of 9–147 days (mean value: 38 days) (Carballas M. et al. 1979; Prieto Fernández et al. 1993; Fernández et al. 1999; González-Prieto and Villar 2003).

The pools of the C and N that are potentially mineralizable, which are formed by the more labile organic C and N compounds, are very small and represent a very low percentage of the total organic C or N (2.1–1.3 % in the case of N), whereas the pools of the recalcitrant organic C and N, represent a high percentage of the total organic C and N. This could explain the low percentages of C and N mineralization and the accumulation of organic matter and nitrogen in these soils, and permit thinking that the variations of the process observed in these soils are likely due to differences in the size and the kinetics of this small compartment, which is more sensitive to external influences—such as humidity and temperature—than the higher C and N recalcitrant pools. Therefore, it is likely that the low percentages of mineralization are mainly due to the scarcity of labile organic C and N.

All the behavior of the N mineralization indices supports the hypothesis of González-Prieto and Carballas (1991) on the existence of two pools or compartments, a recalcitrant one formed by N compounds stabilized by interaction with free Al oxides, and a labile one, composed of N compounds that did not form complexes with Al due to the lack of free Al oxides already consumed; the latter compounds would be mineralized in the first weeks of the incubation, or easily mineralized in the field, producing available N for plants or microorganisms.

Appendix

See Tables 3.3 to 3.16.

Table 3.3 Main characteristics of some profiles of Histosols

No.	Profile code	Location (province)	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Ex. Al ($cmol_C$ kg^{-1})
1	G 1133	Lugo	630	Granite	Hygrophyte scrub	Undulating	H 0–150 (peat)	–	3.8–3.7	92–98	29–62	180–98	8–7	3–2
2	G 1093	Orense	630	Granite	*Sphagnum* sp.	Lacustrine depression	H 0–100 (peat)	Sandy loam	5.4–4.8	52–22	11–13	166–13	12–30	15–2
3	G 551	Coruña	390	Basic schist	*Carex* sp.	Depression (*Braña*)	H 0–150 (peat)	–	4.5–4.8	96–42	12–13	135–45	14–21	13–38
4	A 997	Oviedo	1100	Calcareous	*Phragmites* sp.	Plain near Lagoon.	H 0–90 (peat)	–	6.1–5.7	71–53	11–18	112–142	75–72	1–2
5	G 36	Pontevedra	390	Quartzite	*Carex* sp., *Eriophorum* sp.	Depression	H 0–85 (peat)	–	3.5–3.5	85–55	12–72	135–45	14–21	0 0
6	G 215	Lugo	1100	Granodiorite	Scrub	Smooth slope	H_1 0–15	Loamy-sand	5.2	33	13	98	8	21
							H_2 15–30		5.5	26	15	76	3	35
							H_3 30–45		5.6	20	18	54	1	35
							H_4 45–60		5.6	14	19	36	3	29
							C 60–100							
7	C 1196	Santander	940	Quartzite	Hygrophyte scrub	Plain	H_1 0–15	Sandy loam	4.60	56	18	93	9	12
							H_2 15–40	Clay loam	4.30	61	29	110	6	9
							C_g +40							

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country. Analytic data: range from the top to the bottom of the profile
1, *2* Fibric Limnic Histosol (Dystric); *3* Ombric Sapric Histosol (Dystric); *4* Fibric Limnic Histosol (Eutric, Calcaric); *5–7* Ombric Histosol (Dystric)

Table 3.4 Main characteristics of some profiles of Leptosols

No.	Profile code	Location	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Ex.Al ($cmol_C$ kg^{-1})	Gravels (%)
1	G 1014	Orense	1180	Sandstone	Scrub	Abrupt slope	0–25	Sandy-loam	5.5	12	29	27	2	15	52
2	G 1015	Orense	900	Granite	Oak trees	Undulating	0–25	Sandy-loam	5.7	8	12	32	7	15	63
3	G 1065	Orense	540	Granite	Scrub	High slope	0–20	S.-clay-loam	4.4	21	22	55	3	13	20
4	G 1991	Orense	1000	Slates	Gorse scrub	Undulating	0–10	Sandy-loam	4.9	15	13	31	9	6	71
5	G 1125	Lugo	680	Granite of two micas	Scrub + *P. radiata*	Slight slope	0–25	Sandy-loam	4.6	18	16	60	6	20	–
6	G 207	Lugo	420	Carboniferous schist	Gorse scr. + Pine trees.	Slope	0–20	Loam	5.0	24	23	60	8	25	–
7	A 1033	Oviedo	300	Sandstone	Gorse scrub	Slope	0–15	Loam	6.4	25	25	28	6	6	–
8	A 947	Oviedo	120	Conglomerate of quartzite	*Erica* sp. scrub	Hilly	0–10	Sandy-loam	4.8	11	23	19	15	3	20
9	ACS2_C007	Oviedo	1039	Quartzite	Heath scrub	Hilly	0–16/23	Sandy-loam	4.0	17	–	28	13	0	34
10	C 1208	Santander	2160	Conglomerate of quartzite	Heath scrub	Mountain hill	0–20	Sandy-loam	4.1	39	37	71	13	1	–
11	C 1180	Santander	1300	Limestone	*Sarothamnus* scrub	Slope	0–15	Clay	7.6	22	9	87	92	0	–
12	B P9/2	Bizcaya	470	Volcanic rock	*P. radiata*	Slope	0–15/20	–	4.5	19	10	52	3	10	–
13	B L 9	Álava	980	Dolomite	*Gorse scrub*	Flat	0–35/45	Clay	7.8	7	13	27	82	–	–
14	B AHC4	Guipúzcoa	482	Slates	*Fagus sylvatica*	Slope	0–20	Clay-loam	4.7	6	11	17	7	5	–
15	B ALO3	Guipúzcoa	878	Limestone	*Fagus sylvatica* *Larix kaempfert*	Depression	3–20	S-Clay-L	4.5	5	9	20	18	6	–
16	B URD41	Bizcaya	320	Sandstone/Lutite	Grassland	Slope	A1 0–5	Clay-loam	5.8	10	11	35	46	11	–
							A2 5–18	Loam	6.2	3	8	16	77	1	

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country
1, *2* Umbric Leptosols (Humic, Dystric, Skeletic); *3*, *6*, *7*, *9*, *10*, *12*, *14* Haplic Leptosol (Humic, Dystric); *4* Lithic Leptosol (Humic, Dystric, Skeletic); 5 Umbric Leptosol (Humic, Dystric); *8*, *15* Lithic Leptosol (Humic, Dystric); *11* Rendzic Leptosol (Calcaric, Humic, Eutric); *12* Andic Leptosol (Humic, Dystric); *13* Mollic Leptosol (Calcaric, Humic, Eutric); *16* Haplic Leptosol (Humic, Eutric)

Table 3.5 Main characteristics of some profiles of Vertisols

No.	Profile code	Location	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Clay (%)	pH$_w$	O. M (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Exch. (cmol$_C$ kg^{-1})	
															Ca	Mg
1	G 1124	Lugo	420	Clay sediments	Scrub	Depression (*Braña*)	A < 1	Clay	71	5.2	6.7	23	31	58	8	9
							Bt 149		75	5.5	0.6	–	30	77	13	9
2	A 1038	Oviedo	110	Red marls of Keuper	Grassland	Undulating	A 0−5	Clay-loam	32	6.2	18	17	96	81	55	21
							Bt 5 −90	Clay	60	6.9	1	–	49	79	8	31
3	C 1207	Santander	1030	Marls of Keuper	Grassland	Slight Slope	A 0 −10		45	7.4	7.4	11	34	96	31	1
							Bt 10–100	Clay	49	8.2	0.6	–	34	100	34	0

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country
1 Mazic Vertisol (Humic, Hypereutric); *2*, *3* Mazic Vertisol (Calcaric, Humic, Hypereutric)

Table 3.6 Main characteristics of some profiles of Fluvisols

No.	Profile code	Location	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Color moist	pH_w	O. M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)
1	G 803	Coruña	0	Fluvial sediment (from amphybollite).	Halophytic (*Salicornia* sp.)	Flat (estuary; Forcadas Riv.)	0–20 +	Sandy	–	7.9	4	16	15	100
2	G 802	Coruña	0	Fluvial sediment (from amphybollite).	Halophytic (*Juncetalia*)	Flat (estuary; Forcadas Riv.)	0–15 +	Sandy–loam Sandy	–	7.0–8.4	5–1	8–10	23	80
													10	100
3	G 1117	Lugo	0	Fluvial sediment (from slates, quartzites)	Halophytic	Flat (estuary; Eo River)	0–120	Loam Silty-loam	–	6.3–5.8	8–4	19–12	26	73
													18	58
4	G 1326	Pontevedra	0	Fluvial sediment (from granite)	Halophytic	Flat (estuary; Arosa River)	0–50	Sandy-loam	–	5.0–5.4	7–3	12–16	26	41
													9	43
5	G 1339	Coruña	0	Fluvial sediment (from serpentines)	Halophytic	Flat (estuary; Mayor River)	0–20 +	Sand	–	8.8	1	12	6	100
6	G 275	Lugo	450	Fluvial sediment (from schist)	Scrub	Terrace	A 0–10	Sa-Cl- loam	–	5.4	11	17	23	6
							B 10–70	Sa-loam		6.2	1	11	9	41
7	G 1107	Orense	490	Fluvial sediment (from schist)	Grassland	Flat (alluvial valley, Támega River)	A 0–20	Sandy loam	–	5.6	2	8	10	16
							B 20–100	Sandy loam		5.4	3	–	15	6
8	G 703	Coruña	180	Fluvial sediment (from gneiss)	Grassland	Flat (waterlogged plain)	A 0–20	Sand	–	6.1	5	21	16	14
							B 20–80	Loam-sand		6.1	2	8	14	5
							B 80–200	Loam-sand		6.1	–	–	14	7

(continued)

Table 3.6 (continued)

No.	Profile code	Location	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Color moist	pH$_w$	O. M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)
9	A 1140	Oviedo	260	Fluvial sediment (from calcareous rocks)	Grassland	Flat	A 0–20	Loam	–	7.6	5	8	56	95
							B 20–180	Clay–loam		7.9	2	7	32	93
10	A CS2 014	Oviedo	191	Fluvial sediment (mixed)	Grassland	Slight slope	A 0–11	Sa-Cl-loam Sa-Cl-loam	A: 10YR 3/2.5	6.0	5	–	23	61
							B/C 11–41	Clay-loam	C2 10YR 3/3.5	6.6	2		11	58
							C1 41–101	Sand-loam		6.6	23		–	
							C2 101–176			7.3	1		–	
11	B Ex 2/1	Vizcaya	–	Fluvial sediment	–	–	A1 0–20	Loam	A1: 10YR3/3	6.4	5	–	–	–
							A2 20–38	Loam	A2: 10YR 3/3	7.0	4			
							C 38–80+	Loam	C: 10YR.4/4 (mottles 10YR 6/8)	7.1	3			
12	B LA112b	Vizcaya	–	Fluvial sediment	–	–	A 0–20/25	Loam	A: 10YR 4/3, (mottles 6/8)	6.2	6	–	–	–
							Cg 25–53	Clay-loam	Cg: 2.5Y 4/1 (mottles 4/6)	5.8	8			
							A$_{bg}$ 53–95	Clay	Abg: 2.5Y 2/1	4.8	22			

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country. Analytic data: range from the top to the bottom of the profile

1, *5* Salic Tidalic Fluvisol (Thionic, Humic, Eutric); *2*, *3* Salic Tidalic Fluvisol (Humic, Eutric, Arenic); *4* Salic Tidalic Fluvisol (Thionic, Humic, Dystric); *6* Haplic Fluvisol (Humic, Dystric); *7*, *8* Haplic Fluvisol (Anthric, Humic, Dystric); *9* Haplic Fluvisol (Anthric, Calcaric, Humic, Eutric); *10* Haplic Fluvisol (Humic, Eutric), *11* Umbric Fluvisol (Humic, Eutric); *11* Gleyic Fluvisol (Humic, Dystric)

Table 3.7 Main characteristics of some profiles of Gleysols

No.	Profile code	Location	Altitude (m asl)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Clay (%)	Color (moist)	pH$_w$	O.M (%)	CEC (cmol$_C$ kg^{-1})	V (%)	Exc. Al (cmol$_C$ kg^{-1})
1	G 47	Lugo	425	Tertiary sediments	Scrub	Alluvial Plain	A 0–30	S-Clay	35	10 YR 5/6	5.6	7	34	16	6
							Cg1 30–70	S-C-L	29	10 YR6/4; 2.5 Y 7/4	5.3	–	22	17	3
							Cg2 70–120	S-C-L	26	2.5 Y 7/2; 7.5 YR 5/6	5.3	–	17	26	3
2	G 1073	Pontevedra	380	Gneiss	Hygrophyte Grassland	River valley	A 0–10	S-Loam	16	5 YR 3/2	4.9	6	14	4	8
							Cg1 10–50	S-Loam	13	10 YR 4/1	5.8	2	16	52	4
							Cg2 50–80	S-Loam	11	10 YR 5/2 (positive reaction to ferricyanide)	5.8	–	18	42	5
3	G 1109	Orense	640	Lacustrine sediments	Hygrophyte Scrub	Flat area	A 0–30	S-L	18	5YR 2/2	4.6	9	35	8	19
							Cg1 30–80	S-C-L	24	7.5 YR 5/6	5.5	–	10	13	2
							Cg2 80–115	S-C-L	28	5 YR 5/6 (positive reaction to ferricyanide)	5	–	6	29	1
4	A 1139	Oviedo	260	Calcareous Sandstone	Grassland	Flat area	A 0–40	Loam	12	7.5 YR 5/4	7.3	5	25	100	1
							Cg1 40–120	S-L	16	7.5 YR 6/8	8	0	16	93	0
							Cg2 120–200		18	5 Y 6/1	7.8	1	8	92	0
5	G 540	Coruña	270	Clayed, basic schist Ferriferous	Hygrophyte scrub	Flooding flat area	AB 0–35	S-C-L	28	10 YR 3/3	5.2	7	42	7	27
							Cg 35–90	S-Clay-Loam	26	5 Y 7/4; 2.5 Y 7/8 and gray-blue	5.3	1	8	14	2
6	G 773	Coruña	–	Amphybolite	Grassland	Undulating	A 0–15	Silty-C	28	5 YR 2/2	5	23	73	19	10
							Cg 15–145	S-C-L	25	5 YR 4/3	5	14	46	14	7
7	B LA 172	Bizcaya	–	Lutites	–	–	Ag 0–27	Silt-L	22	2.5 Y 6/2; 7.5 YR 4/6–2/2	6.8	3	1	76	1
							Cg 27–45	–	–	2.5 Y 8/1; 7.5 YR 4/6	–	–		–	0

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B*, Basque Country
1 Umbric Gleysol (Humic, Dystric); *2*, *6* Haplic Gleysol (Humic, Alumic, Eutric); *3*, *5* Umbric Gleysol (Humic, Alumic, Dystric); *4* Mollic Gleysol (Calcaric, Humic, Eutric); *7* Umbric Gleysol (Humic, Eutric)

Table 3.8 Main characteristics of some profiles of Andosols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Ex.Al (cmol$_C$ kg^{-1})	Oxides (%)	
															Al	Fe
1	G 1311	Pontevedra	450	Granite of two micas	Gorse scr. *Eucalypt.*	Flat area in slope	0–200	Sandy-loam	4.5	15–5	11–17	53	4–2	14–11	0.8	0.5
												24			0.5	0.5
2	G 801	Coruña	140	Amphibolites	Gorse scrub	Undulating	0–75+	Sandy-loam	6.4–6.0	13–15	14–14	62	3–16	26–25	–	
												37				
3	G 371	Coruña	240	Gneiss	Gorse scrub	Undulating	0–130+	Loamy-sand	5.0–5.2	14–3	13	72	1–2	46–18	–	–
												16				
4	G 1134	Lugo	50	Phyllites	Gorse scrub	Smooth hill	0–90	Sandy-loam	5.0–5.2	9–7	11–12	32	9–7	31–39	1.0	1.5
												43			1.1	1.9
5	G 1439	Pontevedra	40	Granite	Gorse Scrub	Flat area at bottom slope	0–98+	Loamy-sand	4.5–5.0	8–5	13–16	33	3–1	8–8	0.4	0.5
												31			1.1	0.6
6	G 1317	Coruña	530	Gneissic granite	Pines and Gorse scr.	Flat area in slope	0–190	Sandy-loam	4.0–4.8	18–4	12–16	51	4–4	9–3	1.1	0.6
												24			0.6	0.3
7	B Ex19/6[a]	Bizcaya	–	Volcanic rocks	–	–	A 0–15	–	4.8	16	–	–	15	4–4	–	–
							B$_w$ 15–50/60		5	8			1			
8	B P9/4[b]	Bizcaya	590	Volcanic rocks	*Pinus radiata*	Slope	A$_1$ 0–5	–	4.2	16	–	–	–	–	–	–
							A$_2$ 5–32		4.6	9			2	–		
							B$_{w1}$ 32–53		4.7	8			1	5		
							B$_{w2}$ 53–63/70		4.8	7			–	–		

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1–6 Umbric Melanic Andosol (Dystric, Thixotropic); *7* Leptic Aluandic Andosol (Dystric); *8* Umbric Aluandic Andosol (Dystric)

Detailed data from profiles 7 and 8

[a] *Bw* Bulk density (g.cm^{-3}), 0.8, pH NaF 11.5, phosphate retention 89 %, (Al + 1/2Fe)ox (%), 1.7, (Si)ox (%) 0.11, (Al)py/(Al)ox (%), 1.18

[b] A1, pH NaF 9.0, phosphate retention 86 %; (Al + 1/2Fe)ox (%), 2.5; A2, Bulk density (g.cm-3), 0.83; pH NaF, 9.6, phosphate retention 90 %; (Al + 1/2Fe)ox (%), 2.7, (Si)ox (%), 0.12, (Al)py/(Al)ox (%), 0.53; Bw1, Bulk density (g.cm-3), 0.9; phosphate retention 85 %, (Al + 1/2Fe)ox (%), 2.4, (Si)ox (%), 0.10, (Al)py/(Al)ox (%), 0.58; Bw2, Bulk density (g.cm-3), 0,93

Table 3.9 Main characteristics of some profiles of Podzols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Ex. Al (cmol$_C$ kg^{-1})	Oxides (%)	
															Al	Fe
1	G 1110	Coruña	100	Quartzite	Scrub with pines	Slope	O+A 0–15	Sandy-L	3.6	12	15	65	7	2	0.0	0.4
							E 15–55	Sandy-L	4.2	1	28	7	19	2	0.0	0.2
							B$_h$ 55–60	S-Clay-L	4.5	7	12	34	8	3	1.4	3.7
							Bs 60–130	S-Clay-L	4.8	4	12	32	3	15	2.3	2.9
2	G 1131	Lugo	120	Sandstone	Scrub	Slope	A$_1$ 0–5	Sandy	4.6	4	19	21	14	3	0.2	0.1
							E 5–25		4.9	1	16	15	7	1	0.1	0.1
							Bh 25–35		4.7	7	18	74	4	12	1.1	2.4
							Bs 35–60		5	2	–	26	3	7	1.2	1.0
							C$_1$ 60–200									
3	G 95	Lugo	860	Sandstone Schist	Scrub	Mountain Summit	A$_1$ 0–15	Loamy sand	4.3	25	14	60	8	8	0.2	0.5
							E 15–75		4.9	2	–	16	5	5	0.2	0.7
							Bms 75–78		5.6	3	19	24	2	8	1.0	2.7
							Cg 78–150		5.5	0	–	9	4	6	0.4	1.3
							C +150									
4	G 253	Orense	960	Schist rich in quartzite	Scrub reforested with pines	Peneplain	A 0–20	Loamy sand	4.4	23	32	60	12	10	0.4	0.8
							E 20–35		4.6	5	32	13	2	5	0.2	0.5
							B$_h$ 15-50		5	9	27	53	1	13	0.8	1.6
							Bs 50–350		5.5	5	23	29	2	11	1.3	1.0

(continued)

Table 3.9 (continued)

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Ex. Al ($cmol_C$ kg^{-1})	Oxides (%)	
															Al	Fe
5	A 1030	Oviedo	170	Paleogene Sands	Permanent prairie	Smooth slope	A 0–3	Sandy	5.8	2	53	16	32	4	0.1	0.1
							E 3–20		6.1	0.2	52	9	95	1	0.0	0.0
							B_h 20–35		5.5	5	32	15	7	5	1.0	0.5
							Bsg 35–70		5.2	1	-	15	3	3	0.5	1.9
							C +130								0.6	2.4
6	A 112	Oviedo	825	Quartzite	Scrub	Slope	A 0–35	Sandy-loam	4.7	10	23	46	8	8	0.5	1.4
							E 35–80		5.0	3	19	24	6	6	0.5	1.4
							Bs 80–95		5.5	2	0	11	3	5	0.6	2.9
							Bms 95–98		5.6	3	–	13	3	3	1.2	5.1
							C 102									
7	C 1183	Santander	50	Sandstone	Scrub reforested with *Eucalyptus*	Slope	O 0–15	Sandy	4.2	12	19	32	31	1	0.1	0.2
							A 15–25		3.9	6	19	22	39	1	0.1	0.1
							E 25–60		5.0	1	19	5	53	0	0.0	0.1
							Bh 60–70		4.4	2	25	41	18	1	0.8	2.1
							Bs 70–130		4.3	4	19	21	15	1	1.0	1.5
							C +130									

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country
1, *2*, *4* Haplic Podzol; *3* Gleyic Placic Podzol; *5* Stagnic Podzol; *6* Umbric Orsteinic Podzol; *7* Umbric Podzol

Table 3.10 Main characteristics of some profiles of Stagnosols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Colour (moist)	pH$_w$	O.M. (%)	CEC (cmol$_C$ kg^{-1})	V (%)	Exc. Al (cmol$_C$ kg^{-1})	Oxides (%)	
															Al	Fe
1	G 821	Coruña	370	Amphibolite	Scrub of gorse	Plain	A 0–20	S-Clay	5YR 3/2	5.1	10	52	0	33		–
							B 20–35	Clay	5YR 4/3	5.2	3	23	3	9		
							Cg1 35–65	Clay	7.5YR 6/6; 5 YR 4/6	5.1	–	17	12	8		
							Cg2 65–80	Clay	7.5 YR 6/6;10 R 4/4	5.1	–	13	15	6		
							Cg3 +80		7.5 YR 6/6							
2	G1129	Lugo	360	Clayey Terciary sediments	Scrub	Undulating	A 0–10	S-Clay	5YR 5/2	5.0	12	61	17	3	0.2	0.8
							Cg1 10–60	Clay	5Y 6/2; 7.5 YR 5/4	5.0	1	30	10	3	0.2	0.5
							Cg2 +60	S-C-L	5Y 6/2; 7.5 YR 5/4	4.8	1	27	10	2	0.4	0.4
3	G1104	Orense	620	Sediments with quartzite	Degraded scrub	Peneplain	A 0–25	S-C-L	5YR 2/2	5.0	10	36	7	18	1.0	1.2
							Cg1 25–50	Clay	5YR 4/4	5.0	5	19	7	4	1.0	2.5
							Cg2 50–100	Clay-L	10YR 6/6; 2.5YR 6/8	5.0	–	8	11	2	0.6	1.5
							Cg3 +100	Clay	2.5Y 5/4	4.9	–	12	8	2	0.5	1.5
4	A 975	Oviedo	95	Limestone Marls	Eucalyptus and grassland	Flat area	A 0-20	Clay-L	10 YR 5/2	6.3	10	77	77	2	0.4	1.5
							Cg1 20–40	S-C-L	10 YR 6/2	8.0	6	63	97	0	0.4	2.0
							Cg2 40–105	Clay	10YR 8/3	7.6	–	26	91	0	0.4	2.9
							Cg3 +105	Clay-L	10YR 8/3; 10 YR 7/2	5.7	–	21	84	0	0.3	1.6
5	C1189	Santander	840	Red Marls of the Trias	Oak forest	Undulating	A 0–20	L-Sand	7.5 YR 4/2	6.2	4	13	71	1	0.1	0.8
							Cg1 20–40	S-C-L	2.5 YR 5/4	5.2	1	11	59	0	0.2	0.6
							Cg2 40–200	S-C-L	2.5 YR 6/2 (grey-greenish mottles)	4.8	1	13	63	1	0.2	0.2
							C +200									

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1 Haplic Stagnosol (Alumic, Dystric, Clayic); *2* Haplic Stagnosol (Dystric, Clayic); *3* Umbric Stagnosol (Alumic, Dystric, Clayic); *4* Haplic Stagnosol (Calcaric, Eutric, Clayic); *5* Haplic Stagnosol (Calcaric, Eutric)

Table 3.11 Main characteristics of some profiles of Phaeozems

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Exch. (cmol$_C$ kg^{-1})	
														Ca	Mg
1	G 1114	Lugo	650	Limestone	Holm-oak wood	Undulating	A 0–15	Sandy-C-L	7.7	5	12	47	94	31	11
							Bw 15–130	Clay	7.8	–		15	81	7	3
2	G 44	Lugo	283	Limestone	Scrub	High slope	A 0–30	Sandy-Loam	7.5	3	13	18	61	8	2
							Bw 30–120	Sandy-Loam	8.1	3	9	18	78	9	3
3	A 953	Oviedo	240	Limestone	Gorse scrub.	Hill (*Carcava*)	A 0–25	Clay	6.8	20	14	75	75	55	0
							C +25								
4	A 991	Oviedo	300	Calcareous rocks and sandstone	Grassland + small forests	Undulating	A 0–15	Sandy-C-L	7.2	4	9	24	81	18	1
							Bw 15–25	S-Clay-Loam	7.1	8	8	14	79	8	1
							C +25								
5	A 1000	Oviedo	550	Limestone	Grassland	Hill	A 0–20	Clay	6.8	11	10	64	83	46	6
							Bt 20–45	Silty-Clay	7.8	7	10	9	100	7	2
							C +45	Clay-Loam	8.1	3	16	21	100	15	6
6	C 1182	Santander	75	Limestone	Grassland	Hill	A 0–40	Sandy-Clay-Loam	7	7	11	48	80	37	1
							C 40								
7	C 1186	Santander	1170	Grey limestone.	Scrub	Slope	A 0–30	Sandy-Clay-Loam	6.4	13	11	62	69	42	0
							C +30								
8	C 1211	Santander	400	Marls of the Flysch	Grassland	Slight slope	A 0–10	Clay	7.7	7	10	44	100	43	1
							Bw 10–60	Clay-Loam	8.2	3	10	26	100	25	1
							C +60								
9	C 1209	Santander	570	Marls of the Flysch	Grassland	Abrupt slope	A 0–10	Clay	6.7	7	11	31	76	22	0
							Bw 10–70	Clay	7.1	2	9	28	75	20	0
10	B L9	Álava.	980	Dolomite	Grassland	Flat	A 0–45	Clay	7.8	7	13	27	82	14	8

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B*, Basque Country
1 Haplic Phaeozem (Calcaric, Clayic); *2* Haplic Phaeozem (Calcaric); *3*, *8*, *9* Leptic Phaeozem (Calcaric, Clayic); *4*, *7* Leptic Phaeozem (Calcaric); *5*, *10* Leptic Phaeozem (Anthric, Calcaric, Clayic); *6* Leptic Phaeozem (Anthric, Calcaric)

Table 3.12 Main characteristics of some profiles of Alisols and Acrisols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Clay (%)	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1} soil)	CEC ($cmol_C$ kg^{-1} clay)	V (%)	Exch. ($cmol_C$ kg^{-1})	
																Ca	Mg
1	B P2[a]	Vizcaya	–	Dolerite	Pinus radiata	Slope	A 0–40	Clay-Loam	33	5.8	6	–	12	36	45	8	2
							2Bw 40–80	Clay-Loam	32	5.3	1	–	–	–	–	2	0
							2Bwt/R 80–100	Clay-Loam	31	5.1	1	–	15	48	11	–	
2	C 1199	Santander	90	Sandstone	Oak forest	Undulating	A 0–15	Sandy-Loam	15	6.1	7	17	21	140	70	11	3
							Bt 15–120	Sandy-C-L	28	5.0	1	9	12	43	28	3	0
3	C 1205	Santander	100	Sandstone	Oak forest + Gorse scrub	Undulating	A 0–25	Sandy-Loam	24	6.4	7	15	29	121	56	16	1
							Bt 25–50	Clay	51	4.9	1	–	15	29	15	2	0
4	G 1136	Lugo	340	Marginal Sediments	Grassland	Depression	A 0–20	Sandy-Loam	12	5.0	4	30	27	225	9	1	0
							Bt 20–100	Sandy-Loam	21	4.5	1	–	11	52	16	1	0
5	B L1	Álava	640	Schist	Pine forest	Undulating	A 0–35	Sandy-C-L	26	4.7	3	13	16	62	17	3	0
							Btg 35–70	Clay-Loam	37	5.0	1	8	13	35	17	2	0
6	G 1103	Lugo	540	Tertiary sediments	Scrub + pines	Undulating	A 0–10	Clay-Sandy	27	4.8	11	13	32	12	12	3	0
							Bt 10–30	Clay Sandy	33	4.5	6	12	26	8	9	2	0
							Btg 30–125	Clay	44	5.0	–	–	–	–	–	–	

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1 Leptic Umbric Cutanic Alisol (Humic); *2*, *4* Haplic Alisol (Humic); *3* Leptic Umbric Alisol (Humic, Clayic); *5* Umbric Gleyic Alisol (Humic); *6* Haplic Acrisol (Hyperdystric)

[a] Frequent coatings 7.5YR 5/8; few coatings 5YR 5/8

Table 3.13 Main characteristics of some profiles of Luvisols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Clay (%)	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1} soil)	CEC (cmol$_C$ kg^{-1} clay)	V (%)	Exch. (cmol$_C$ kg^{-1})	
																Ca	Mg
1	A 996	Oviedo	300	Mountain Limestone	Deciduous forest	Abrupt Slope	A 0–10	Clay	61	5.8	10	28	43	70	57	24	1
							Bt 10–30		63	5.8	7	12	34	54	42	14	1
							C1 +30										
2	A 1028	Oviedo	80	Limestone	Grassland	Undulating	A 0–20	Cl-loam	38	5.8	6	12	21	55	71	13	2
							Bt 20–85	Clay	58	6.5	2	–	21	36	53	6	6
3	A 1036	Oviedo	140	Limestone (Karst)	Gorse scrub Chestnut.	High slope	A 0–20	S-C-loam	25	7.2	6	10	36	144	68	19	6
							Bt 20–40	Clay-L	30	7.6	2	7	15	50	70	9	1
							C +40										
4	C 1193	Santander	90	Limestone	Gorse scrub	Slope	A 0–15	S-C-loam	25	6.1	5	13	15	60	63	8	1
							Bt1 15–45	S-C-loam	28	7.0	3	11	11	39	60	8	0
							Bt2 45–10	Clay-L	33	6.7	2	12	10	30	71	6	0
5	C 1178	Santander	1550	Mountain Limestone	Alpine prairie	Undulating	A 0–20	Clay	48	5.2	10	9	58	121	71	6	0
							Bt1 20–50	Clay	48	4.7	5	8	49	102	52	26	3
							Bt2 50–100	Clay	59	4.4	3	8	38	65	29	10	0
6	C 1194	Santander	150	Limestone	Scrub (young oak trees)	Slope	A 0–10	S-Clay	37	7.0	9	13	37	100	73	23	1
							Bt1 10–45	Clay	62	7.0	3	12	18	29	73	11	1
							Bt2 45–100	Clay	63	7.0	2	9	19	30	71	12	1
							C +100										
7	B L10	Álava	640	Calcareous Marls	Oaks, *Ulex sp.*	Undulating	A 0–10025	Clay-L	37	7.8	5	13	26	70	100	24	1
							Bt1 25–40	Clay	46	7.8	2	9	25	54	100	24	0
							Bt2 40–60	Clay	57	7.8	1	8	29	51	100	29	0
8	B 33	Bizcaya	200	Metamorphic Limestone	Heath scrub +Pine forest	Undulating	A 0–10	S-C-loam	23	5.9	6	16	19	83	51	9	2
							Bt1 10–40	Clay-L	36	6.6	2	11	16	44	44	7	0
							Bt2 40–80	Clay	57	6.6	1	7	20	35	52	10	0
							C + 80										

(continued)

Table 3.13 (continued)

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Clay (%)	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1} soil)	CEC (cmol$_C$ kg^{-1} clay)	V (%)	Exch. (cmol$_C$ kg^{-1})	
																Ca	Mg
9	B P31/4[a]	Bizcaya	205	Dolerite	*Pinus radiata*	Slope	A 0–25	Silty/C/L	39	5.2	5	–	37	95	42	13	2
							2Bt1 25–50	Silty/C/L	36	5.5	1	–	24	67	58	10	3
							2Bt2 50–80	Silty/C/L	36	5.4	0	–	29	81	63	9	8
							2Ct 80–90+	Silt-loam	22	5.6	–	–	–	–	–	–	

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1, *2*, *8* Leptic Luvisol (Humic, Clayic); *3* Leptic Luvisol (Humic); *4* Haplic Luvisol (Humic); *5*, *6* Haplic Luvisol (Humic, Clayic); *7* Leptic Luvisol (Humic, Hypereutric, Clayic); *9* Cutanic Luvisol (Manganiferric, Humic)

[a] 2Bt$_1$, Abundant 5YR5/8 coatings, freq. black concretions, abundant 7.5YR2/1 mottles; 2Bt2, abundant 5YR5/8 coatings, abundant 7.5YR2/1mottles; 2Ct, YR5/8 coatings

Table 3.14 Main characteristics of some profiles of Umbrisols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Exc. Al ($cmol_C$ kg^{-1})
1	G 343	Coruña	110	Granite	Pine forest + Gorse scrub	Slope	A_0 0–20	Loamy-sand	5.3	7.3	18	27	3	28
							A_1 0–50	Loamy-sand	5.3	5.3	17	21	6	14
							C_1 +50							
2	G 764	Coruña	325	Micacites	Oak forest	Undulating	A 0–30	S-C-loam	4.8	13.8	11	50	2	26
							Bw 30–70	Loamy-sand	5.2	0	–	19	1	3
							C_1 +70							
3	G 180	Coruña	420	Amphibolite	Pine forest + Gorse scrub	Slope	A 0–25	S-loam	5.7	7.1	7	32	2	2
							Bw 25–80	S-loam	5.6	5.1	18	16	8	4
							C1 +80							
4	G 572	Coruña	430	Gabbro	Gorse scrub	Undulating	A 0–30	S-loam	5.5	16	15	52	5	2
							Bg 30–65	S-loam	5.4	2	17	33	4	1
							C1g + 65							
5	G 578	Coruña	390	Clayed schist	Gorse scrub	Undulating	A 0–30	S-Clay	5.2	13	17	59	0	30
							B 30–40	Clay	5.3	5.4	17	37	2	9
							C1g 40–150							
6	G 87	Lugo	500	Porphydic granite of biotite	Scrub	Undulating	A 40	Loamy-sand	5.6	9.5	26	34	5	18
							B 15	Loamy-sand	5.7	0	–	12	3	4
							C1 445							
7	G 1132	Lugo	350	Sandstone	Scrub+Pines	Slope	A 30	Loamy-sand	4.3	6.8	19	41	4	8
							C1 +30							
8	G 1044	Pontevedra	200	Gneiss	Scrub	Slope	A 0–30	S-loam	5.6	6.7	12	43	5	20
							B 30–60	Loamy-sand	5.6	1.7	11	14	7	5
							C1 +60							
9	G 1993	Orense	1020	Granite	Gorse scrub	Undulating	A 0–30	S-loam	4.5	14.1	16	56	3	16
							B 30–70	Loamy-sand	5.6	4.2	14	26	3	9
							C1 70–+400							
10	A 124	Oviedo	452	Gneiss	Gorse scrub	Abrupt slope	A 0–30	Loamy-sand	5.3	12.8	13	55	2	18
							B 30–60	Sand	5.4	4.2	9	37	2	4
							C1 +60							

(continued)

Table 3.14 (continued)

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Exc. Al ($cmol_C$ kg^{-1})
11	A 1145	Oviedo	870	Phyllites	Scrub+Pines	Hilly	A 0–40	S-loam	4.3	4.0	8	27	8	6
							C1 +40							
12	C 1185	Santander	1200	Red Sandstone	Scrub	Slope	A 0–60	Clay	6.5	11.2	12	61	49	5
							C1 +60							
13	C 1205	Santander	100	Sandstone	Oak forest+ gorse scr.	Undulating	A 0–25	S-loam	6.4	6.7	17	29	56	1
							Bw 25–50	Clay	4.9	1	–	15	15	2
							Cg +50							
14	B L3	Álava	850	Limestone	Scrub	Slope	A 0–30	Loamy-sand	5.5	3	18	8	25	–
							B 30–45	Loamy-sand	5.0	0	–	6	21	–
							BC 45–70							
15	B URB-2	Guipúzcoa	1335	Limestone	Grassland	Depression	A 0–14	Clay-Loam	4.6	8.5	9.3	27	18	8
							AB 14–40		4.8	3.3	–	22	9	9
							Bw 40–60		6.0	3.6	–	27	53	–
16	B AHC	Guipúzcoa	685	Granitic Colluvium	Pasture	Slope	A 0–35	Sandy-L	5.1	8.6	12	28	3	6
							2Ag 35–60	Sandy-L	5.3	5.6	–	19	1	3
							2C 60–120	Sandy-L	6.3	2.5	–	24	20	–

Profile code G Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1 Leptic Umbrisol (Humic, Alumic, Hyperdystric, Pachic); *2* Cambic Umbrisol (Humic, Alumic, Hyperdystric); *3* Cambic Umbrisol (Humic, Hyperdystric); *4* Leptic Endogleyic Umbrisol (Humic, Hyperdystric), *5* Endogleyic Umbrisol (Humic, Alumic, Hyperdystric, Clayic); *6* Haplic Umbrisol (Humic, Alumic, Hyperdystric, Clayic); *7*, *11*, *15* Leptic Umbrisol (Humic, Hyperdystric); *8*, *10* Leptic Umbrisol (Humic, Alumic, Hyperdystric); *9* Haplic Umbrisol (Humic, Alumic, Hyperdystric); *12* Mollic Umbrisol (Humic, Pachic, Clayic), *13* Cambic Mollic Umbrisol (Humic, Clayic); *14* Haplic Umbrisol (Humic); *16* Endogleyic Umbrisol (Humic, Hyperdystric)

Table 3.15 Main characteristics of some profiles of Cambisols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Structure Bw horizon	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Exc. Al (cmol$_C$ kg^{-1})
1	G 542	Coruña	350	Amphybolite	Gorse scrub	Undulating	A 0–8	S-C-loam	Prismatic	5.4	9.9	13	30	4	27
							Bw 8–45	S-C-loam		5.4	0	–	23	6	4
2	G 1103	Lugo	540	Terciary sediments	Scrub + pines	Undulating	A 0–10	Clay-loam	Granular	4.8	11.0	13	32	12	15
							Bw 10–125	Clay-loam		4.7	3.0	12	27	9	13
3	G 56	Lugo	620	Ferriferous schist	Grassland	Plateau	A 0–5	L-Sand	Granular	6.1	5.2	16	33	5	1
							Bw 5–20	L-Sand		5.4	1	–	20	2	1
4	G 1013	Orense	860	Grey clayed Slates	Grassland	Abrupt slope	A 0–10	Loam	Polyhedrons	5.7	5.4	11	19	18	8
							Bw 10–75	Loam		6.0	4.3	11	19	10	9
5	G 164	Orense	380	Clayed schist	Holm-oak wood	Slope	A 0–20	Sand	Polyhedrons	5.8	3.8	11	20	32	2
							Bw 20–40	Sand		5.9	1.6	7	11	15	2
6	G 1066	Orense	320	Granite	Scrub	Undulating	A 0–20	S-loam	Granular	4.7	2.9	18	15	21	33
							Bw 20–80	S-C-loam		5.2	0	–	13	11	26
7	A 990	Oviedo	150	Marls of the Bunt and Permotrias	Mixed Deciduous Forest	Scarped hills	A 0–10	S-C-loam	Polyhedrons	4.8	8.2	16	20	19	2
							Bw 10–40	S-C-loam		4.7	4.6	29	14	8	1
							Cg 40–70	Clay-loam		4.9	1.7	14	14	6	1
8	A 1137	Oviedo	390	Phyllites	Scrub + Pines	Slope	A 0–5	Loam	Granular	3.9	22.2	23	63	4	8
							Bw 5–60	S-C-Loam		4.5	4.5	15	27	19	3
9	A CS1-013	Oviedo	683	Limestone	Grassland	Undulating	A 0–11	Loam	Subangular polyhedrons	7.5	7.9	–	34	96	–
							Bw 11–40	S-C-loam		7.7	3.5	–	32	74	–
							C +40								
10	C 1198	Santander	130	Sandstone	Scrub + Eucaliptus	Slope	A 0–8	S-loam	Granular	4.5	9	27	21	9	3
							Bw 8–120	S-C-loam		4.6	1.4	18	17	5	2
11	C 1201	Santander	970	Limestone	Beech tree forest	High slope	A 0–20	S-C-loam	Granular	5.8	5.6	10	52	28	3
							Bw 20–120	S-C-loam		6.7	2	10	33	40	1
12	C 1210	Santander	650	Conglomerate of sandstone	Gorse scrub	Slope	A 0–15	S-loam	Granular	4.1	11.9	16	35	8	6
							Bw 15–70	S-loam		4.6	1.7	13	16	6	4
13	C 1191	Santander	150	Marls of the Buntsandstein	Pasture	Slope	A 0–5	S-loam	Granular	5.3	3	11	16	62	0
							Bw 5–100	S-loam		5.0	0	–	12	27	1
14	B L4	Álava	700	Ofite	Oak forest	Abrupt slope	A 0–10	S-C-loam	Subangular Polyhedrons	6.2	11.1	20	33	69	0
							Bw 10–35	S-C-loam		6.4	5.1	14	24	67	0
15	B L6	Álava	715	Limestone Marls (interc sandstone)	Oak forest	Smooth slope	A 0–20	S-C-loam	Subangular Polyhedrons	7.8	5.3	15	27	100	0
							Bw 20–102	S-C-loam		8	1.1	-	18	100	0

(continued)

Table 3.15 (continued)

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	Structure Bw horizon	pH$_w$	O.M. (%)	C/N	CEC (cmol$_C$ kg^{-1})	V (%)	Exc. Al (cmol$_C$ kg^{-1})
16	B L7	Álava	470	Sandstone + Lutite	Vineyard	Undulating	Ap 0–12	S-loam	Subangular Polyhedrons	7.7	1.4	11	18	100	0
							Bw 12–55	S-C-loam		8.0	1.2	9	19	100	0
17	B P 9/1	Vizcaya	-	Volcanic rocks	Pasture	-	A 0–17	Clay-loam	Fine granular	4.4	17.4	–	2	6	–
							Bw 17–55/70	Loam		4.7	3.8	–	16	2	
18	B ALO1	Guipúzcoa	945	Limestone	Pasture	Slope	A 0–10	Sandy-C-L	Prismatic	4.7	8.8	10	24	26	4
							Bw 10–95	Sandy-C-L	Prismatic	5.0	3.4	8	17	11	6
							C 95–110			5.6	–	–	15	18	0
19	B ALO2	Guipúzcoa	908	Limestone	Pasture	Slope	0–18	Sandy-C-L	Granular	5.1	5.9	11	24	25	3
							Bw 18–12/22	Sandy-C-L	Subang/bloky	5.4	–	–	17	42	2
20	B AHC33	Guipúzcoa	310	Colluvium de Sandstone	Pasture	Slope	A 0–10	Loam	Subang/bloky	4.5	4.5	11	19	13	6
							Bw 10–80	Loam	Subang/bloky	4.7	2.1	–	12	2	4

Profile code G Galicia; *A* Asturias; *C*,Cantabria; *B* Basque Country

1, *4*, *6* Leptic Cambisol (Alumic, Humic, Dystric); *2* Haplic Cambisol (Alumic, Humic, Dystric); *3*, *5*, *7*, *8*, *19*, *20* Leptic Cambisol (Humic, Dystric); *9*, *13*, *14*, *16* Leptic Cambisol (Humic, Eutric); *10*, *18* Haplic Cambisol (Humic, Dystric); *11*, *15* Haplic Cambisol (Humic, Eutric); *12*, *17* Leptic Cambisol (Humic, Dystric)

Table 3.16 Main characteristics of some profiles of Regosols

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Exc. Al ($cmol_C$ kg^{-1})
1	G 401	Coruña	180	Altered granite	Gorse scrub	Undulating	A 0–30	Sandy-L	4.9	16	15	111	0	19
							B 30–80	Sandy-L	5.2	10	16	46	0	13
							C1 +80							
2	G 1051	Pontevedra	500	Amphybolite	Scrub	Undulating	A 0–20	S-Cl-Loam	5.7	7	10	31	7	15
							B 20–35	S-Cl-Loam	5.5	3	10	15	8	8
							C1 +35							
3	G 1046	Pontevedra	170	Altered granite of Lage	Scrub + Pines	Undulating	A 0–20	S-Loam	5.5	10	17	46	4	14
							B 20–40	S-Loam	5.7	4	14	24	8	11
							C1 +40							
4	G 141	Lugo	420	Porphydic granite	Old oak forest	Undulating	A 0–20	S-Loam	5.3	10	12	37	5	17
							B 20–40	S-Loam	5.5	3	9	15	11	4
							C1 +40							
5	G 1122	Lugo	1250	Altered schist	Scrub	Mountain summit	A 0–20	S-Loam	4.6	13	68	78	8	7
							Bg 20–30	Loam	4.5	1	–	14	4	6
							C1 +30							
6	G 154	Orense	820	Altered gneiss	Oak forest	Slope	A 0–10	S-Loam	5.6	7	12	26	30	5
							B 10–40	S-Loam	5.7	2	17	14	18	2
							C1 +40							
7	G 1989	Orense	830	Phyllites	Scrub of *Erica australis*	Undulating	A 0–15	S-Clay	4.6	15	19	39	5	24
							B 15–75	Clay-Loam	5.0	3	14	9	18	3
8	A CS2-PA061	Oviedo	1387	Sandstone (colluvial)	Grassland	Mountainous	A 0–10	L-Sandy	5.0	5	–	10	44	–
							C1 10–59	L-Sandy	6.0	2		6	69	–
							C2 59–110	L-Sandy	6.5	0		–	–	–
9	C 1181	Santander	1595	Schist	Scrub of *Erica* and *Sarothamnus*	High slope	A 0–20	Loam	5.0	8	10	52	17	6
							B 20–40	Sandy-L	4.4	1	8	28	12	0
10	C 1210	Santander	650	Colluvium of microconglomerate of sandstone	Scrub of gorge	Slope	A 0–15	Sandy-L	4	14	16	35	8	6
							B 15–70	Sandy-L-	4.6	2	13	16	6	4
							C +70							
11	C 1190	Santander	860	Sandstone	Scrub	Slope	A 0–31	Sandy-L	4.9	8	22	37	48	8
							C +31							

(continued)

Table 3.16 (continued)

No.	Profile code	Location	Altitude (m a.s.l.)	Parent material	Type of vegetation	Topography	Depth (cm)	Textural class	pH_w	O.M. (%)	C/N	CEC ($cmol_C$ kg^{-1})	V (%)	Exc. Al ($cmol_C$ kg^{-1})
12	B P 7/1	Vizcaya	–	Lutites	–	–	A 0–18	Loam	4.0	5	–	–	3	–
							B/C 18–45	Clay-Loam	4.2	4	–	–	5	–
13	B Ex5/1	Vizcaya	–	Lutites	–	–	A 0–25/30	Clay-loam	6.6	6	–	–	65	–
14	B L16	Álava	640	Sandstone intercal, phyillites	Scrub	Slope	A1 0–9	Sandy-L	5.2	12	20	27	12	–
							A2 9–22	Sandy-C-L	5.2	9	19	30	7	–

13*Profile code G* Galicia; *A* Asturias; *C* Cantabria; *B* Basque Country

1, *2*, *3*, *4*, *6*, *7*, *9*, *10*, *12*, *14* Leptic Regosol (Humic, Dystric); *5* Endogleyic Regosol (Humic Dystric); *8* Haplic Regosol (Humic, Eutric); *8* Haplic Regosol (Humic, Eutric); *11*, *13* Leptic Regosol (Humic, Eutric)

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Soils of the Arid Areas

4

David Badía-Villas and Fernando del Moral

4.1 Introduction

The soils in arid areas tend to have relatively soluble mineral accumulations such as carbonates, sulphates, and chlorides. The carbonates, gypsum, and other more soluble salts found in soils may have their origins in the parent material itself—marine aerosols—and even be of anthropogenic origin (secondary salinization). In wet areas, where average annual precipitation exceeds evapotranspiration, these compounds can be removed entirely from the soil profile. However, in arid lands, calcium carbonate, gypsum, or other salts remain within the soil, or else they accumulate within a profile depth according to the salt solubility and the soil depth reached by the wetting front. In this sense, Dan et al. (1981) observed a good correlation between long-term mean annual precipitation (MAP) and the depth where salic, gypsic, calcic and even argic horizons are located. While Chromic Luvisols are found in moister environments (MAP about 500–650 mm yr^{-1}), Calcic Luvisols or Luvic Calcisols are located in semi-arid regions (MAP 350–500 mm yr^{-1}) and Petric Calcisol is predominant in driest areas with vegetation changing from Mediterranean sclerophyllous wood to open scrublands.

Peninsular Spain is noted for its aridity in the northeast, specifically in the Middle Ebro Basin (south of the Provinces of Navarra, Zaragoza, Huesca, and Lleida), as well as in the southeast (provinces of Alicante, Murcia, Almería); both areas (Fig. 4.1) are discussed in this chapter. Similar areas can be also seen in Fig. 1.4 of Chap. 1, Fig. 2.1 of Chap. 2, and Fig. 5.1 of Chap. 5.

In the Ebro Basin, dryness is caused by the effect of the rain shadow (Föehn effect) exerted by the surrounding mountains as well as the drying effect of the wind (Herrero and Snyder 1997). In the southeastern peninsula, the lack of rain, combined with the arrival of dry winds from North Africa (*calimas*), causes severe water deficits (Table 4.1). In addition to climatic aridity, soil aridity must be added, related to the low water-holding capacity (WHC) of the soils, mainly due to its low thickness and/or high level of stoniness (Fig. 4.2).

The steep slopes increase surface runoff and therefore reduce the penetration of water into the soil (Badía et al. 2007), and the southern slopes increase evaporation losses by insolation. All these conditions cause these regions to have a dry soil profile during most of the year, i.e., an aridic moisture regime (I.G.N. 2006) in a globally xeric Mediterranean context (see the chapter on Soils of Spain: Distribution and Classification).

4.2 Processes of Soil Formation

The soil-forming factors (climate, vegetation, lithology, geomorphology, and time) proceed through various processes, which may occur over time, act simultaneously, and even be antagonistic (Hugget 1998). The processes acting on a soil can be grouped into three categories: transformations, translocations, and additions/losses.

4.2.1 Transformations (Organic and Inorganic)

This is the group of processes that involve changes in the composition and shape of the organic and/or inorganic material that can affect the soil

4.2.1.1 Weathering

Weathering is the transformation of soil mineral material or bedrock by various atmospheric agents. Therefore, weathering processes can be considered pedogenetic and pre-pedogenetic prior to soil-horizon differentiation

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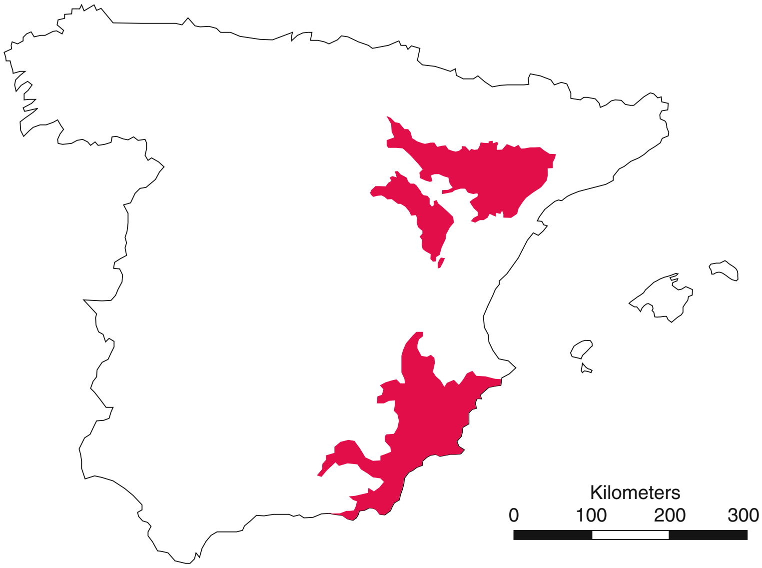

Fig. 4.1 Schematic map with arid lands described in this chapter (*red color*)

Table 4.1 Mean annual temperature (MAT), mean annual precipitation (MAP), and evapotranspiration of reference (ETo) in some cities of arid environments in the world

Location	MAT (°C)	MAP (mm)	ETo (mm)	ETo-MAP (mm)
Zaragoza (Spain)	14.9	337	1406	1069
Almería (Spain)	18.0	233	1297	1030
Davis (USA)	14.3	435	1333	898
Athens (Greece)	18.3	402	1242	840
Tunis (Tunisia)	18.3	443	1159	716
Casablanca (Morocco)	17.8	426	1076	650
Seville (Spain)	18.8	564	1161	597
Brindisi (Italy)	16.8	644	1141	497

Source Herrero and Snyder (1997)

processes. They can be physical in nature (fragmentation of rocks), chemical (changes in the nature of materials), or biological (which ultimately includes physical or chemical processes) caused by organic activity.

In arid soils, the most significant weathering processes are: dissolution, which affects carbonates from (marls, limestones, sandstones), gypsum and more soluble salts, and weathering by salt crystallization (gypsum, mirabilite, halite, etc.). Sometimes hydration is included, which causes an increase in volume, cupping and disintegration of marl, sandstone, and other parent materials.

4.2.1.2 Rubefaction and Brunification

Both processes involve iron release by the weathering of primary minerals whose differentiation is based on a secondary formed Fe mineral, which in turn is related to the environmental conditions of their formation. In the rubefaction, ferrihydrite (the mineral precursor) rapidly evolves into hematite (Fe_2O_3) in hot, dry conditions, in a dehydration process of the Fe oxides bound in clay. It is an almost irreversible process that gives the soil an intense red color, typical of Mediterranean climates or climates with well-marked seasonal contrasts. In the Middle Ebro Valley, it does not appear in the more arid areas but rather in glacis and Pleistocene alluvial terraces. In wetter and cooler temperate climates, the dehydration of the iron oxide is not possible, and this promotes the formation of goethite (Fe-OOH), so that the soil becomes brown (brunification).

4.2.1.3 Gleyzation

Hydromorphic conditions (excess of water) and oxygen demand by organisms favor the reduction of oxides of iron and manganese (gleying), which gives the soil a greenish-gray color. The formation of hydrogen sulphide by sulphate reduction is frequent, for example, in the salt-playa lakes of Monegros (Conesa et al. 2011), also named “crypto-wetlands” (Badía et al. 2011a; Pedrocchi 1998). Alternating wet and dry conditions, i.e., reducing and oxidizing throughout the year, appears with gray colors alternating with red and brown (mottled), and speckled black, also caused by precipitation of pirolusite (MnO_2). In arid lands, these conditions are observed, in addition to endorrheic areas, on recent alluvial deposits, close to the main riverbeds (Ebro, Cinca, Gállego, etc.).

4.2.1.4 Melanization

Melanization is a darkening process of the surface soil horizons from the evolution of fresh organic residues into complex forms (humus), with the participation of microorganisms. The darkening is more intense or less intense, according to whether mineralization or humification

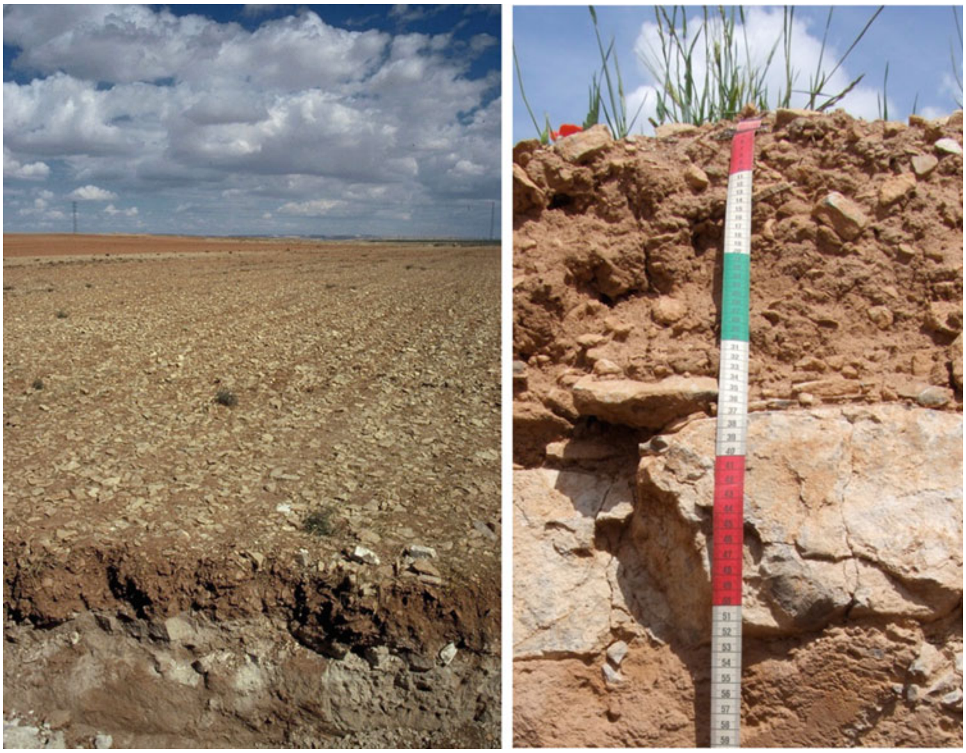

Fig. 4.2 General view and detail of a soil in the Monegros Desert. Low thickness and high stoniness reduces its water-holding capacity, adding soil aridity to the climatic one

Table 4.2 Effect of conventional tillage on soil organic matter content and melanization index in three surface horizons (0–20 cm) of the Ebro Valley (*n* = 8)

Soil properties	Land use	Soil unit		
		CLcch	*CLpt*	*RGca*
Organic matter %	Farming	0.9 ± 0.1	1.1 ± 0.1	0.5 ± 0.0
	Forest	4.1 ± 0.5	4.0 ± 0.5	2.6 ± 0.3
Value (dry)	Farming	5.0 ± 0.0	5.3 ± 0.5	6.8 ± 0.5
	Forest	4.3 ± 0.5	4.0 ± 0.0	5.3 ± 0.3
Value (moist)	Farming	4.0 ± 0.0	4.0 ± 0.0	5.0 ± 0.0
	Forest	3.0 ± 0.0	3.1 ± 0.2	3.9 ± 0.2
Melanization index[a]	Δ	18 ± 4.6	21 ± 5.8	26 ± 5.8

Source Lorenzo and Badía (2002). *CLcch* Hypercalcic Calcisol; *CLpt* Petric Calcisol; *RGca* Calcaric Regosol

[a] Melanization Index: 10*(Δ Value dry) + 10 * (ΔValue moist)

dominates. Thus, soil tilling favors mineralization, so that the darkening in agricultural soils is less intense than in the areas of natural vegetation (Table 4.2).

4.2.1.5 Pedoturbation

Pedoturbation is the process in which soil materials undergo changes consisting of positioning and mixing effects. The mixture may be due to an effect of the shrink-swell capacity of clay (clay turbation) or even the action of frost churning (cryoturbation); mixing layers and horizons and meso- and macro-fauna movement (bioturbation) can also take place. Bioturbation is the most widespread and obvious process in the Middle Ebro Basin, mainly by worms.

4.2.2 Translocations

Translocations involve the concentration of materials in certain horizons of the profile. Depending on the cause that generates this movement, we may distinguish between translocations in solution (carbonation, gypsification, salinization), and translocations in suspension (clay illuviation). The movement of these components is usually downward, although it can also be upward to the most soluble salts.

4.2.2.1 Carbonation

This process involves the solubilization of carbonates in the rainy season, which requires transformation into bicarbonates (decarbonation). This occurs due to CO_2 and organic acids produced by biological activity, so that its intensity is highest in the surface horizons. The bicarbonates migrate within the profile to a certain depth, where they are precipitated in the form of carbonates (carbonation) due to the loss of CO_2 gas pressure or increasing cation concentration. This precipitation may also be due to the drying out of the soil:

Decarbonation -->

$CaCO_3$ (solid) + CO_2 + H_2O <-----> Ca^{2+} + $2HCO_3^-$ (solution)

<-- Carbonation

Under a percolating moisture regime, the bicarbonates are virtually eliminated from the soil profile, but in drier conditions they are precipitated as carbonates (carbonation) at depth. The precipitation of carbonates (or carbonation) occurs under various morphologies: vermiform accumulations (*pseudomycelia*) or spherical (nodules or concretions), filling voids of roots (rhizo-concrections), or as a layer under the stones (pendent). Generalized accumulations also observed include both soft (i.e., calcic and hypercalcic horizons) and hard, strongly cemented developing petrocalcic horizons (Alonso-Zarza and Wright 2010; Meléndez et al. 2011; Badía et al. 2013b).

The frequency of the occurrence of petrocalcic horizons in Spanish arid zones is reflected in the many names given to them: *mallacán*, *caliche*, *tosca*, *taparàs*, *calicanto*, and *cervell de gat* (Badía 1989). These accumulations may be polygenic (polycyclic soil genesis), resulting from different paleo-environments. We can find examples of paleosols in the Monegros Desert (Middle Ebro Valley), where successive nodular calcic horizons alternate with argic horizons, being the soil a record of bio-climatic changes during the Quaternary (Badía et al. 2013b). This occurs analogously in the Vera and Sorbas Basins (Province of Almería), where relict Mediterranean red soils are found, showing re-calcification phenomena, fossilization by colluviums, or redeposit. In both cases, leaching of the carbonates may have taken place before eluviation processes and clay dispersion, and even redness and neo-formation of clay minerals (Schulte 2002). Then, evolution of soil morphology showing the distribution of soil-carbonate accumulation (Badía et al. 2015a, b) is sometimes perceptible (Diagram 4.1).

4.2.2.2 Gypsification

Gypsification is the process that involves the solubilization of gypsum (degypsification) in wet seasons to precipitate during dry periods (gypsification), after translocation into the soil. The heterogeneity of the landforms, where pedogenic gypsum appears, may mean that there have been different models of genesis. Thus, in slopes it may have been dissolving materials high in gypsum (alabaster gyprock, gypseous marls, and gypseous sandstones) with precipitation at a short distance; the continuing dissolution and precipitation of gypsum would homogenize and purify the horizon (which turns into a hypergypsic horizon). In the bottom valleys this process may have been accompanied by gravitational contributions. By contrast, in the alluvial terraces, gypsum precipitates from the evaporation of surface water previously enriched by Ca sulphate (Smith 1991; Artieda 1996).

The accumulations of gypsum into the soil adopt various morphologies in the field: vermiform, pendent, and even massive accumulations. Some pedogenic gypsum accumulations are composed of mainly silt-sized crystals (microcrystalline gypsum) and have a flour-like consistency in the field. By contrast, infillings in pore spaces, with a powdery consistency in the field, are composed of sand-sized lenticular gypsum (Fig. 4.3). Both accumulations are interpreted

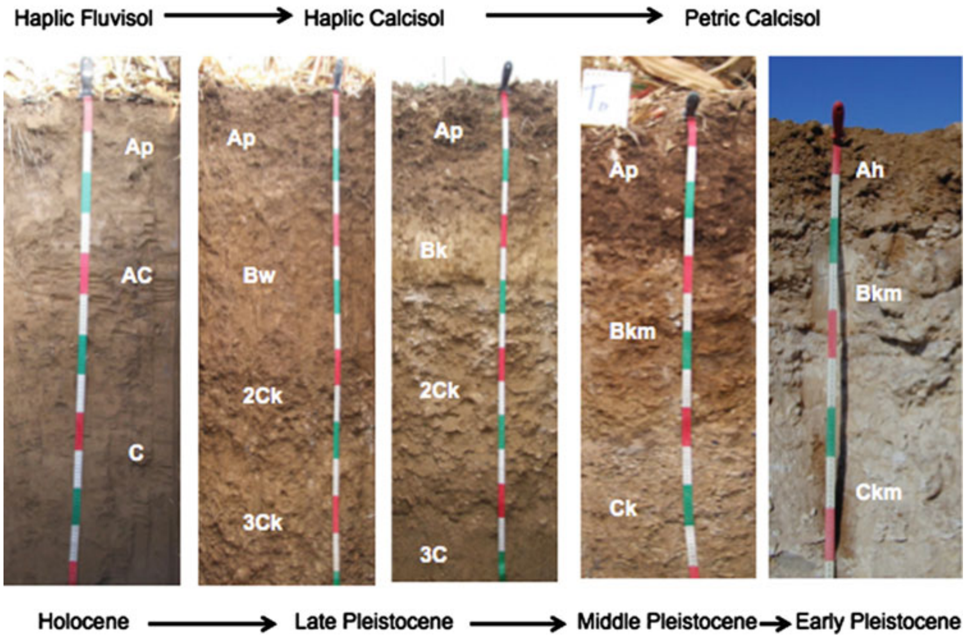

Diagram 4.1 Evolution of the soil morphology and distribution of carbonate accumulations in soils on alluvial terraces of the Alcanadre River (Huesca)

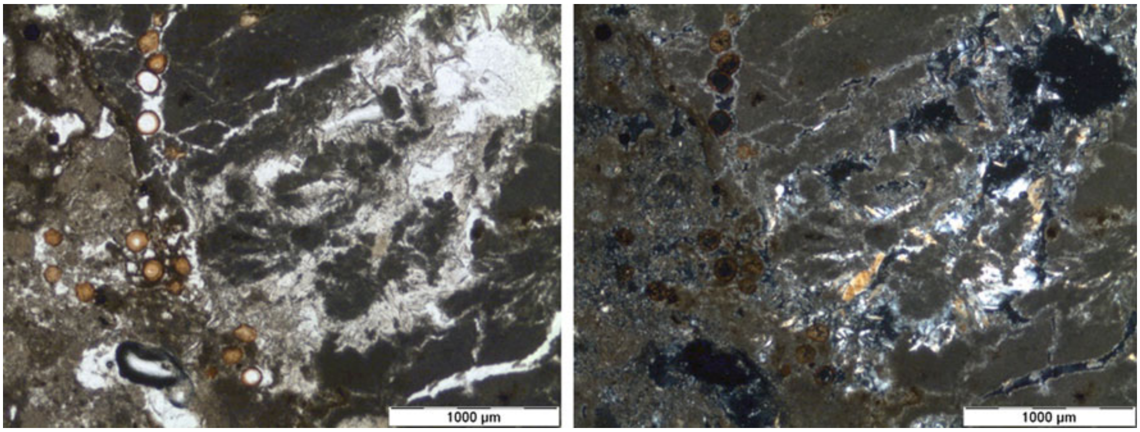

Fig. 4.3 Lenticular gypsum in pores and fissures in a B_y-horizon; *Gypsisol* in Tauste (Province of Zaragoza). Photomicrographs with plane-polarized light (*left*) and cross-polarized light (*right*). Cross sections of roots (brown circles) can be also observed

as being formed by in situ alterations of gypsum rock (Poch et al. 2010; Aznar et al. 2013).

4.2.2.3 Salinization and Sodification

In Spanish arid lands, saline soils are common and even, to a lesser extent, saline-sodic soils. Salinization is a process of soil enrichment with salts more soluble than gypsum, which have important effects on vegetation: an osmotic effect and a specific ion effect and an effect on energetic imbalance. In particular, the salts in saline soils are sodium chloride (NaCl), magnesium chloride ($MgCl_2$), magnesium sulphate ($MgSO_4$) and sodium sulphate (Na_2SO_4). Such salts in the Ebro Basin may originate in soil parent materials such as marls or sandstones (Cuchí 1989; Badía 1992), whose alteration implies a certain distribution of salts in the relief that accumulate on low valleys or depressions (Badía et al. 2011a; Herrero 2008) with poor drainage (Fig. 4.4). Their location and identification would prevent certain land movements from bringing them to the surface or subsequent irrigation (even with good quality water coming from the Pyrenees) to cause secondary salinization of the soil. By contrast, in Sorbas (Province of Almería), on Quaternary materials, the use of poor quality irrigation water has caused the salinization of the land.

In addition to saline soils, sodic soils with Na adsorption ratios above 13.0 and pH higher than 9.0 can be found, for example, in the southern part of the provinces of Huesca and Zaragoza (Cuchí 1989; Rodríguez et al. 1990; Badía et al. 2011a). The management of sodic soils is much more complex than that of saline soils, caused by the dispersing effect of Na (Qadir et al. 2007). In some cases, sodification is related to the presence of certain holocene deposits on hillsides, composed of alternating millimetric lamellae (Badía et al. 2009a, b) of sodic silt and clay particles (chlorite and illite), parent material which, by its appearance, has come to be called flaky (puff pastry = ‘*hojaldre*’) substrate. This sodic substrate is very unstable and extremely vulnerable to

Fig. 4.4 Salt-playa lake in the Monegros Desert (Ebro Basin), where salt efflorescence covers its surface (*left*) and where “*nebkhas*”, desert wind erosive forms, are common (*right*)

Fig. 4.5 Eroded slopes showing saline marls and sandstones strata (*left* Castildetierra, Bardenas Reales, Province of Navarra) and gypseous marls strata in the Montes de Tauste site (*right* Tauste, Province of Zaragoza)

the erosive action of rainfall, often forming tunnels by the subsurface flow of water, as well as the formation of numerous domes and micro-pedestals and conferring a lunar aspect to the environment (Fig. 4.5).

4.2.2.4 Clay Illuviation

Besides carbonation, clay illuviation (also called "argilluviation" or "lessivage") is another common pedo-feature in semi-arid to subhumid regions of Spain. The presence of soils with accumulated illuvial clay (argic horizons), specifically Luvisols, occurs in relatively stable landforms (Dorronsoro and Alonso 1994; Roquero et al. 1999; Gallardo et al. 2002; Ortíz et al. 2002). The illuviation of clays is a mobilization process after clay suspension in water, which acts as a means of physical transport without reacting chemically with clay. The translocation process of clays along the profile requires the existence of intense wet seasons and dry periods. In the first, the clays in water suspension infiltrate through the macropores which, when dry, leaves, by suction, the clays in their walls ("cutans" or clay films). Clays are required to be dispersed, and therefore it is necessary to have a prior removal of carbonates and a slight acidification, conditions of a moister paleoclimate than the current one.

The presence of carbonated argic horizons is interpreted as a record of climate changes during the evolution of these soils, where the dryness plays an increasing role (Schulte 2002; Badía et al. 2013b). In fact, some authors (Hamer et al. 2007) believe the Luvisols were dominant from the Late Oligocene-Early Miocene in the Ebro Basin under a seasonal moisture regime (ustic moisture regime) that was wetter than the present; they estimated that with a MAT of 10–14 ± 4 °C and MAP of 560–830 ± 200 mm yr^{-1}, an argic horizon (Bt) occurred over 10,000 years. Similarly, Quénard et al. (2011) estimated that the complete decarbonation and desaturation (previous to argilluviation or lessivage) of loess (with 20 % carbonate content) needs over 13,600 years for an annual effective rainfall (rainfall-evapotranspiration) of about 150 mm; after that, the lessivage takes place during a similar period.

Schulte (2002) found red paleosols on Early Pleistocene terraces of the Aguas and Antas Valleys (Vera Basin, Province of Almería, southeast Spain), with pedologic processes such as leaching, rubefaction, clay formation, and illuviation, which classify the soils as Rhodic Luvisol (Rhodoxeralf). On the Middle Pleistocene terraces, soils are classified as Calcic Luvisols (Haploxeralfs with calcic and petrocalcic horizons). Luvisols are also distributed on Pleistocene glacis and terraces in the periphery of the Ebro Basin, where there are wetter conditions than in the center of this valley. More rarely, the illuviation of Na clay, highly dispersed in soils with low ionic strength (Herrero et al. 1989; Rodríguez et al. 1990; Badía et al. 2011a) is observed.

4.2.3 Additions and Losses

Additions and losses include the enrichment and removal, respectively, of materials and components of the edaphic profile (Fig. 4.6).

4.2.3.1 Cumulization

Cumulization is a process of material input that results in a thickening of the surface horizon of mineral matter. It is a process that involves soil rejuvenation. It can be divided into two types, based on either alluvium contributions or colluvium ones, deposits that, in many cases, are easily edaphized.

4.2.3.2 Erosion

Erosion is the process of physical soil degradation that is the loss of part or all of the profile. In arid areas with little

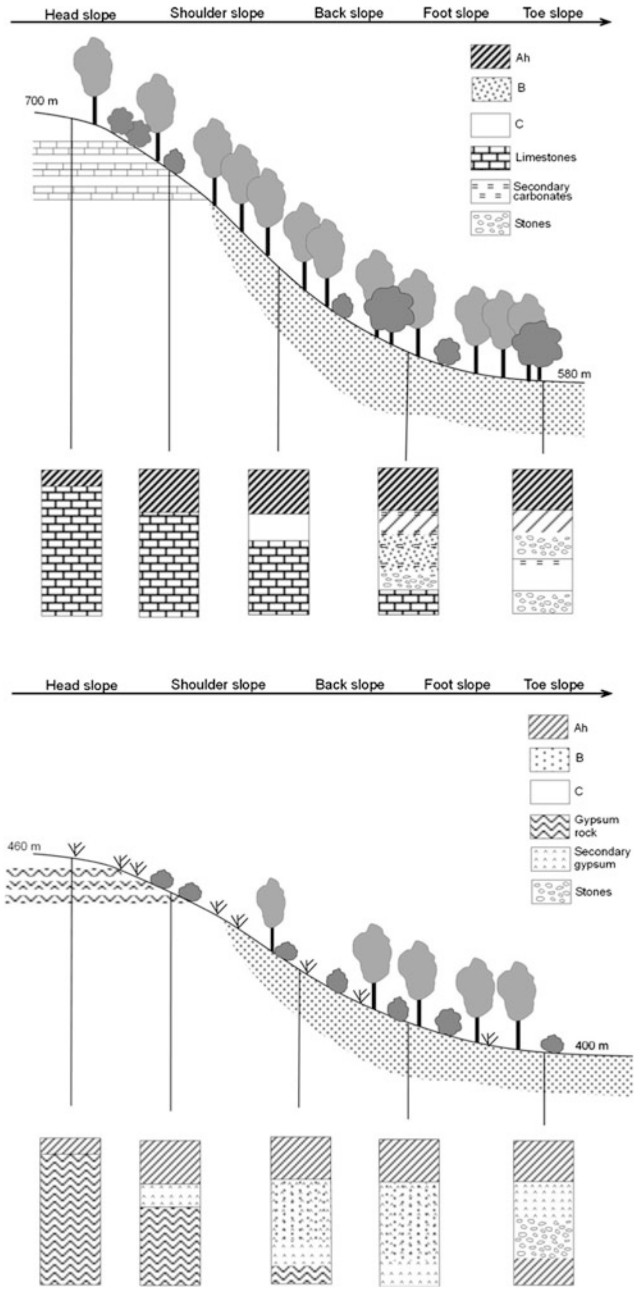

Fig. 4.6 In a semi-arid hilly relief, additions and losses along a slope causes variations of soil thickness and its water storage capacity and, therefore, the plant cover. Toposequences in Zuera (*top*) and Remolinos (*bottom*), near Zaragoza City. *Source* Badía et al. (2013a)

vegetation cover, erosion is common and develops spectacular scenery and records of past climate (Sancho et al. 2008; Pérez-Lambán et al. 2014). Human actions have a strong impact on soil erosion, either favoring or controlling it (Badía et al. 2011b, 2015a; García-Ruiz 2010). The substrates on which these processes are most evident are on sodic or gypseous marls (Fig. 4.7).

Definitively, soil development is carried out by the combination of two groups of processes: the pro-anisotropics, which tend to differentiate horizontal layout layers (horizons) from bedrock, and pro-isotropics, which slow and even hinder the differentiation of horizons (Huggett 1998). The slow performance of the first and the destructiveness of the latter in arid conditions explain the presence of certain types of soils that we will describe next.

4.3 Reference Soil Groups and Units

Soil groups (WRB) in arid lands are mainly represented by Calcisols, Gypsisols, Regosols and Solonchaks, and secondarily by other groups (such as Leptosols, Luvisols and Cambisols). Correlations, if possible, between WRB and Soil Taxonomy are given in Appendix, where any soil unit from WRB, in the same box, could be classified using any of the subgroups of the Soil Taxonomy (USDA 2014) located in that box, depending on other characteristics, such as soil moisture and soil temperature regimes.

4.3.1 Calcisols

Calcisols (from the Latin "*calx*," meaning "lime" (Fig. 4.8)) have an accumulation of calcium carbonate at some depth, which can occur in several forms: powdered, nodules with different morphology and hardness, coatings under the gravel pebbles becoming quite thick and forming rinds or pendents, and even massive calcic accumulations that were once cemented are transformed into petrocalcic horizons, representing a reduction of the depth of the rooting of plants and a reduction in water holding capacity (WHC) of these soils. Calcisols have a basic pH and high saturation of basic cations. The presence of carbonates increases the bicarbonates' concentration in the soil solution, which blocks the iron uptake by plants (iron chlorosis). The abundance of Ca causes retrogradation of phosphates. By contrast, these soils act as carbon sinks in very stable forms of $CaCO_3$. It is estimated that the carbonated soils of arid and semi-arid Spain accumulate about 4.8 Pg C–$CO_3^{=}$ (Sánchez et al. 2004). Calcisols are abundant on limestone or calcareous detrital deposits in seasonally dry areas with irregular rainfall, especially in stable reliefs (Gómez-Miguel 2005; Guerra and Monturiol 1970).

Thus, in the Middle Ebro Valley they appear on old structural platforms and gently sloping hillsides (glacis, mesas), such as those existing to the south of the External Pyrenees (northern part of the Province of Huesca). They are also abundant in former alluvial terraces from the Ebro River and its tributaries (Lewis et al. 2009; Meléndez et al. 2011).

Fig. 4.7 *Left* Erosion forms in the Val de Canales Valley (Ontiñena, Province of Huesca); the alternation of dry periods and wetter ones throughout the Holocene led to the deposition and erosion of sediment at the bottom of the valley. *Right* Gully forms in soil and sodic substrates in Monzorroval, Province of Huesca

In old glacis and terraces (i.e., from the Middle and Lower Pleistocene), Haplic Calcisols give way to Petric Calcisols, where the accumulation of carbonates appears strongly cemented (Porta and Julià 1983; Badía et al. 2013b, 2015a). Petric Calcisols are very common soils in the southern part of the provinces of Zaragoza, Huesca, and Lleida (Ebro Basin), as well as in the Sierra de Almagro and Sierra de María (Province of Almería, southeast Spain). Occasionally, other Calcisols can be found on volcanic materials in Cabo de Gata (Aridic Calcisols and Luvic Calcisols) and coastal salt marshes of the Provinces of Murcia and Almería (Hypercalcic, Sodic Calcisols).

4.3.2 Cambisols

Cambisols (from the Latín “*cambiare*,” meaning “change” (Fig. 4.9)) are moderately developed deep soils, with a significant altered or secondary mineral content in the silt and sand fractions. They usually have adequate fertility, both from the physical and chemical points of view. Cambisols have a cambic horizon with a developed structure, some mobilization of carbonates, and more or less intense brunification.

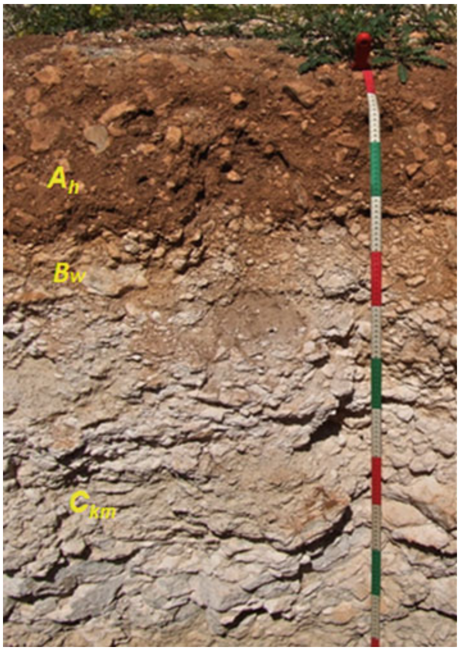

Fig. 4.8 View of a Calcisol in Ballobar (Province of Huesca)

In the arid Ebro Basin, where the parental material is calcareous, it is more frequent that Regosols evolve into Calcisols than to Cambisols. In any case, they have been defined as Haplic Cambisols (calcaric) at the outer edge of the Ebro Basin (Ibarra 2004). In an increasing gradient of moisture, Haplic Cambisols (Eutric) are in the subhumid and humid areas that surround the Central Ebro Basin (Badía et al. 2009b), and between 1100 and 2000 m asl in the Sierra Nevada Mountains (southeastern Spain).

In southeastern Spain, Cambisols are typically associated with Calcisols too, in the most disadvantaged topographic

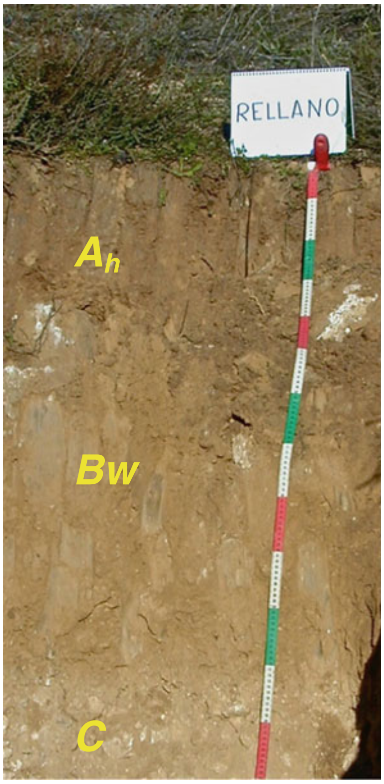

Fig. 4.9 View of a Cambisol in Zaragoza (Aragón)

positions, where the development of the profile has not been intense, or where erosive phenomena have had a leading role. In the Province of Almería, they are well represented in the proximities of Sierra de Gádor, from 400 m asl and on soft reliefs of the left margin of the Almanzora River, and in the lowest slope areas, next to the mountainous areas of the Sierra de las Estancias, Sierra del Maimón, Sierra del Gigante and Sierra Larga.

4.3.3 Phaeozems

Phaeozems (from the Latin "*phaios*," meaning "dark," and the Russian "*zemlja*," meaning "dark land" (Fig. 4.10)) are characterized by having a very dark *A* horizon due to their high content of soil organic matter. This gives them a high level of structural stability, porosity and fertility (mollic horizon). Phaeozems are biologically very active, which is manifested in the successful integration of organic matter with the mineral. They usually develop on basic reaction materials, such as marls or limestones, in relatively stable landforms.

Rendzic Phaeozems can be occasionally found under a relatively dense pine forest, in the northern slopes of some of the mountains (Sierras de Zuera, El Castellar, Alcubierre, Serreta Negra) surrounding the Ebro Basin (Badía et al. 2013a, 2014) and in the Sierra de Gádor Mountains (Province of Almería) on extremely calcareous materials. Their presence is discontinuous on some ranges with Kastanozems and Chernozems (Alberto et al. 1984), where a mollic horizon overlaps the calcic one.

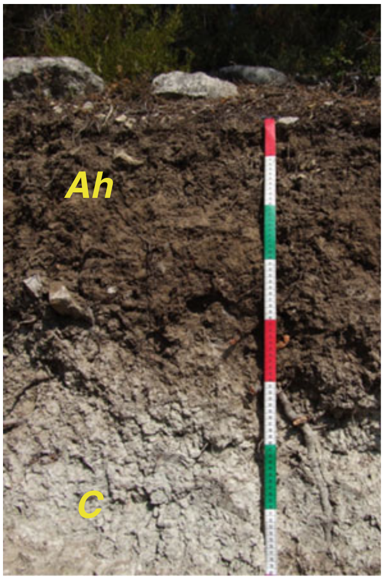

Fig. 4.10 View of a Phaeozem in the Montes de Zuera (Province of Zaragoza)

4.3.4 Fluvisols

Fluvisols (from the Latin "*fluvius*," meaning "fluvial" (Fig. 4.11)) are poorly developed soils, without diagnostic horizons and with stratified alluvial sediments. This stratification is shown by the presence of *C* layers with various particle sizes and/or irregular and relatively high (sometimes with buried *A* horizon) soil organic matter content. Fluvisols occur in the lower and therefore younger (Holocene) terraces of rivers, because after a certain time (higher, older alluvial terraces) these soils become Calcisols (Badía et al. 2009a, b). These soils are deep, with coarse textures and, often, with abundant polygenic gravels (so they get the suffix qualifier of skeleletic), which makes them very permeable (Badía et al. 2008). Their matrix is mainly calcareous (so they get the suffix qualifier of calcaric). Near riverbeds or in the presence of water tables, Fluvisols cause the appearance of hydromorphic processes (Gleyic Fluvisols).

Fluvisols are present on flood plains and terraces closer to the current course of several rivers belonging to the Ebro Basin, occupying greater extent himself Ebro River and its main tributaries (i.e., the Gállego, Segre, Cinca, Alcanadre Rivers and others) as well as U-valleys (Sancho-Marcén

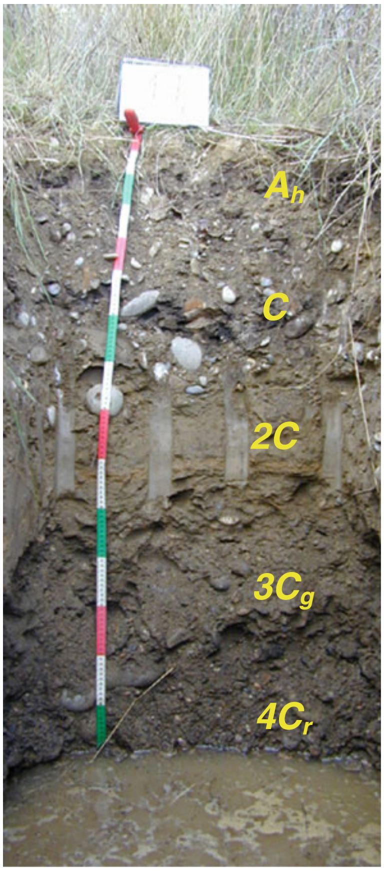

Fig. 4.11 View of a Fluvisol in Torrente de Cinca (Province of Huesca)

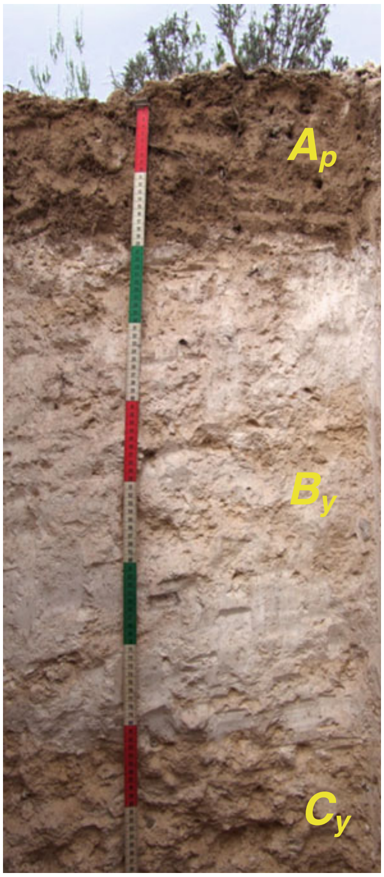

Fig. 4.12 View of a Gypsisol in la Vall de la Vila (Mequinenza, Province of Zaragoza)

et al. 2008). In southeastern Spain, these soils usually appear associated with the "*rambla*" network systems (dry, wide gullies, intermittently over-flooded), usually designated for agricultural crops.

4.3.5 Gypsisols

Gypsisols (from the Latin "gypsum=calcium sulphate 2-hydrated," (Fig. 4.12)) are soils with a secondary accumulation of gypsum (dihydrate calcium sulfate) that may occur in various sizes and forms, from thick lenticular lenses (powdery gypsum), to microcrystalline gypsum (flour-like gypsum). From lower to higher gypsum content, the soil can be classified as Hypogypsic, Haplic or Hypergypsic Gypsisol.

The presence of Gypsisols in Spain is related to the outcrop of gypseous substrates, the largest in Europe. Thus, they are abundant on Mio-Oligocene strata in the center of the Ebro Basin (Badía 1989; Artieda 1996; Badía et al. 2008, 2009a, b; Badía et al. 2013a) and even on Eocene gypsum substrates in the Barbastro-Balaguer anticline, between the Provinces of Huesca and Lleida (Herrero 1991; Badía et al. 2006). Gypsisols are also found in the valleys of the Duero, Tajo and Guadalquivir Rivers, with some locations at the foot of the Sub-Betic Basin, extending to coastal and pre-coastal areas of the provinces of Valencia and Murcia (Gil and Ramos 2011). Occasionally, Gypsisols occur on glacis and alluvial terraces with high gravel content (skeletic), which are even accompanied by a calcic horizon (calcic Gypsisol). In the Province of Almería (Aguilar et al. 2004), they appear both on terraces and in hilly reliefs in the Vera and Sorbas Basins, and in the "Campos de Tabernas" (Aridic Gypsisols, Hypergypsic Gypsisols).

From the viewpoint of their management, the Gypsisols are soils with a low quantity and quality of phylosilicates, which determine a low nutrient exchange capacity, especially at soil depths where gypsum (and even carbonates) are accumulate. Its WHC varies with the gypsum crystallization size, but they would be particularly influenced by the

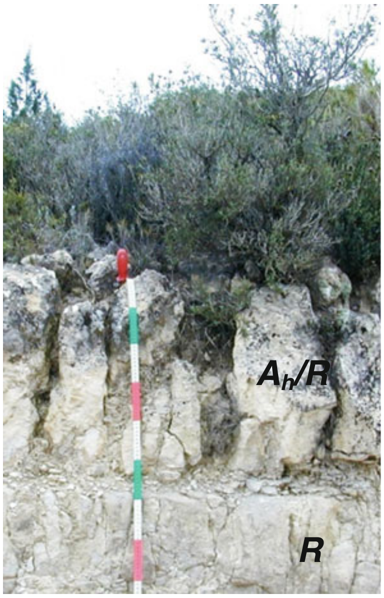

Fig. 4.13 View of a Leptosol in Mequinenza (Province of Zaragoza)

thickness of the soil, in turn related to topographic position: scarce in ridges (with *A*-*R* sequum), and abundant in foot slopes and bottom valleys (with *A*-*By*-*C* sequum).

The dissolution of gypsum in these soils, such as by irrigation with a high leaching fraction, creates problems of land subsidence. From the viewpoint of chemical fertility, the Ca^{2+} cation is very abundant; it binds with phosphates for making them insoluble, and results in a very low availability of P for plants.

A common process in Gypsisols is surface crusting or self-mulching, produced as the result of an upward moisture regime that brings the dissolved salts to the surface by capillary action in the water. As the water evaporates, the recrystallized salts form new gypsum crystals and the resulting surface crusts with low porosity, which can reach considerable thickness and contribute to preserving the moisture in the soil, a very important phenomenon for gypsophila flora, adapted to these soils.

4.3.6 Leptosols

Leptosols (from the Greek "*leptos,*" *meaning* "thin" (Fig. 4.13)) are thin soils that have a shallow physical barrier, such as continuous hard (lithic contact) or high stoniness, or a chemical barrier as a very carbonated substrate. Due to these characteristics, they have a reduced volume searchable by roots and a reduced WHC and nutrients content, especially in Lithic or Hyperskeletic Leptosols. Depending on its parent material, it may acquire the suffix "calcaric" or "gypsiric." Its shallowness, and even the abundance of rock outcrops (Nudilithic), limits agricultural use but it can support grazing or occasional recreational use.

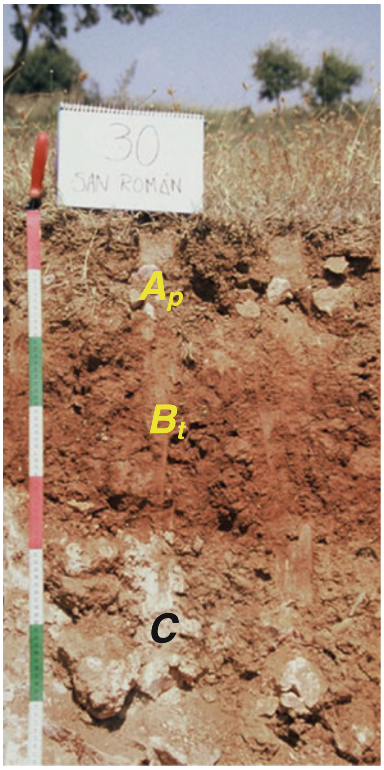

Fig. 4.14 View of a Luvisol in the Somontano de Barbastro (Huesca)

Its distribution is linked to areas with steep slopes and rocky substrates i.e. Sierra de Alcubierre, Sierra de Sijena and Montes de Zuera, in northeastern Spain. In southeastern Spain, they appear in the mountains (sierras) of Saliente, Gabar, Muela, Pericay, Madroño, Estancias, Lúcar, Partaloa, Lisbona, Demián, Talavera, Alhamilla, Gádor, and María, on hard limestones, although it is posible to find them on metamorphic materials in the "sierras" of Las Estancias, Partaloa, Castillarico, Almagrera, Bédar, Cabrera, Madroño, and Sierra Nevada in the Province of Almería; it is also possible to find this soil on volcanic rocks (dacites and andesites) in the Cabo de Gata (in the same province).

4.3.7 Luvisols

The Luvisols (from the Latin "*luere*," meaning "to wash" (Fig. 4.14)) have an accumulation of clays subsurface horizon by translocation (argilluviation or lessivage) that is related to a stable geomorphic surface and a seasonally contrasted climate, with alternating wet and cold, dry and warm seasons. Bio-climatic conditions should enable (or

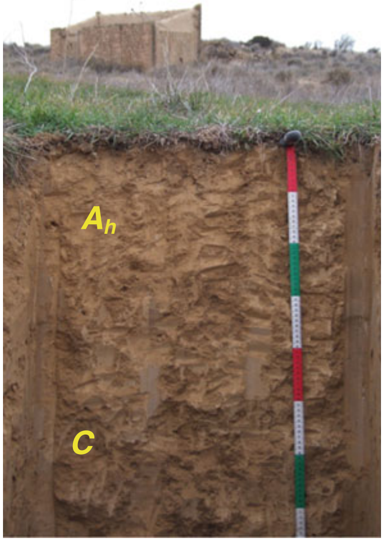

Fig. 4.15 View of a Regosol in Monegros (Aragón)

have enabled in the past) in the current conditions or paleo-conditions, first washing carbonates (calcic horizon), and later clay illuviation (argic horizon), so it is common to observe the sequence *A-Bt-Bk* (Calcic Luvisols). In the Province of Almería, these soils are well represented in flat reliefs near Gergal and Oria, and associated with Haplic Cambisols (calcaric) and Haplic Regosols (calcaric) in the northern part of the same province, as well as in the nearby Province of Murcia.

Furthermore, the clay coated with Fe oxides, incompletely dried during wet periods, is dehydrated in warm seasons (rubefaction, fersialitization), and the soil acquires a characteristic reddish color (chromic or rhodic qualifiers). This soil unit appears on schists, quartzites, and conglomerates, on flat or gentle slope areas in southeastern Spain but, as previously mentioned, their pedogenesis occurred under climatic conditions other than the current ones (paleosols).

Sometimes argic horizons are carbonated, so the Calcic Luvisol evolves to Luvic Calcisol. In these soils, clays are of good quality (2:1) and soil reaction is never too acidic because of seasonal drought (no percolating regime). When the increase in clay is very fast (abrupt textural change), the rate of water infiltration is reduced. Luvisols appear on Pleistocene glacis or alluvial fans of the Ebro Basin with a sub-humid (MAP: 500–650 mm yr^{-1}) climate.

4.3.8 Regosols

Regosols (from the Greek "*rhegos*," meaning "sheet" (Fig. 4.15)) develop on unconsolidated parent materials with *A-C* sequum. Their presence is associated with areas where formation processes have operated for a short time or at a low intensity, by very hot weather, or as a result of rejuvenation by erosion. Therefore, as happens with Leptosols, their soil properties are directly related to the parent material from which they derive. Thus, Haplic Regosols (calcaric), with fine textures and basic reaction, were found on marls; sometimes they have some salinity (hyposalic) or some primary gypsum content (gypsiric). On some slopes, the construction of dry stone terracing has allowed the conservation of soil and optimized the rainwater collection (qualifier escalic). Given the difficulty of mechanization, the narrow terraces are clearly in a process of abandonment.

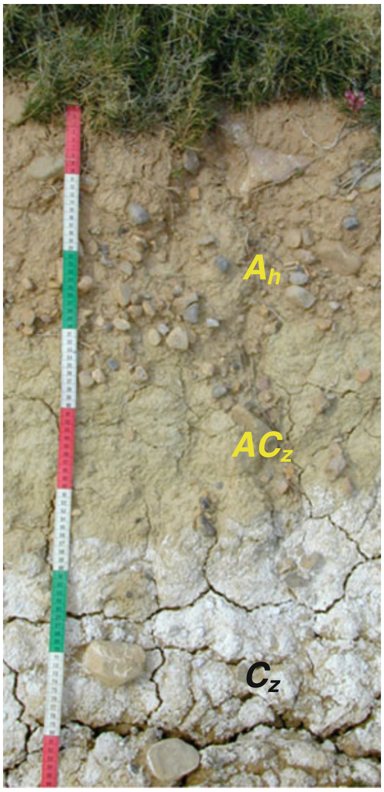

Fig. 4.16 View of a Solonchack in the Hoya de Huesca (Aragón)

Regosols appear in numerous areas of Spain, interspersed with other types of soils (Gómez-Miguel 2005). In northeast Spain, Miocene and Oligocene marls are frequently found in the south of the provinces of Zaragoza, Huesca, and Lleida and north Teruel (Guerra and Monturiol 1970; Ibarra 2004; Institut Geològic de Catalunya 2012; Nogués-Navarro 2002). In southeast-Spain, Regosols appear also on volcanic rocks, i.e., the Cabo de Gata (Province of Almería).

4.3.9 Solonchaks

Solonchaks (from the Russian "*sol*," meaning "salt," and "*chak*," meaning "salty soil" (Fig. 4.16)) have a high concentration of soluble salts at shallow depths (salic horizon). In arid environments, these salts are usually present in the parent material; low rainfall, long surpassed by evapotranspiration, can only redistribute the salts without leaching them out from the soil profile. Usually the most common salt is halite (common salt, NaCl), so that the dominant ion in the soil solution is chloride (Haplic Solonchak, chloridic), sometimes highly concentrated (Hypersalic Solonchak, chloridic). Solonchaks are abundant in the central part of the Ebro Basin (Monegros Desert, Bardenas) and are more infrequent in the Hoya de Huesca County (Badía 1989; 2009a, b; Cuchí 1989; Herrero 2008; Nogués-Navarro 2002). These soils, with complex agricultural management, give origin to peculiar landscapes without vegetation or with a gradient of very specialized plants, from tolerant to hyper-halophytes, according to the soil moisture and salinity gradients (Badía 1992; Álvarez-Rogel et al. 2001, 2007; Conesa et al. 2012). In cases where the salt is accompanied by sodicity (Sodic Solonchaks), the agricultural use of soils is further limited by their poor stability.

In the Province of Almería, Solonchaks are usually present with calcarenites and marls with inter-bedded Miocene gypsum (Haplic Solonchak, aridic) being severely eroded and producing typical “badland” landscapes (i.e., the Tabernas Desert). In coastal areas of southern Spain, Gleyic Solonchaks appear either in pond-type formations (such as the Adra surroundings), or marshes (such as in the Natural Park of Punta Entinas-Sabinar), or old salt mines (like Salinas de Cerrillos), all them in the Almería Province. They also appear in typical endorheic basins such as Cabo de Gata (Province of Almería), which, as in the previous case, originated in a lagoon that was separated from the sea by a belt of dunes, creating a drainage area that has been silting over time.

Appendix

See Table 4.3.

Table 4.3 Most common correlations between WRB (IUSS 2007) and Soil Taxonomy (Soil Survey Staff 2014) for soils of the Spanish arid areas, cited in the text

WRB (2007)		Soil Taxonomy (2014)			
RSG	Soil units	Soil orders	Suborders	Great groups	Subgroups
Leptosols	Lithic Leptosol Nudilithic Leptosol	Entisols	Orthents	Torriorthents	Lithic Torriorthent
					Lithic Xeric Torriorthent
					Lithic Ustic Torriorthent
				Xerorthents	Lithic Xerorthent
	Calcaric Leptosol Gypsiric Leptosol Hyperskeletic Leptosol	Entisols	Orthents	Torriorthents	Xeric Torriorthent
					Typic Torriorthent
				Xerorthents	Typic Xerorthent
Fluvisols	Gleyic Fluvisol	Entisols	Fluvents	Torrifluvents	Aquic Torrifluvent
					Oxyaquic Torrrifluvent
					Xeric Torrifluvent
					Ustic Torrifluvent
				Xerofluvents	Aquic Xerofluvent
					Oxyaquic Xerofluvent
Solonchaks	Gleyic Solonchak Haplic Solonchak (Aridic) Haplic Solonchak (Chloridic) Sodic Solonchak	Aridisols	Salids	Haplosalids	Typic Haplosalid
		Inceptisols	Xerepts	Haploxerepts	Typic Haploxerept
		Entisols	Orthents	Torriorthents	Xeric Torriorthent
					Typic Torriorthent
				Xerorthents	Typic Xerorthent
	Hypersalic Solonchak (Chloridic)	Aridisols	Salids	Haplosalids	Typic Haplosalid
Phaeozems	Rendzic Phaeozem	Mollisols	Xerolls	Haploxerolls	Aridic Lithic Haploxeroll
					Lithic Haploxeroll
					Aridic Haploxeroll
					Entic Haploxeroll
					Typic Haploxeroll
Gypsisols	Hypogypsic Gypsisol Haplic Gypsisol Hypergypsic Gypsisol Aridic Gypsisol	Aridisols	Gypsids	Haplogypsids	Xeric Haplogypsid
					Ustic Haplogypsid
					Typic Haplogypsid
		Inceptisols	Xerepts	Haploxerepts	Gypsic Haploxerept
	Calcic Gypsisol	Aridisols	Gypsids	Calcigypsids	Xeric Calcigypsid
					Ustic Calcigypsid
					Typic Calcigypsid
		Inceptisols	Xerepts	Calcixerepts	Typic Calcixerept
				Haploxerepts	Gypsic Haploxerept
Calcisols	Luvic Calcisol	Aridisols	Argids	Calciargids	Xeric Calciargid
					Ustic Calciargid
					Typic Calciargid
		Alfisols	Xeralfs	Haploxeralf	Calcic Haploxeralf

(continued)

Table 4.3 (continued)

WRB (2007)		Soil Taxonomy (2014)			
RSG	Soil units	Soil orders	Suborders	Great groups	Subgroups
Calcisols	Petric Calcisol	Aridisols	Calcids	Petrocalcids	Calcic Petrocalcid
					Xeric Petrocalcid
					Ustic Petrocalcid
					Typic Petrocalcid
		Inceptisols	Xerepts	Calcixerepts	Petrocalcic Calcixerept
	Haplic Calcisol Aridic Calcisol Hypercalcic Calcisol	Aridisols	Calcids	Haplocalcids	Xeric Haplocalcid
					Ustic Haplocalcid
					Typic Haplocalcid
		Inceptisols	Xerepts	Calcixerepts	Typic Calcixerept
				Haploxerepts	Calcic Haploxerept
	Sodic Calcisol	Aridisols	Calcids	Haplocalcids	Sodic Haplocalcid
					Sodic Xeric Haplocalcid
					Sodic Ustic Haplocalcid
					Xeric Haplocalcid
					Ustic Haplocalcid
					Typic Haplocalcid
		Inceptisols	Xerepts	Calcixerepts	Sodic Calcixerept
Luvisols	Rhodic Luvisol Chromic Luvisol	Alfisols	Xeralfs	Rhodoxeralfs	Typic Rhodoxeralf
				Haploxeralfs	Typic Haploxeralf
		Aridisols	Argids	Haplargids	Xeric Haplargid
					Ustic Haplargid
					Typic Haplargids
	Calcic Luvisols	Alfisols	Xeralfs	Haploxeralfs	Calcic Haploxeralf
		Aridisols	Argids	Calciargids	Xeric Calciargid
					Ustic Calciargid
					Typic Calciargid
Cambisols	Haplic Cambisol (Calcaric) Haplic Cambisol (Eutric)	Aridisols	Cambids	Haplocambids	Xeric Haplocambid
					Ustic Haplocambid
					Typic Haplocambid
		Inceptisoles	Xerepts	Haploxerepts	Typic Haploxerept
Regosols	Haplic Regosol (Eutric) Haplic Regosol (Calcaric) Haplic Regosol (Gypsiric) Haplic Regosol (Hiposalic)	Entisols	Orthents	Torriorthents	Lithic Torriorthent
					Lithic Xeric Torriorthent
					Lithic Ustic Torriorthent
					Ustic Torriorthent
					Xeric Torriorthent
					Typic Torriorthent
				Xerortents	Lithic Xerorthent
					Typic Xerorthent

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Web Sites

Introduction to Soil science www.cienciadelsuelo.es (Spanish and English versions)

Soil and landscape relationships in Aragon region and WRB classification www.suelosdearagon.com (Spanish version)

Books, monographs, image atlas, research and all kinds of information on soil science (in Spanish). www.edafologia.net

Millenium Ecosystem Assessment www.maweb.org

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Soils of the Mediterranean Areas

5

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5.1 The Olive Tree as an Indicator of Mediterranean Environment

Typically, red Mediterranean soils can be found in Spain (García et al. 1990) not too far from other soils that have no such characteristics; even more, Guerra et al. (1972) indicated that the Mediterranean soils (which are close to Alfisols, in theory) can frequently rather be considered to be Paleosols, which are not really found nowadays in a Mediterranean environment.

Nevertheless, these soils (Photo 5.1) cannot be formed in such a semi-arid environment; they should have been formed in the past, during the interglacial Geological eras, and they should actually be considered to be Paleosols that are submitted to "brunification" (brownish coloring) on the surface, which means that at the bottom of these deep red soils (sometimes several meters deep), strong weathering should be present, including "pisolithes".

It is possible to observe deep weathering in the borders of these paneplains, which are less arid, where Typical colors of tropical weathering are found (Photo 5.2), in very acid soils, in this case rather related with Ultisols and covered by deciduous broadleaf oaks (*Quercus pyrenaica*).

5.2 Occurrence of Olive Trees: Delimitation of the Mediterranean Area of Spain

The olive tree is a botanical species belonging to the olea genus and oleaceae family, many of whose species are cultivated in numerous regions around the world. Olive cultivars correspond to the *Olea europea L.* subspecies, variety *sativa*, while wild olives (or *O. sylvestris*, "acebuche") generally correspond to the oleaster cultivar (Photos 5.3 and 5.4).

The olive is an evergreen tree www.botanical-online.com/florolivo.htm that may reach a significant height, although it is generally maintained with a medium to low height (Barranco et al. 2008). The trunk base is known as "peana" and, depending on the method of harvesting, is grown with a single trunk and arboreal habit, or with two or even three trunks (Ortega 2011).

Wild olive trees grow in the Mediterranean region, spreading from the Algarve (Portugal) to the eastern Balearic Islands (Spain), where the rainfall is about 400 mm yr^{-1}. Although the olive tree is very resistant to drought, the optimal rainfall is close to 650 mm yr^{-1}. If rainfall is not sufficient, irrigation is recommended (Martínez Raya and Sánchez Blázquez 2004).

Since 1972, olive growing areas in Spain have been classified into ten large regions (Fig. 5.1). At present, olive trees are cultivated in 34 provinces of 13 autonomous communities (out of a total of 17) in Spain. Olive tree distribution in Spain covers a 25,106 ha surface, of which 96 % (23,779 km^2) is dominated by olive cultivars used for olive oil production, while only 4 % (986 km^2) is used for table olive production. There are several studies that analyze the

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Photo 5.1 Flat, deep red soils in the semi-arid, Castilian preserved peneplain, in this case these are classified as Rhodoxeralfs

Photo 5.2 Strong soil weathering in the border of Castilian pen-plain (southern border, close to Extremadura, Spain)

types of soils of Spain of olive groves in southeastern Spain that were carried out by Ortega et al. (1983, 1990b, 1996) and Sierra et al. (1981, 1989, 1992, 1993).

Comparing Fig. 5.1a, b, a strong correlation between areas where olives grow in Spain and delimited Mediterranean zones can be found.

Photo 5.3 Olive grove soils in Úbeda (Province of Jaén, Spain)

5.3 Geology of the Mediterranean Area

The orography of southern Spain (where Andalusia is situated) is the result of a complex orogeny that resulted in the formation of two mountain systems: the Hesperian Massif and the Baetic System http://aguas.igme.es/igme/publica/libros1_HR/libro110/Pdf/lib110/in_6.pdf.

In the Baetic ranges, olive groves are dispersed over outer areas in sandstone, limestone, loam, or loamy limestone soils, in Neogene basins, and in intra-mountain depressions with sedimentary or conglomerate materials. Due to its large extension, the Guadalquivir River Basin is of special relevance (Junta de Andalucía 1998). In non-olive grove areas, soils having a high content of smectite clays appear, with swelling and shrinking properties derived from Miocene materials, mostly facies showing Flysch sequences.

Photo 5.4 Olive tree (Spain)

Eastern and southeastern parts of Spain have an extremely complex orography. These regions are also located in the Baetic System, which was formed during the Alpine folding. Depressions are composed of Miocene sediments of marine origin, mostly conglomerates. The strata near the surface are Quaternary alluvial deposits (Sánchez-Martos et al. 2001).

The Valencian Community (eastern Spain) is dominated by limestone, dolomite, basalt, ophites, conglomerates, sandstones, clays, marls, gypsum, slate, and quartzite with tuff. Considering the Province of Alicante (southeast part), lime conglomerates and gravels are dominant, with a set of Neogene-Quaternary sedimentary basins, among which are the low Segura River Basin outcomes (Estévez et al. 2004). In the Murcia region (southeastern Spain), materials from three areas are found: Pre-Baetic and Sub-Baetic (external), and Baetic (internal).

Spanish soils' olive groves in Extremadura developed on metamorphic, detrital and plutonic rocks. Afterwards, a variety of lithologies occurred in olive groves in the center of the Iberian Peninsula. An example of this is the Montes de Toledo region (the largest olive oil Protected Designation of Origin, P.D.O.) located in the center of the Iberian Peninsula. In geological terms, it is a relatively complex area made up of Silurian, Cambrian, Miocene, and Quaternary materials (Porras et al. 1985).

The Ebro River Basin is also relevant in geological terms, since it is edged by detritus material from the mountains surrounding the valley, and the internal part of the basin is composed of gypsum-rich evaporite materials. In addition to this, single-trunks, 15–20 years old, of *Empeltre* and *Arbequina* varieties of olive trees, are found in salt water ponds, such as those in Alcañiz (Province of Teruel).

5.4 Relief of the Mediterranean Area

Spain is characterized by a highly heterogeneous relief. Large plains are surrounded by mountains, and river basins occasionally form plateaus separated by interior plains in the form of platforms criss-crossed by several rivers.

The orography of olive-growing regions in Spain is varied. Olive groves are mainly found on the slopes of the mountains, in Class 1-, 2-, and 3-Slopes (FAO 2009). While the foothills and plains are used for cereal crops. Nevertheless, olive groves can also be found in the foothills, valleys, and plains surrounding mountain ranges. There are some rare exceptions of olive groves in very steep areas, but their presence there is erratic and the areas they cover are small, since they are exposed to severe erosion.

5.5 Climate of the Mediterranean Area

Therefore, we can classify the area indicated as Mediterranean climate, which is occupied mostly by olives. The Mediterranean climate becomes continental in the Center of the Iberian Peninsula and along the Ebro Basin (Aragón). In those parts of the country, temperatures are extreme, with longer and colder winters, cool summers in the north and warm in the south, and olive trees are restricted to protected gardens. Therefore, according to Peinado et al. (1994), the Mediterranean macro-bio-climates in areas of olive groves are thermal and meso-Mediterranean, similar to those of southern California (USA).

In general terms (Chazarra 2004), considering Thornthwaite's climate classification for Spain obtained using GIS techniques (between 1971 and 2000), we can conclude that moisture and aridity indices (*Ih* and *Ia*, respectively) in soils of olive groves are as follows: almost all moisture regimes are subhumid-dry; semi-arid in parts of eastern Spain, Andalusia, and Aragón; and arid in some parts of the Provinces of Almería, Murcia, and Alicante (southeastern Spain).

The potential evapo-transpiration (PET) is a useful index for representing thermal efficiency. The climate of Spain is prevailingly *B'2* Mesothermal II (712–855 mm yr^{-1} of estimated precipitation) and *B'3* Mesothermal III (855–997 mm yr^{-1} of PET) in the low Guadalquivir River Basin; the Tajo and Segura River Basins and the coastal regions of Southeastern Spain are included here as well.

Seasonal moisture variation can be characterized by the letter *s* (humid in part of the territory with moderately dry

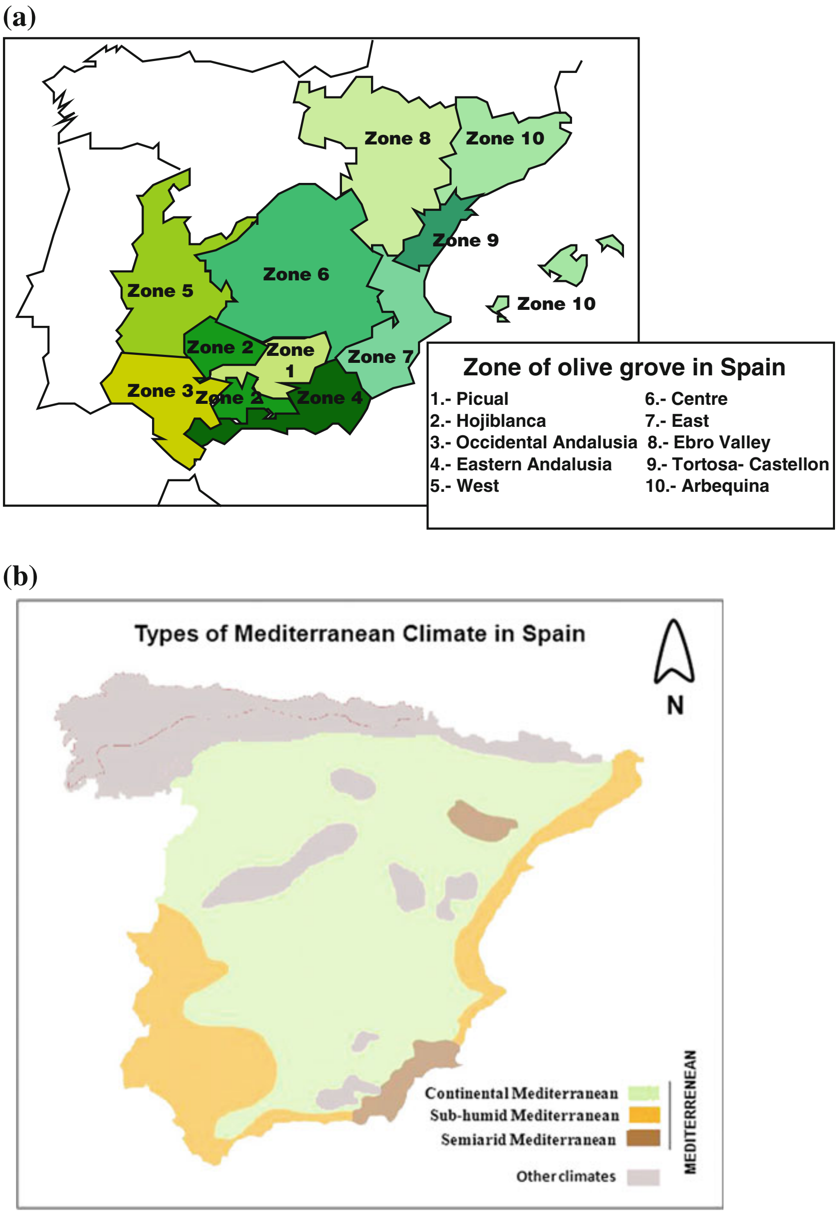


Fig. 5.1 **a** Olive-growing regions in Spain (*top*). **b** Spanish climates: Mediterranean varieties (*bottom*)

summers, and dry with moderately humid winters). This *s2* type covers most of the territory (including the Balearic Islands), with the rest of the territory corresponding to the *s* type. The *d* type corresponds to a dry climate (without any rainy season), which defines the climate of Ebro Valley and southeastern Spain. The thermal efficiency concentration in continental regions in summer corresponds to a moderate *b'3* type, while the *b'4* type is found along the Mediterranean coast, including the Balearic Islands.

For a better study, we consider three modal climates supporting olive trees.

5.5.1 First Modal Climate

Andalusian olive-growing areas represent the first modal climate. They extend from the southern Province of Córdoba to southwest of the Province of Jaén, north of that to Málaga, and west of that to Granada. The reference is the axis marked by the thermo-pluviometric stations installed in Montefrío (Table 5.1 and Fig. 5.2) and Almedinilla. According to Sierra et al. (2003), it is an area protected against Atlantic "*abrego*" winds (humid southwesterly winds), which annually bring from 560 to 700 mm yr^{-1} of rainfall.

Table 5.1 Modal climate 1 record (Montefrío, Province of Granada, Andalusia)

Climate data and soil water balance. Montefrio

Month	J	F	M	A	M	J	J	A	S	0	N	D	Total
Temperature	6.2	7.5	9.9	11.0	14.5	20.3	24.1	23.1	20.7	13.7	9.2	7.2	14.0
Precipitation	69.6	90.9	60.7	69.6	37.7	21.1	6.2	9.0	26.4	51.6	95.1	116.0	653.9
PE	13.7	19.1	32.6	46.3	67.8	112.1	146.7	129.0	96.6	55.0	24.2	16.5	759.4
RPE	13.7	19.1	32.6	46.3	67.8	91.0	6.2	9.0	26.4	51.6	24.2	16.5	404.3
AWCV	0	0	0	0	−30.1	−69.9	0	0	0	0	70.9	29.1	–
AWC	100.0	100.0	100.0	100.0	69.9	0	0	0	0	0	70.9	29.1	–
Surplus	55.9	71.8	28.1	23.3	0	0	0	0	0	0	0	70.5	249.6
Deficit	0	0	0	0	0	21.1	140.5	120.0	70.2	3.4	0	0	355.2

AWC: 100 mm

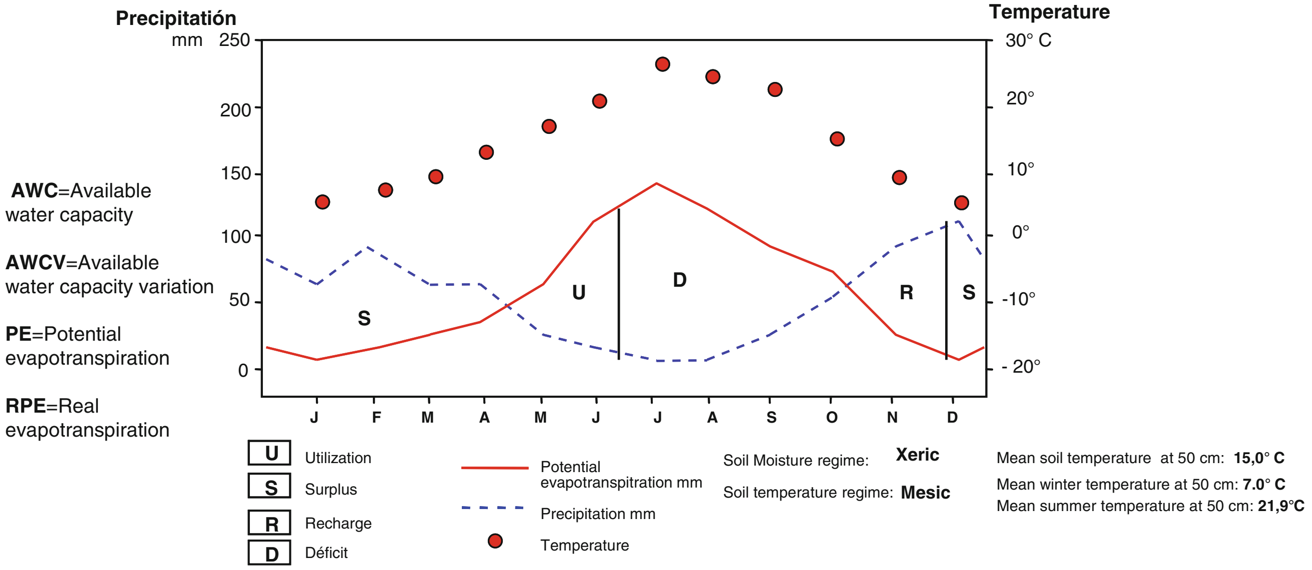


Fig. 5.2 Modal water balance 1 (Montefrío, Province of Granada, Andalusia) (Latitude: 37° 19′ 15″ N; Longitude: 4° 0′ 37″ W; Altitude: 834 m asl)

The western sector of Andalusia has a continental Mediterranean and dry/subhumid mesophytic climate, while the eastern sector has a humid/dry-subhumid xerophytic climate, according to Thornthwaite and Papadakis (Capel Molina 1981), respectively. The moisture regime is Xeric, while the temperature regime is Mesic. According to Thornthwaite, the classification is *C2 B'2 s2 b'4*; i.e., subhumid climate, second metohermic, with severe droughts in summer and moderate concentrations of thermal efficiency during winter. This area is classified, according to the Papadakis as agro-climate, with winters of the "*avena cálido*" (warm oats) type, while summers allow the cultivation of cotton, continental Mediterranean, and dry Mesophytic. The Martonne index is 27.3, which is favorable for the cultivation of olive trees and cereals. On the other hand, the Baetic System has a Mediterranean mountain climate, with annual average temperatures 2 °C lower than those of the areas with a continental Mediterranean climate, although it has similar precipitation and three-month periods with the risk of frost (Junta de Andalucía 2001).

The prevalence of irregular and torrential rains, added to the fragility of soils, has a negative impact on the areas with a steeper slope, since they favor erosion and lead to a serious soil loss. Causing rills and gullies etc., to leave tree bases exposed. The annual average soil temperature at −50 cm deep is estimated to be 14.9 °C (8.0 °C in winter and 21.9 °C in summer).

5.5.2 Second Modal Climate

The second modal climate (Table 5.2 and Fig. 5.3) is represented in the Central Tableau ("Meseta," Toledo,

Table 5.2 Modal climate 2 record (Toledo, Central Spain)

Climatic data and soil water balance. Toledo													
Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Temperature	6.4	8.3	11.0	12.9	16.9	22.1	26.0	25.7	21.6	15.6	10.2	7.3	15.4
Precipitation	28.0	28.0	25.0	41.0	44.0	28.0	12.0	9.0	22.0	38.0	40.0	44.0	357
PE	13.5	18.5	23.4	33.9	78.1	121.6	159.3	153.2	108.8	60.4	27.8	15.4	813.9
RPE	13.5	18.5	23.4	33.9	78.1	89.8	12.0	9.0	21.6	15.6	27.8	15.4	358.6
AWCV	14.5	9.5	1.6	7.1	−34.1	−61.8	0	0	0	22.4	12.2	28.6	–
AWC	77.7	87.2	88.8	95.9	61.8	0	0	0	0	22.4	34.6	63.2	–
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0
Deficit	0	0	0	0	0	31.8	147.3	144.2	0.4	0	0	0	323.7

AWC: 100 mm

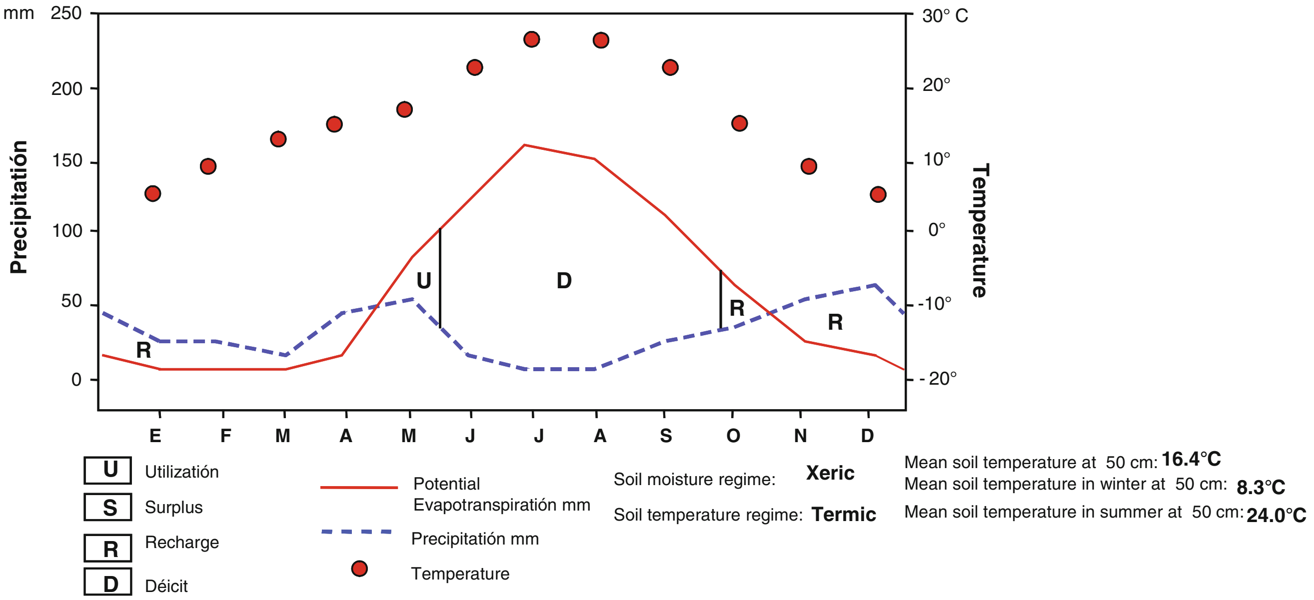


Fig. 5.3 Modal water balance 2 (Toledo, Central Spain) (Latitude: 39° 55′ 5″ N; Longitude: 4° 2′ 43″ W; Altitude: 515 m asl)

Castile-La Mancha), where the annual average temperature ranges from 6.4 to 26.0 °C (January and July, respectively). The annual average rainfall is 357 mm yr^{-1}, with 2 months of maximum rainfall in May and December (44 mm month^{-1}).

The Central Meseta has a Xeric moisture regime and a thermic temperature regime, with an average temperature of 8.3 °C in winter and 24.0 °C in summer. Since there is more than 5.0 °C difference between the average temperature in summer and winter, the temperature regime cannot be said to be Isothermic.

The PET is 814 mm yr^{-1}, which is only partly compensated by rainfall (actual evapotranspiration, AET, being significantly lower). The soil-water balance in olive groves in Toledo can be established using the reference water reserve for this modal soil, as established by Ortega et al. (1990a).

The Central Meseta presents a severe water shortage from June to September (summer). The rainy season starts in October and ends in March; however, the soil available water capacity (AWC) is not completely filled and the soil reserves are used in May and part of June.

5.5.3 Third Modal Climate

The third modal climate is found in the Provinces of Alicante and Murcia (southeast Spain), which is a Mediterranean coastal olive-growing region (Table 5.3 and Fig. 5.4). This region has the Typical climate of the coast, with a continental regime inland, and an Aridic soil moisture regime and thermic temperature regime, as are usual in southeast Spain.

Table 5.3 Modal climate 3 record (Alicante, southeastern Spain)

Climatic data and soil water balance. Alicante

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Temperature	11.5	12.4	13.7	15.5	18.4	22.2	24.9	25.5	23.1	19.1	15.2	12.5	17.8
Precipitation	22.0	26.0	26.0	30.0	33.0	17.0	6.0	8.0	47.0	53.0	42.0	26.0	336
PE	24.3	27.6	29.1	40.7	85.0	122.1	152.6	152.0	116.4	74.0	41.4	26.4	891.6
RPE	22.2	26.0	26.0	30.0	33.0	17.0	6.0	8.0	47.0	53.0	41.4	26.4	358.6
AWCV	−0.2	0	0	0	0	0	0	0	0	0	0.6	−0.4	–
AWC	0	0	0	0	0	0	0	0	0	0	0.6	0.2	–
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0
Deficit	2.1	1.6	3.1	10.7	52.0	105.1	146.6	144.0	69.4	0	0	0	556.6

AWC: 100 mm

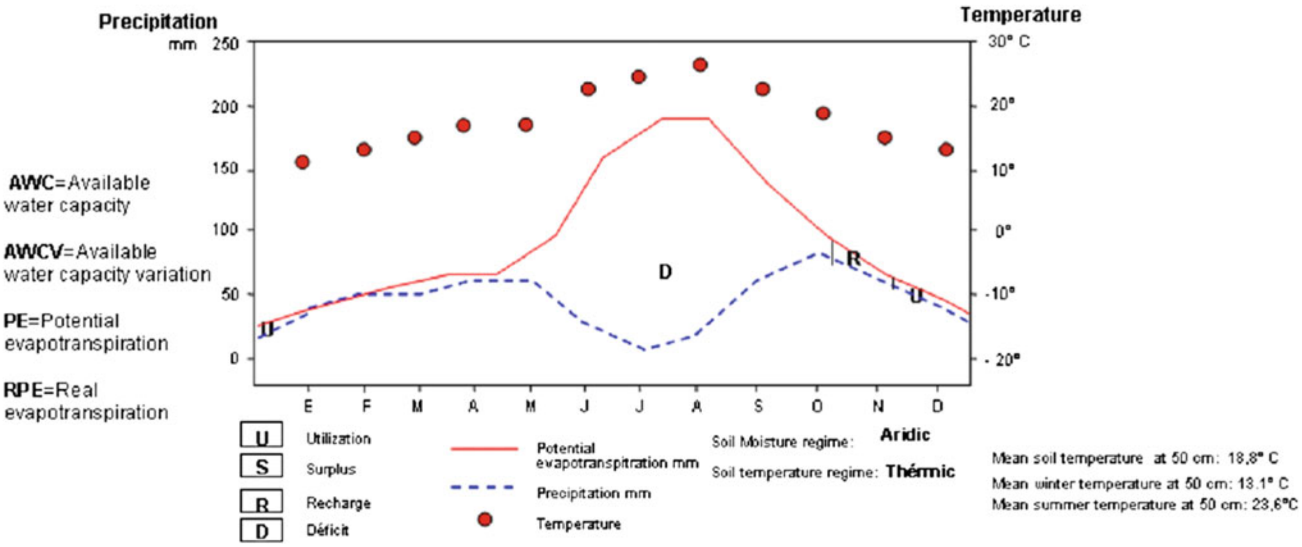


Fig. 5.4 Modal water balance 3 (Alicante, Southeastern Spain) (Latitude: 38° 22′ 21″ N: Longitude: 0° 29′ 39″ W; Altitude: 81 m asl)

5.6 Soil Water Reserves (SWR)

After a thorough analysis of the three climate records described above (and other records not described for reasons of simplicity), with the water balances established as modal, we drew the following conclusions:

(1) In all cases, PET exceeded the actual annual precipitation. Therefore, the soils of Spanish olive groves have a water deficit during some periods of the year.
(2) The soil water reserve is depleted from July to October and filled between January and April.
(3) During the most intense vegetative growth period (end of spring and beginning of summer), plants use soil water reserves intensively. As a result, the soil water reserve (SWR) is exhausted by the beginning of summer.
(4) The SWR is recharged in 1–2 months of rain, i.e., towards the end of fall and beginning of winter.

The Mediterranean climate becomes continental in the center of the Iberian Peninsula and along the Ebro River Basin in Aragón. In this part of the country, temperatures are extreme, with longer and colder winters; the summers are cool in the north and warm in the south.

The olive tree has traditionally been a rain-fed crop. It can yield acceptable crops even after severe periods of drought

www.aemet.es/es/serviciosclimaticos/datosclimatologicos/

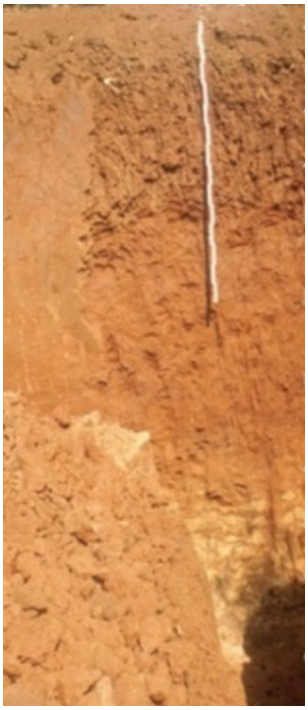


Photo 5.5 Typic Rhodoxeralf thapto-rodoxerálfic (Loja, Province of Granada)

valoresclimatologicos and www.juntadeandalucia.es/medioambiente/web/bloques_tematicos/estado_y_calidad_de_los_recursos_naturales/suelo/criterios_pdf/almeria.pdf.

Nonetheless, the quantity and distribution of rainfall is a determinant for the availability of water, tree growth, olive production, planting density, pruning, risks of erosion, etc. (Junta de Andalucía 2002).

5.7 Soil-Forming Processes

There is a wide diversity of soils in the Mediterranean area of Spain, which are the result of various dynamic processes induced by the activity of the soil-forming factors mentioned above. The main pedogenesis processes in olive tree soils are carbonation, illuviation, gypsification, and salinization.

The carbonated nature of the lithological materials in large parts of this area results in calcium carbonate leaching, which is involved in the genesis of many soils, although leaching is rarely total. $CaCO_3$ precipitation in soil depth forms horizons of diagnostic value when such accumulation is intense enough; these are the so-called “Calcic” and/or “Petrocalcic” horizons (Photo 5.6).

Other non-olive growing soils show swell-shrink mechanisms, which are characterized by the formation of considerable width and depth cracks during the dry season, resulting in Gilgai micro-relief formations during the wet season; consequently, we include these soils in different sections because olive trees cannot be planted there.

5.8 Different Types of Mediterranean Soils in Spain

In 1976 the Spanish territory was divided into regions to make the work of the Ministry of Agriculture easier. In 1996 the General Technical Secretary of the Spanish Ministry of Agriculture, Fisheries and Food (MAPA) established 326 agricultural regions (Fernández et al. 2011), which are still being used. Since then, many researchers have based their

Photo 5.6 Petrocalcic Palexeralf (deifontes, Province of Granada)

studies on this division (the National Geographic Institute, among others: www.idee.es/clientesIGN/wmsgenericclient/index.html?lang=es).

Both Civantos (2001) and the MAPA (2006) have found olive groves over the south and east of the Spanish territory, except for Galicia, Asturias, and Cantabria. Olive groves are mainly found (in order of prevalence) in Andalusia, Castile-La Mancha, Extremadura, Catalonia, Valencia, Aragón, and the Balearic Islands. We used NRCS-USDA (2014) to characterize the Mediterranean soils in Spain, since there are universal classification systems that allow the detailed classification of these soils.

5.8.1 Alfisols

The Alfisol order includes the suborders of Xeralfs, with a Xeric moisture regime, and Udalfs (Table 5.4). Xeralfs are Alfisols that are, in all sub-horizons in the upper −100 cm of the Argillic or kandic horizon, more than 50 % red. Xeralfs include three great groups: Rhodoxeralfs, which are Alfisols with a hue of 2.5YR or redder value, moisture value of 3.0 or less, and dry value no more than one unit higher than the moist value. Palexeralfs are Alfisols that have a Petrocalcic horizon within −150 cm; and an Argillic or kandic horizon that has both:

(1) Within −150 cm of the mineral soil surface, either no clay decrease of 20 % at this depth;
(2) A 5 % or more skeletons; orthodensic, lithic, or paralithic contact within −50 cm, and both; 35 % or more non-carbonate clay; and a clay increase (in fine earth fraction) of 20 % or more.

When the conditions detailed above are not met, found Haploxeralfs.

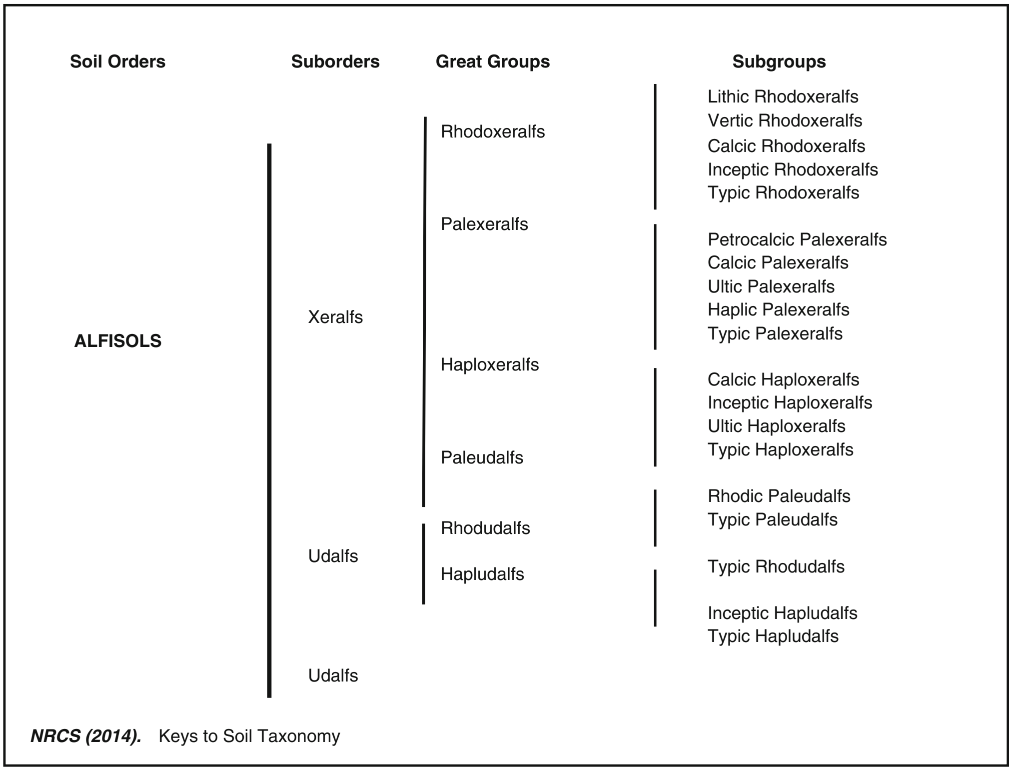
5.8.2 Aridisols

Soils of the Aridisol order have an Aridic moisture regime and an Anthropic or Ochric epipedon, an Argillic or natric horizon, or a salic horizon. The main suborders found in the Mediterranean area in Spain are Gypsids, Calcids and Cambids (Table 5.5).

5.8.3 Entisols

The Entisol order includes arents in NRCS 2010, but in NRCS (2014), this suborder does not exist. Table 5.6 shows the great groups and subgroups of Entisols. In general, Entisols are soils having one or more of the following characteristics: a Cambic horizon that is within −100 cm of

Table 5.4 Alfisols from the Mediterranean area of Spain (suborders, great groups, and subgroups)



Soil Orders	Suborders	Great Groups	Subgroups
ALFISOLS	Xeralfs	Rhodoxeralfs	Lithic Rhodoxeralfs Vertic Rhodoxeralfs Calcic Rhodoxeralfs Inceptic Rhodoxeralfs Typic Rhodoxeralfs
		Palexeralfs	Petrocalcic Palexeralfs Calcic Palexeralfs Ultic Palexeralfs Haplic Palexeralfs Typic Palexeralfs
		Haploxeralfs	Calcic Haploxeralfs Inceptic Haploxeralfs Ultic Haploxeralfs Typic Haploxeralfs
		Paleudalfs	Rhodic Paleudalfs Typic Paleudalfs
	Udalfs	Rhodudalfs	Typic Rhodudalfs
		Hapludalfs	Inceptic Hapludalfs Typic Hapludalfs
	Udalfs		

NRCS (2014). Keys to Soil Taxonomy

Table 5.5 Aridisols from the Mediterranean area of Spain (suborders, great groups, and subgroups)

Soil Orders	Suborders	Great Groups	Subgroups
ARIDISOLS	Gypsids	Petrogypsids	Petrocalcic Petrogypsids
			Calcic Petrogypsids
			Xeric Petrogypsids
			Typic Petrogypsids
		Calcigypsids	Xeric Calcigypsids
		Haplogypsids	Xeric Haplogypsids
			Typic Haplogypsids
	Calcids	Petrocalcids	Xeralfic Petrocalcids
			Calcic Petrocalcids
			Xeric Petrocalcids
			Typic Petrocalcids
		Haplocalcids	Xeric Haplocalcids
			Typic Haplocalcids
	Cambids	Anthracambids	Typic Anthracambids
		Haplocambids	Xerofluventic Haplocambids
			Fluventic Haplocambids
			Xerertic Haplocambids
			Xeric Haplocambids
			Typic Haplocambids
			Anthropic Haplocambids

NRCS (2014). Keys to Soil Taxonomy

Table 5.6 Entisols from the Mediterranean area of Spain (suborders, great groups, and subgroups)

Soil Orders	Suborders	Great Groups	Subgroups
ENTISOLS	Psamments	Torripsamments	Xeric Torripsamments
			Typic Torripsamments
		Xeropsamments	Typic Xeropsamments
			Dystric Xeropsamment
	Fluvents	Xerofluvents	Typic Xerofluvents
		Torrifluvents	Xeric Torrifluvent
			Anthropic Torrifluvents
			Typic Torrifluvents
	Orthents	Torriorthents	Lithic Torriorthent
			Xerertic Torriorthent
			Xeric Torriorthents
			Typic Torriorthents
		Xerorthent	Dystric Xerorthent
			Typic Xerorthent
		Udorthent	Typic Udorthent

NRCS (2014). Keys to Soil Taxonomy

the mineral soil surface, or a Calcic, Petrocalcic, or Gypsic within a depth of −100 cm of the mineral soil surface. In one or more horizons between −20 and −50 cm below the mineral soil surface, either an *n* value of 0.7 or less, or less than 8 % clay content in the fine earth fraction and one or both of the following features: a salic horizon, plaggen or, in the 50 % or more of the layers between the mineral soil surface and a depth of −50 cm, a SAR of 13 % percent or more, which decreases with increasing depth below −50 cm, and also ground water within −100 cm of the mineral soil surface at a time during the year when the soil is not frozen in any part.

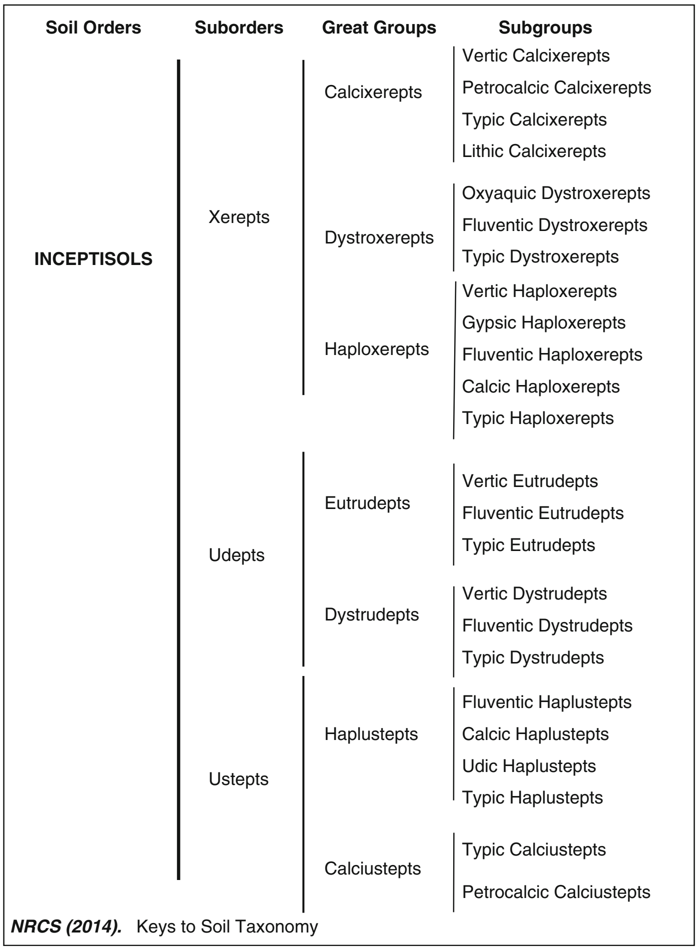
5.8.4 Inceptisols

The Inceptisol order spreads over a large area, where two suborders predominate: Xerepts and Udepts (Table 5.7). Many olive groves grow in Inceptisol soils, competing with cereal and vineyards, although vineyards are more prevalent in Vertic soils. As already indicated, when expansible clays are present, Vertic movements of Inceptisols have deleterious effects on olive roots, obstructing the installation of olive groves.

5.8.5 Vertisols

Vertisols are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. The Vertisol order includes six suborders (NRCS-USDA 2014), four of them common in the Spanish Mediterranean area: Xererts, Torrerts, Usterts, and Uderts (Table 5.8). Xererts are the most represented suborder of Vertisols in Andalusia, showing a broad range of original materials and topographic positions, with a prevalence of Calcixererts and Haploxererts.

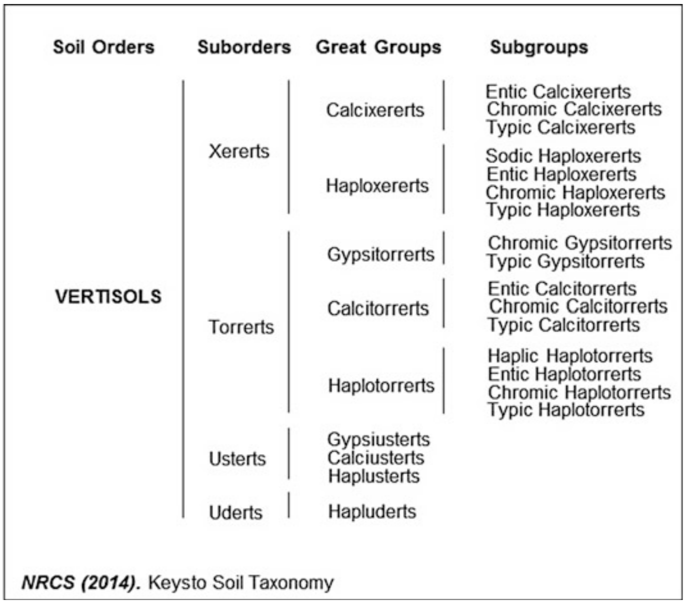
Table 5.7 Spanish Inceptisols from the Mediterranean area of Spain (suborders, great groups, and subgroups)



Soil Orders	Suborders	Great Groups	Subgroups
INCEPTISOLS	Xerepts	Calcixerepts	Vertic Calcixerepts
			Petrocalcic Calcixerepts
			Typic Calcixerepts
			Lithic Calcixerepts
		Dystroxerepts	Oxyaquic Dystroxerepts
			Fluventic Dystroxerepts
			Typic Dystroxerepts
		Haploxerepts	Vertic Haploxerepts
			Gypsic Haploxerepts
			Fluventic Haploxerepts
			Calcic Haploxerepts
			Typic Haploxerepts
	Udepts	Eutrudepts	Vertic Eutrudepts
			Fluventic Eutrudepts
			Typic Eutrudepts
		Dystrudepts	Vertic Dystrudepts
			Fluventic Dystrudepts
			Typic Dystrudepts
	Ustepts	Haplustepts	Fluventic Haplustepts
			Calcic Haplustepts
			Udic Haplustepts
			Typic Haplustepts
		Calciustepts	Typic Calciustepts
			Petrocalcic Calciustepts

NRCS (2014). Keys to Soil Taxonomy

Table 5.8 Spanish Vertisols from the Mediterranean area of Spain (suborders, great groups, and subgroups)



Soil Orders	Suborders	Great Groups	Subgroups
VERTISOLS	Xererts	Calcixererts	Entic Calcixererts Chromic Calcixererts Typic Calcixererts
		Haploxererts	Sodic Haploxererts Entic Haploxererts Chromic Haploxererts Typic Haploxererts
	Torrerts	Gypsitorrerts	Chromic Gypsitorrerts Typic Gypsitorrerts
		Calcitorrerts	Entic Calcitorrerts Chromic Calcitorrerts Typic Calcitorrerts
		Haplotorrerts	Haplic Haplotorrerts Entic Haplotorrerts Chromic Haplotorrerts Typic Haplotorrerts
	Usterts	Gypsiusterts Calciusterts Haplusterts	
	Uderts	Hapluderts	

NRCS (2014). Keysto Soil Taxonomy

5.9 Geographical Repartition of Mediterranean Soils of Spain

To conclude the section on soil types, a description of soils of Mediterranean Spain in the various indicated communities is included below.

5.10 Mediterranean Soils in Andalusia

A wide variety of soils can be found in southern Spain. However, within the order of Inceptisols, Xerepts are the most common types of soil in Andalusia since they represent 57 % of its total area (Junta de Andalucía 2001), and a significant amount of them are used for olive cultivation.

5.10.1 Alfisols

The Xeralf suborder corresponds to Alfisols with a Xeric moisture regime, i.e., a Mediterranean regime. According to authors such as Aguilar et al. (1987c), Rhodoxeralf soils are the prevalent types of soil in Andalusia (597,750 ha).

Olive groves are found in all soil subgroups, mainly in Calcic, Inceptic and Typic Rhodoxeralf (Photo 5.5). The Lithic and Vertic Rhodoxeralf subgroups are rarely used for olive growing, due to the presence of rock in the first and the vertic nature of the latter (Table 5.4). Calcic, Inceptic and Typic Rhodoxeralfs are followed in relevance by Palexeralfs with 473,591 ha. Olive grove soils within these subgroups are Petrocalcic (Photo 5.6), Calcic, Ultic, Haplic, and Typic Palexeralfs.

Finally, Haploxeralf are another type of Xeralfs, which covers an area of 319,898 ha. The subgroups where olive groves are more frequently found are Calcic, Inceptic, Ultic and Typic Haploxeralfs (Table 5.4).

5.10.2 Aridisols

Aridisols (Table 5.5) usually cover areas used for olive-growing in southeastern Spain and the Ebro Basin. Mediterranean soils covered by olive trees in the Provinces of Almería, Granada, and Málaga are prevailingly Calcids; they cover an area of 3,775.3 km^2 and are represented by two great groups: Petrocalcids and Haplocalcids. Petrocalcids are Aridisols with a Petrocalcic horizon (strongly cemented limestone horizon) within 100 cm of the soil surface. Relevant subgroups are: Xeralfic, Calcic, Xeric and Typic Haplocalcids, which are Calcids with a Calcic horizon within 100 cm of soil surface, and belong to the Xeric and Typic subgroups.

Cambids are Aridisols that have none of the characteristics of the remaining suborders; they cover an area of 560 km^2. Their great group is Haplocambids, in which there are other Cambids (Xerofluventic, Fluventic, Xeric, and Typic).

The last group is that of Gypsids (292 km^2). The great groups identified are Petrogypsids, with a Petrogypsic

Photo 5.7 Xeric Calcigypsid, Almería (Sánchez Garrido 1992)

horizon within −100 cm (Petrocalcic, Calcic, Xeric, and Typic); Calcigypsids (subgroup Xeric; Photo 5.7); and Haplogypsids (subgroups Xeric and Typic).

In eastern Spain, soils are prevailingly Calcids, which cover 45 % of the total area.

5.10.3 Entisols

Among Entisols, Psamments are not appropriate for the cultivation of olive groves, although in some sandy areas near the Colomera River (Province of Granada), Typic Xeropsamments have been identified on medium slopes eroded by canals and trails (Photo 5.8). Fluvents used for olive growing are located in the margins of rivers and streams. Photo 5.9 shows an olive grove in a Typic Xerofluvent in the Torrente River (Sierra et al. 1986). Xeric Torrifluvents are Fluvents with a moisture regime between Xeric and Aridic. The area covered by Torrifluvents and **Xerofluvents** is similar, ranging from 27,841 to 22,103 ha, respectively.

Orthents are the soils most used for growing olives in Andalusia; within this group, Xerorthents dominate, covering a 229,298 ha area (the most representative soil being Typic Xerorthent; Photo 5.10). The Torriorthents great group covers 55,783 ha (Xerertic, Xeric or Typic Torriorthent; Photo 5.11), where different irrigation systems are used.

Photo 5.8 Typic Xeropsamment, on medium slopes eroded by canals and trails

Photo 5.9 Typic Xerofluvent in the Torrente River (Province of Granada)

Photo 5.10 Typic Xerorthent, with young olives in Rute (Province of Córdoba)

5.10.4 Inceptisols

Among olive-growing Inceptisols, the Xerepts suborder is the most prevalent. Some Dystroxerepts are also found, although their presence is not relevant. The dominant great group is that of Haploxerepts, which includes the Vertic, Gypsic, Fluventic, Calcic, and Typic subgroups.

Vertic soils are located in bed streams, presenting the limitation of vertic movements and a saturated clay content that negatively affects roots. Gypsic soils are found in the most arid areas of southeastern Spain, while Fluventic **Haploxerepts** occur near riverbeds or on regular slopes. Calcic and Typic Haploxerepts are very common (Photos 5.12 and 5.13). Although Calcixerepts and Haploxerepts are not appropriate for the cultivation of olives, they can be used in Mediterranean climates if the *Cmk* horizon is broken, as shown in Photo 5.14 (Petrocalcic Calcixerepts).

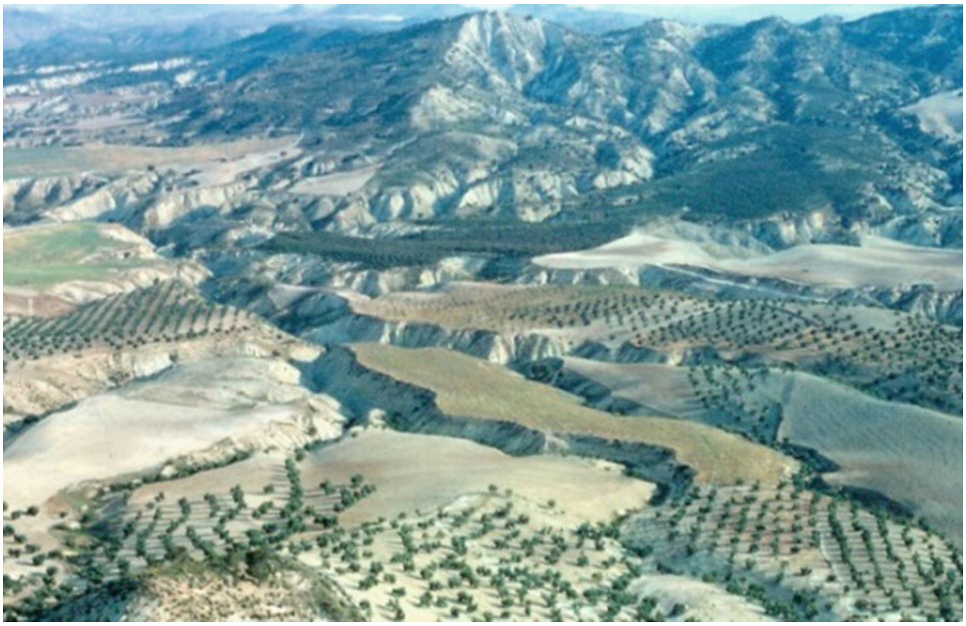


Photo 5.11 Typic Torriorthent with an olive grove (Province of Jaén)

Photo 5.12 Calcic Haploxerepts (Province of Jaén)

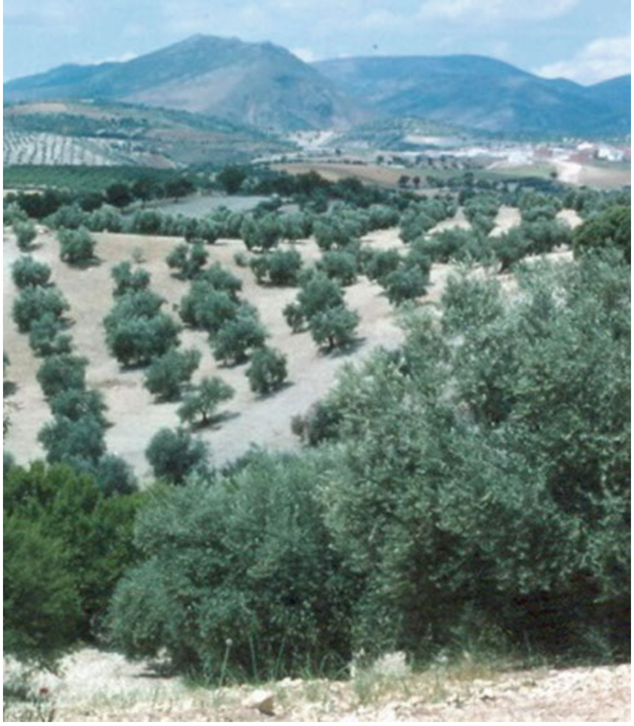


Photo 5.13 Calcic Haploxerepts (Province of Granada)

Of special note is the case of Almería (Aguilar et al. 1987a, b, c; 1988; 2004; Pérez Pujalte and Oyonarte 1989; Fernández et al. 2011), where the dominant soil is calciorthid (NRCS-USDA 2010). Haplocalcids in NRCS-USDA (2014) which occupy 45 % of its area, occur mainly in areas east of the Province of Almería, and are majority soils www.dipalme.org/Servicios/Anexos/Anexos.nsf/CC01550DB1528F2EC125756E004AFDC1/$file/Cap_5_Suelos.pdf.

Xerept is the dominant soil on the western border of the Province of Almería (27.5 % of the surface), which is the most common Inceptisol in the Iberian Peninsula. Other soils (less common ones), can also be found in this province—Torriorthents (6.3 % of the area) in the Alto Almanzora

Photo 5.14 Cmk horizon in Petrocalcic Calcixerepts

agricultural region, and in coastal regions near the Cabo de Gata Cape. Another relevant type of soil are Cambids (5.7 % of the area), which are characteristic of desert lands, and are associated with the great group of Calcids. Finally, Haploxeralfs can also be found, although rarely.

5.10.5 Vertisols

Vertisols are found in large farmland areas in Andalusia; these are used for growing dryland grain, cotton, and leguminous plants, which are the most representative crops (Photo 5.15). They are mainly distributed along the Guadalquivir River, from its source in Cazorla Mountain Range to the coastal areas of the Provinces of Málaga, Cádiz, and Huelva, with a substantial presence in inner areas such as the Provinces of Jaén, Córdoba, and Seville, and a minor presence in those of Granada and, especially, in Almería.

Asensio (1994) examined entic Chromoxererts affected by salts in the Province of Málaga, focusing on genesis and degradation processes. Lozano et al. (2000) analyzed crops in Vertisols in Málaga, and designed a set of gradation matrices that are applied to the mapped soils of the area, providing information on the limiting factors of the soil (as in Photo 5.16) from an agronomic perspective.

Photo 5.15 Crack in a Vertisol with a chickpea crop

5.11 Mediterranean Soils in the Community of Madrid

There are 25,000 ha of olive groves in the Autonomous Community of Madrid. These olive groves are mostly found (97 %) in the agricultural regions of Las Vegas (southeast), Campiña (east), and Sur Occidental (southwest). As much as 50 % of the olive oil production in the Province of Madrid is

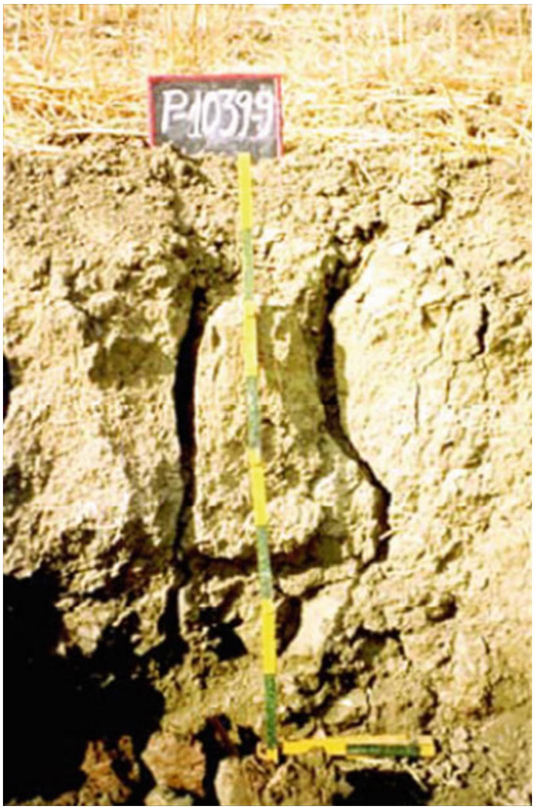


Photo 5.16 Vertisol morphology (Typic Haploxerert) from Colmenar (Province of Málaga)

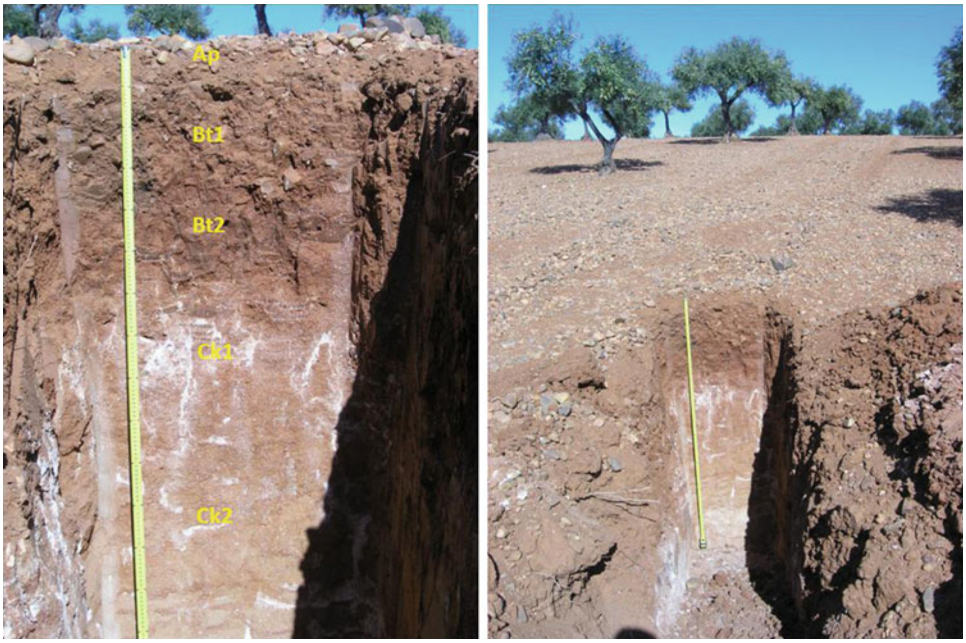


Photo 5.17 Calcic Haploxeralf. Campo Real (Province of Madrid)

produced in Villarejo de Salvanés, Tielmes, Valdaracete, Colmenar de Oreja, Morata, Arganda, Carabaña, Chinchón, and Campo Real. In the 2011–2012 season, a total of 26,000 tons of olives were harvested, with a production of high-quality olive oil of nearly 6,000,000 L.

5.11.1 Alfisols

Argillic horizons are dominant in the Province of Madrid. Three great groups are identified within the group of Alfisols: First are the Haploxeralfs—the most common—according to the Map of Soils of the Autonomous Community of Madrid (Bienes et al. 2011). Olive groves in Madrid are prevailingly cultivated in the calcic, Inceptic, Ultic and Typic Haploxeralf subgroups (Table 5.4). Photo 5.17 shows a Typical example of these soils. Palexeralfs are the second most common type of soil in Madrid. Soils of olive-groves within this great group are Petrocalcic (as in Photo 5.6), Calcic, Ultic, Haplic and Typic Palexeralfs. Rhodoxeralfs rarely occur in this area, but in all subgroups present of this order (Lithic, Calcic, Inceptic and Typic) are found olive trees.

5.11.2 Inceptisols

After Alfisols, the order of Inceptisols is the one with the greatest number of olive groves in Madrid. Olive groves compete with cereal and vineyards; the olive groves are cultivated only in the suborder Xerepts. Within this group, Calcixerepts are the most common type of soil in this province, which includes three subgroups: Lithic, Petrocalcic and Typic Calcixerept (Photo 5.18). These Calcixerepts are the predominant soils in the eastern area of the Madrid region.

Dystroxerepts are found in the southwest, developed on arkosas as well as on terraces of the Alberche River. This type of soil is characterized by low base saturation throughout the soil profile. Consequently, Dystroxerepts need a good supply of nutrients. Within this great group, two suborders are identified: Oxyaquic, with transient waterlogging at depth (Photo 5.19), Fluventic, and Typic. Fluventic soils are not common, since olive groves are rarely cultivated in valleys, which are usually used for the cultivation of vineards and orchards.

The dominant great group is that of Haploxerepts, which includes the Gypsic, Fluventic, Calcic, and Typic subgroups. The Gypsic subgroup is located at the base of moors, which are generally associated with Quaternary deposits. The Fluventic subgroup only occurs in stream beds and valleys, while Calcic Haploxerepts are located in soils on arkoses in the center and south of the Province of Madrid. Finally, the rest of the soils belong to the Typic Haploxerepts subgroup.

5.11.3 Entisols

The erosive activity, which is appreciable in gently sloping hills and hillsides, determines the frequent presence of Entisols (Table 5.6). The same occurs in areas of recent deposits and low hills, as a result of erosive upsloping activity. During the rainy season, waterlogging occurs, which suggest a poor drainage. However, the presence of

Photo 5.18 Typic Calcixerept on a high terrace in the Jarama River, Arganda del Rey (Province of Madrid)

Photo 5.19 Oxyaquic Dystroxerept, Navalcarnero (Province of Madrid)

hydromorphy features may be considered to be local and generally restricted to lower soil horizons. Small lattice-shaped calcium carbonate accumulations are frequent in *C* horizons (which is a characteristic of arkose soils in the Campiña de Madrid) not associated with calcic diagnostic horizons due to their low carbonate content. Fluvents intended for the cultivation of olives are located in the margins of rivers and ravines, although olive groves are rarely cultivated in this type of soil for two reasons: the occurrence of frequent frosts in valleys, and the strong presence of verticillium.

Orthents are the dominant suborder. The only olive-growing great group is that of Xerorthents, with two suborders: Typic Xerorthent in southern and southeastern Madrid, and Dystric Xerorthent in southwestern Madrid, with a weaker presence of olive groves.

5.12 Mediterranean Soils in Castile-La Mancha

The Autonomous Community of Castile-La Mancha (near the Province of Madrid) is one of the 10 large areas into which Spanish olive grove soils are generally divided (Fig. 5.1a). The largest concentration of olive groves is located north and south of the Montes de Toledo Mountains, in the Provinces of Toledo and Ciudad Real. Olive groves are also found in the Provinces of Cuenca, Guadalajara and southwest of that, in Albacete, being almost entirely used for the cultivation of olives for olive oil (Ruiz Lorente 1995).

5.12.1 Alfisols

With regard to Alfisols, the presence of Argillic horizons is common in the western and southern parts of the Province of Guadalajara and western areas of Toledo—specifically, north of the city of Toledo, and in southeastern Talavera de la Reina, on glacis. Alfisols also occur south of the Province of Ciudad Real (southern Valdepeñas and Puertollano) and, to a lesser extent, in that of the Province of Cuenca. They are rarely found in the Province of Albacete (southern, as in Villarobledo). Only a suborder of Alfisols occurs in this region: Xeralfs, i.e., Mediterranean Alfisols.

Three great groups have been identified in this agricultural region. According to the *Soils of Spain Map* (scale: 1:1,000,000), Haploxeralfs are great group dominant soil in this region, although it is sometimes found associated with other great groups, such as that of Rhodoxeralfs, Palexeralfs and, unusually, Epiaqualfs. The most common subgroups of soils used for the cultivation of olives are Calcic, Inceptic, Ultic and Typic Haploxeralfs. Rhodoxeralfs are the next most important great group in this region, although they cover a smaller area.

Rhodoxeralfs also occur in association with Haploxeralfs to the west of the Montes de Toledo Mountains and, to a lesser extent, in La Alcarria (Province of Guadalajara), but they always occur as secondary soils. Two subgroups of Rhodoxeralfs have been identified in this region: Calcic and Typic.

Palexeralfs are rare, and always occur as secondary soils in association with Haploxeralfs. Palexeralfs are almost exclusively found in La Alcarria, in the western part of the Province of Guadalajara. Within this great group, different subgroups have been identified: Petrocalcic, Calcic and Typic Palexeralfs. Olive groves are found in all subgroups, especially in Calcic, Inceptic and Typic Haploxeralf soils.

5.12.2 Entisols

The Entisols (Table 5.6) are strongly present in all olive groves in Castile-La Mancha, especially in the Montes de Toledo and Montes de Alcaraz Mountains. Orthents are the dominant suborder used for the cultivation of olive trees and are found all over Castile-La Mancha.

Two great groups of the Orthents suborder have been identified in this region: Xerorthent, which is the dominant soil, and Torriorthent. Two suborders of Xerorthent soils are found: Dystric Xerorthents on siliceous materials and Typic Xerorthents on limestone, gypsum, and other sedimentary rocks.

Often, we find soils of this suborder resulting from the mixture of fragments diagnostic horizons. These soils can easily be found since growers have plowed the limestone crust (Petrocalcic horizon, which is quite near the soil surface) to enable the cultivation of olive and vineyards. These soils with fragments of diagnostic horizons are also found in terraces where Argillic and Petrocalcic horizons have been mixed by growers.

Within the great group of Torriorthents, two suborders have been identified: Xeric and Typic Torriorthents.

5.12.3 Inceptisols

In Castile-La Mancha, olive groves are prevailingly found in Inceptisols. Olive groves compete with cereal crops, almond trees and vineyards, and they are only found in the Xerepts suborder (Table 5.7).

Calcixerepts are the dominant great group; they appear all over Castile-La Mancha, especially in agricultural areas of Campo de Calatrava, Campo de Montiel, Montes de Toledo, and La Alcarria. Calcixerepts are rare in subgroups identified as Petrocalcic, but common in the Lithic and Typic subgroups. Both in Montes de Toledo and La Alcarria, Calcixerepts sometimes alternate with Alfisols in more stable areas, and with Entisols in areas subjected to more intense erosion.

Haploxerepts are present in the form of several subgroups: Gypsic, Fluventic, Calcic and Typic. The Gypsic subgroup is located at the base of moors, generally associated with Quaternary deposits, and they exclusively occur in the northern areas of Montes de Toledo Mountains and in the south of La Alcarria.

Fluventic subgroup soils only occur in valleys and stream beds, where vineyards are the dominant crop, while olive tree is preferably cultivated in elevated areas; therefore, Fluventic soils are rarely used for olive-growing. Calcic Haploxerepts generally occur in carbonate-rich rocks, such as limestones, calcarenites, marlstones, and, to a lesser degree, arkoses. Typic Haploxerepts also develop in these Lithologies, but unlike the calcic subgroup soils, the accumulation of secondary carbonates is not sufficient for the development of a Calcic horizon.

The great group of Dystroxerepts covers significant areas of the Montes de Toledo and develops in a variety of materials (usually on granitic rocks), although they are also frequently found on sandstone, quartzite, and slate.

Dystroxerepts are also found in the Campo de Montiel and Campo de Calatrava districts (De la Horra et al. 2008) on slate, sandstone, and quartzite, although they are not as common in these regions as in the Montes de Toledo.

5.12.4 Vertisols

Jiménez Ballesta et al. (2010) examined the biochemical properties of vertic soils in Castile-La Mancha and the impact of its geological characteristics on the chemical composition of the soil. These soils are found almost exclusively north of the Province of Toledo, in the county of La Sagra, and they are used for cereal crops.

5.13 Mediterranean Soils in Extremadura

Olive groves are the dominant crop in Extremadura, covering a 255,310 ha area, of which 75 % are located in the Province of Badajoz (southern Extremadura). The average olive production is 350,000 tons (more than 10 % of the total olive production in Spain), of which 75 % are olive oil olives and 25 % are table olives. Olive groves in Extremadura are cultivated in soils with variable pH. However, in terms of nutrients, the soils are quite similar and are generally deficient in N, K, Ca, and Mg (Pérez et al. 2011).

5.13.1 Alfisols

Within the Alfisol order, the Xeralf suborder stands out, with a Xeric moisture regime (Typical Mediterranean climate), although the moisture regime in the Gata-Hurdes district (Province of Cáceres, Northern Extremadura) is almost ustic. In fact, Lázaro et al. (1978) mapped the northeastern area of the Gata-Hurdes district, which they classified as an ustic soil-moisture regime. However, the annual rainfall registered in olive groves in spring and summer is not sufficient to classify these soils within the Ustalfs suborder.

Within the Xeralfs suborder, the great group Haploxeralfs was identified, with three subgroups: Inceptic, Ultic and Typic Haploxeralfs (Table 5.4) and, to a lesser extent, Palexeralfs associated with Haploxeralfs and always as a secondary soil, as they do not cover areas large enough to be individually mapped. These soils of the olive groves in Extremadura correspond to the Haplic and Typic Palexeralfs.

5.13.2 Entisols

Photo 5.20 Rocky Entisol in western Spain

Photo 5.21 Entisols in Extremadura “dehesa”

These soils do not have a diagnostic horizon, and are frequently associated with the Spanish “*dehesas*” (Photos 5.20 and 5.21), sheltered by disperse Holm oaks (*Quercus rotundifolia*), occupying uniform large spaces in Extremadura, in flat or rolling topography; this, associated with the presence of very big land properties, has caused the traditional poverty and emigration of people from these areas (western and southwestern Iberia). Nowadays, paradoxically, the dehesas are praised because they have been ideologically shielded by, and integrated in, a “flourishing” wave of ecology (biodiversity); afterwards they are paradoxically maintained by the European Union and their landowners, and are financially supported. We also found this soil order in the mountainous area of northern Extremadura and in the northeast, in the La Vera district (Photo 5.22).

The Entisols order is dominant in the districts of Gata-Hurdes and Monterrubio, with the Orthents suborder the most representative. Only a Xerorthents great group has been identified in this area, with some Dystric Xerorthent and Typic Xerorthent subgroups, and, less frequently, the Aquic subgroup. In the area of Gata-Hurdes, Entisols occur on slopes that are subject to intense erosion. Entisols are

Photo 5.22 Typic Xerorthent developed on sandy material (La Vera district, northeast Extremadura)

often associated with Calcixerepts and Haploxerepts, with Haploxeralfs sometimes in less eroded areas.

Fluvents are devoted to the cultivation of irrigated crops, as is the case of the Alagón and Tiétar River Valleys, where tobacco is still a major crop (but production is decreasing because of the European agrarian political laws). Nevertheless, Fluvents are not an olive-growing soil suborder, although they are found in the area of the Gata-Hurdes District. As in the case of Fluvents, most Psamments are in the Tiétar River Valley and, to a lesser extent, in the Jerte and Alagón River Valleys, where olive groves are very rare. However, some olive groves have been identified in soils developed on sandstone to the southeast of Zalamea de la Serena (Table 5.6); the Psamments subgroups identified are mainly Dystric and Typic Xeropsamments, and, to a lesser extent, the Aquic subgroup.

5.13.3 Inceptisols

Olive groves have also been located in a subgroup of Inceptisols—Xerepts (Table 5.7). Olive groves from the area of Gata-Hurdes grow in soils of the Dystroxerepts great group, of the Xerepts suborder (partially unsaturated soils as a result of the characteristics of the parent material, intensified by a heavy rainfall). Olive groves from the area of Monterrubio grow in Calcixerepts and Haploxerepts.

Photo 5.23 Typical surface polygonal pattern of cracks in Vertisol

5.13.4 Vertisols

García Navarro and López Piñeiro (1987) focused their attention on the fertility of Vertisols in the Province of Badajoz. According to previous studies, the genetic evolution of this soil was Alfisol-Vertisol and corresponds to the entic Chromoxerert subgroup. However, considering the proposal by the International Committee on Vertisols, clay soils used for growing woody crops are chromic Haploxererts, while those used for growing herbaceous crops are, or almost are, Aridic Haploxerert. This difference at subgroup level is a result of the tillage techniques used, which determine the period during which cracks are open; their surface polygonal pattern is quite Typical (Photo 5.23).

5.14 Mediterranean Soils in Aragón

Olive groves in the Community of Aragón cover an area of 50,000 ha and they are predominantly found in the Provinces of Huesca and Teruel. However, the presence of olive groves in this area has progressively decreased and is currently concentrated in the Bajo Aragón District. The soils are represented by four orders: Inceptisols (51.2 %), Aridisols (26.5 %), Entisols (20.8 %), and Alfisols (0.6 %).

5.14.1 Alfisols

Alfisols (Table 5.4), which are rarely found in Aragón, are represented by Xeralfs (Haploxeralfs and Palexeralfs).

5.14.2 Aridisols

Aridisols (Table 5.5) are represented in the Alcañiz area (Province of Teruel), where Calcids are the dominant type of soil. Among the other types are Xeric Haplocalcids and Typic Haplocalcids. Other Aridisols, such as Cambids, are found in this area, although with a weaker presence, represented by Xeric/Anthropic Haplocambids and Fluventic Haplocambids, located in river basins with saline influence in the Ebro Basin. Aridic/fluvic gypsids cover only 1 % of the total olive-growing area and are represented by Calcic and Typic Haplogypsids.

5.14.3 Inceptisols

Inceptisols are represented by Xerepts and Calcixerepts, both Petrocalcic and Typic. There are also Haploxerepts with the Gypsic, Fluventic, Calcic and Typic Haploxerepts subgroups. Residually, there are some areas in the Pyrenees Mountains where Udepts have been identified.

5.14.4 Entisols

The third order is that of Entisols (Table 5.6), with the two suborder Orthents (Typic Xerorthents), which account for 16 % of the total area and are found in the three Provinces of Aragón, with a greater presence in that of Zaragoza; and Fluvents—Typic Xerofluvents, and Xeric, Anthropic and Typic Torrifluvents.

5.14.5 Vertisols

The Regional Department of Environmental Affairs of Aragón (MARM 2011) has identified in this region Vertisols of the Xererts and Usterts suborders. More specifically, the MARM has estimated that there are 3,305 ha of Chromoxererts and 39,515 ha of Haplustert in Aragón. However, these areas should be included in the great groups of Haploxererts and Haplusterts, since Chromoxererts and Chromousterts are not used in current taxonomy.

5.15 Mediterranean Soils in Catalonia

Olive groves in Catalonia cover an area of 116,112 ha, which accounts for 4.6 % of olive-growing soil in Spain. Especially relevant is the Province of Tarragona, with an olive-growing area of 77,649 ha. A wide variety of olive cultivars are grown in Tarragona (Tous et al. 1998), in the Baix Ebre-Montsià region (where half the area is designated for the cultivation of olives in Catalonia and where "*margens*" (stone walls) are used to protect soil from erosion.

Some of the olive grove soils in Catalonia are located northwest of the Alt Empordà region (Province of Girona), with a planting density of 200–700 trees ha^{-1} (Vilar Hernández 2009). These soils are Typic Xerorthents, Typic Udorthents, Typic Calciusteps and Petrocalcic Calciusteps. Other soil types that have been identified are Fluventic, Calcic, Calcic-udic and Typic Haplustepts, with Xerepts located in the South. In the Baix Empordà district, olive grove soils are Calcic and Typic Haploxeralfs, and Calcic and Typic Rhodoxeralfs. The regions of Noguera, Urgell, and Alt Camp, at the border with Aragón (Terra Alta and Priorat), and to the south in the Province of Tarragona, display the same planting density. The Baix Ebre region (bordering the Community of Valencia), with 27,776 ha, is the one with the highest olive grove density; it includes areas of the Ebro River Delta.

Two soil orders can be perfectly distinguished in the Baix Ebre district: a dominant order, Entisols (Orthents, with a high proportion of Fluvents: Typic Xerofluvents), which are used for the growing of rice. The other soils are Xerorthents, used for olive groves. To a lesser

Psamments have also been identified (Typic Xeropsamments). Finally, the area of Montsia, located to the south of the Baix Ebre and with 15,000–20,000 ha of olive groves, has a large area of Inceptisols, which have been classified as Xerepts and Typic Calcixerepts alternating with Entisols (Typic Xerorthent). To the north, there are two other areas with similar soils and characteristics (Ribera d'Ebre and Les Garrigues).

In the Gorgos (Province of Girona) and Serpis River Basins, soils are Typic Xerofluvents. Along these rivers, there are many olive groves with soils between Entisols and Aridisols: Lithic and Xeric Torriorthents for soils with a moisture control section that, in a normal year, is dry for less than three-quarters of the cumulative day per year, with a thermic or mesic soil temperature regime and an Aridic or torric soil moisture regime (that borders on xeric). Xeric Torriorthents are dominant; the others are Typic Xerorthents. There are also Inceptisols belonging to the Xerept suborder, in the great group of Calcixerept, subgroup Typic Calcixerept and Haploxerept, subgroups Gypsic, Fluventic and Calcic Haploxerept.

5.16 Mediterranean Soils in the Valencian Community

Olive groves cover a total area of 91.701 ha, of which 99 % are rain-fed olive groves, 0.6 % are conifers, and the remaining 0.4 % are irrigated olive groves (www.revistaalcuza.com/revista/articulos/GestionNoticias_662_alcuza.asp). Olive grove density is higher in the Province of Valencia as compared to Alicante, but lower than that in Castellón, which is the dominant province in terms of production.

The Province of Castellón has the highest concentration of olive groves that are grown in foothill areas along the coast. The soils in this province are similar to those discovered in Valencia—namely, Inceptisols and Entisols (NRCS-USDA 2014).

In the Province of Valencia, olive groves are mainly located to the south and northwest of the province (Fig. 5.1). These soils of olive groves are Inceptisols, Xerepts (Calcixerepts great group), with the subgroups Petrocalcic Calcixerept and Typic Calcixerepts; some anthrepts can be found where there is only an Anthropic horizon: Haplanthrepts, subgroup Typic Haplantrepts (NRCS 2010). Today this suborder does not exist (NRCS-USDA 2014). Other Xerepts are also present as Calcic and Typic Haploxerepts subgroups.

In the Province of Alicante (Fernández et al. 2011), there are some olive groves near the coast, where soils are predominantly Entisols in the area of Cabo de la Nao Cape, with Orthents, subgroup Typic Xerorthent.

In the southern part of the Province of Alicante (on the border with Murcia), the soils are Aridisols, belonging to suborder Cambid, subgroup Typic Haplocambid and subgroups Xerertic and Xeric.

5.17 Mediterranean Soils in the Region of Murcia

There is also a significant pedodiversity in the Murcia Region (www.atlasdemurcia.com/index.php/secciones/5/los-suelos and www.um.es/docencia/geobotanica/ficheros/tema16.pdf). In general, soils in Murcia are similar to those in the southern Community of Valencia (Province of Alicante). Among the dominant soil orders in Murcia, olive groves grow primarily in Aridisols (Alías et al. 1990a, b, 1997a, b), which cover almost half the area of this region and are widely distributed. Soils in this region are mainly Calcids and Cambids and, in some specific areas, Gypsids. These soils are used for the cultivation of rain-fed woody plants, especially almond tree and olive tree in the south and vineyards in the northern half.

Three other orders have a significant presence in this region: Entisols, great groups Xerorthent and, to a lesser extent, Torriorthent, Torrifluvent and Xerofluvent, depending on the moisture regime and the presence of fluvic influence; Inceptisols, great group Xerochrepts; and Alfisols, great group Xeralfs, which have also been identified, but with a weaker presence.

5.18 Mediterranean Soils in Balearic Islands

The Balearic Islands are characterized by a relatively high humidity in the air, which has a positive impact on the development and maintenance of olive groves and on the quality of olive production. Olive groves in Mallorca are found at various altitudes, ranging from sea level to 800 m asl.

Photo 5.24 Olive tree in terraced soil on Mallorca Island (Baleares)

In the Tramontana Mountain Chain, olive groves are very irregular and are located on slopes, forming the Typical terraces of Mallorca (Photo 5.24). Terraces are made of limestone, and they are useful for removing stones, preventing erosion, favouring farming, and overcoming the existing slopes. In Mallorca, irregular olive tree terraces form part of the Typical landscape of the island. In the Sierra de Tramontana, terraces are cultivated facing south, exploiting the slope and higher insulation, and protecting groves from the cold northerly wind (called Tramontana), which allows cultivation of olives (Photo 5.24). The quantity of olive production in Mallorca is small, due to the characteristics of its soil, the complex orography, irregular rainfall, and old age of the olives.

The soils used for olive cultivars in Mallorca are composed of two orders: Inceptisols and Entisols, which cover most of the cultivated area of Mallorca (70–80 %). They are represented by Xerepts (Calcixerepts: Petrocalcic and Typic Calcixerepts). Some young olive groves are grown in Typic Haploxerepts.

The next most common soil order (20–30 %) is that of Entisols (suborder Orthent): Lithic Xerorthent, for olive groves in mountainous areas of Mallorca and Ibiza, and Typic Xerorthents, for the rest.

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Future Issues

6

Agustín Merino, Gerardo Moreno, Francisco B. Navarro,
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6.1 Changes of Land and Soil Uses in Spain

Throughout history, Mediterranean landscapes, soil, and vegetation have been subjected to intense and continuous transformations, usually involving vast degradations of forest ecosystems (Bauer 1991; Marty et al. 2007). Cultivation and grazing have been the driving forces behind progressive deforestation by plowing, browsing, and trampling, as well as by the use of fire (Stevenson and Harrison 1992; Grove and Rackhman 2001; Shakesby et al. 2001; Asner et al. 2004).

During the nineteenth and twentieth centuries, deforestation by humans reached unprecedented rates due to greater population pressures and an intensification of agricultural practices. In Spain, this process was serious because numerous public lands were put out to tender, mainly between 1860 and 1900, when 5,000,000 ha of forestlands and grasslands were converted to cereal crops (SECF 2011) or to *dehesas* (open oak forests, with moderate to low tree density, and grazing use), mainly in western Spain. This phenomenon paralleled the growth of human populations from the eighteenth century onwards, with the subsequent need for arable and grazing lands (Linares and Zapata 2003), and was exacerbated by advances in soil mechanization. As a result of the rapid loss of trees and denudation of soils, there were serious problems of soil and water conservation (slipping, landslide, erosion, and flooding events), mainly since 1860 (Camacho et al. 2002; Araque 2009).

After the Spanish Civil War (1936–1939), the smallest forest surface area of modern history was reached (0.24 million km^2), of which a major part showed serious processes of degradation together with soil problems (SECF 2011). From that time onwards and, especially from the 1970s, rural depopulation caused widespread land abandonment. The mass departure from agricultural lands in Spain was a complex phenomenon driven by socio-economic and ecological conditions (soil and climatic limitations), both strongly related to the observed spatial and temporal changes in land use (Nainggolan et al. 2012), and in some cases, by land mismanagement (Rey Benayas et al. 2007; García-Ruiz and Lana-Renault 2011).

As a result of the demographic exodus from rural to urban areas, and the implementation of two afforestation programs, from 1940 the trend of forest loss changed. From 1940 until 2010, 4,400,000 ha of agrarian lands and around 3,000,000 ha of grazed pastures were converted to shrublands or forests. This process has led to one of the major landscape changes in many areas of Spain, especially in the less profitable lands (González-Bernáldez 1991; Vicente-Serrano et al. 2000), with consequences for plant and fauna communities in various ways, but also for the development of soil properties and for soil conservation. In some areas, crops and pastures were mostly neglected, and a natural vegetation succession occurred, increasing forestland recovery. In other cases, the adoption of measures aimed at reducing intensive agricultural methods involved afforestation schemes or conversion to grazing lands.

On the other hand, in southern and southeastern Spain, large surface areas of land have been covered by plastic greenhouses (Photo 6.1) or converted to irrigated fields, drastically changing the land use and increasing pollution and the risk of soil salinization. According to the Ministerio de Medio Ambiente y Medio Rural y Marino (Environmental, Agricultural, and Marine Ministry) (2008) Spain has

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Photo 6.1 View of typical plastic-covered greenhouses in Southern Spain

65,989 ha of greenhouses, with 44,500 ha in the region of Andalusia, 9,100 in the region of Murcia, 7,500 in the Canary Islands and 1,735 in the region of Valencia. In addition, progressive soil salinization has been reported in irrigated lands of the valleys of the Tajo, Guadiana, Guadalquivir, and Ebro Rivers (Crespi et al. 2007). This problem is frequently reported in some Spanish Mediterranean areas, because waters having high electrical conductivity are used for irrigation, which can lead to large increases in the concentrations of sediment and solutes in soil (chloride, sodium, sulphate, calcium, and magnesium). In some cases, high concentrations of sulphates and calcium in the soil water result in piping (García-Ruiz 2010). Sometimes farmers avoid these problems by flooding with low-conductivity water and channelling the excess salinity towards waterways. In other cases, fields may become unprofitable because of low productivity and therefore they are usually left to undergo secondary succession (Cañadas et al. 2010).

In Spain, more than 6,000,000 new ha of abandoned land have been afforested since 1940 (SECF 2011). As a result, since 2005 the forest surface area exceeds the area of land designated for agriculture (SECF 2011). All this makes Spain the country that has most contributed to the increase in forest surface area, both in Europe and in the Mediterranean region (FAO 2011). In some regions (Galicia, Castilla-León, Andalucía), the new forest land makes up around 2.2 % of the total surface area (the highest increase in Europe). This process of land abandonment has both positive and negative effects on the environment.

Although soil erosion usually decreases immediately after land abandonment (Dunjò et al. 2003; García-Ruiz 2010; Navas et al. 2012), in many cases land degradation and erosion persist for years afterward (Pardini et al. 2003; Boellstorff and Benito 2005; Navas et al. 2012). On abandonment, soils have a weak water-storing capacity and low levels of N and P (Sardans and Peñuelas 2004; Sardans et al. 2006). Cuesta et al. (2012) reported the loss of available P for years following land abandonment, while Duguy et al. (2007) reported losses of SOM, total N, and available P because of recurrent fires. In addition, García-Ruiz (2010) reported an intense erosive activity for many years when abandoned fields were subjected to overgrazing and periodical fires. However, Dunjó et al. (2003) showed a progressive increase in SOM content when cultivated fields (olive and vineyard, tilled or untilled) were abandoned in Catalonia (northeastern Spain). Clearly, edapho-climatic conditions of abandoned or reforested lands may be of crucial importance for the SOM evolution.

6.2 New Challenges for Soil Science in Spain

Intensive agriculture, overexploitation, and the mismanagement of soils in Spain have led to serious degradation, such as erosion, low SOM content, or salinization. In many cases, restoration techniques, such as afforestation, have been undertaken (Bonet and Pausas 2004; Vallejo et al. 2006; Rey Benayas et al. 2007; Cuesta et al. 2012). In other cases, the previous fertilization has encouraged the establishment of the new plant species, even trees, where there are not climatic and soil limitations (e.g., lack of depth), or grazing. Although positive effects of fertilization last long after crop abandonment (Duguy et al. 2007; Moreno and Obrador 2007; Cuesta et al. 2012), long-term negative effects of cultivation have been frequently reported (see reviews from Rey Benayas et al. 2007; García-Ruiz 2010).

One of the most important negative effects of intensive agriculture on soil properties is the loss of soil organic matter (SOM). Agricultural and rangeland soils show major SOM depletions with respect to forests (Hontoria et al. 1999; Rodríguez-Murillo 2001; Romanyà and Rovira 2011). This significant decrease of SOM contents is due to multiple factors: (1) lower plant-waste input; (2) higher mineralization rates (as a result of the intensive tillage); and (3) recurrent or planned fires. Romanyà et al. (2000) showed that the SOM content was consistently lower (<2.0 %) for arable lands than for woodlands, regardless of the climate and region; thus, olive groves, vineyards, and dryland farming show the lowest SOM contents (~50 % respect to forest and shrublands; Rodríguez-Murillo 2001). Results from Ganuza and Almendros (2003), Trasar-Cepeda et al. (2008), Paz-Ferreiro et al. (2010), and Fernández et al. (2012) in the Spanish moist temperate areas showed that with respect to natural or semi-natural forests, intensive management of croplands leads to sharp decreases in the SOM content (>60 %). Nevertheless, the SOM contents of these arable soils are much higher than those found in other Spanish continental and semi-arid regions.

The various climates in Spain control biogeochemical processes and determine remarkable differences in certain chemical soil properties. For example, salinization is a frequent problem in irrigated agricultural soils in arid or semi-arid regions (Aragüés et al. 2011). On the contrary, in wetter regions, liming during cultivation favors the availability of certain elements and promotes early tree growth after afforestation of these acidic soils. The amendment with liming material, such as wood ash (as proposed by Solla-Gullón et al. 2006) or stabilized sewage sludge (e.g., Mosquera-Losada et al. 2012), in the establishment of new plantations, counteracts this acidification, although it has a limited effect over time. These practices improve the levels of available P, Ca, Mg, and K, and nutritional status of the plantations for the first 3–5 years.

Also, intensive forest harvesting (thinning, pruning, and leaf raking for animal feed) of these areas can cause a progressive impoverishment of soil quality, reducing the base saturation of soils (Moreno and Gallardo 2002), a process that can be worrisome for sites with acidic weathered bedrock, as is common in western mountainous areas.

However, although this effect is general, important variations can be found under the above-mentioned different climatic areas and management regimes found in Spain. SOM contents are especially low in arid and semi-arid areas, both in croplands and forests. On the contrary, soils from the Atlantic and some continental areas show rather high SOM contents, croplands included; usually, the SOC sequestered by the soil is higher than C found as biomass in temperate and Mediterranean areas (Gallardo and González 2004, 2005). In general, mountain pastures have a higher SOM content than do forests. The loss of SOM leads to multiple negative consequences on soil conservation, promoting soil compaction by load machinery, implying lower porosity and infiltration rates, and higher run-off (Richter and Markewitz 2001; Sánchez-Marañón et al. 2002).

Furthermore, the soil-water holding capacity is also reduced, which is a major disadvantage for the establishment of new vegetation in Mediterranean environments (Rey Benayas et al. 2007). Soil-water content (SWC) varies notably among land uses, and the lowest values are usually associated with abandoned lands (Errea et al. 2001). Cubera and Moreno (2007) and Moreno and Rolo (2011) found that shrubs significantly diminished SWC with respect to adjacent pasture areas, irrespective of soil depth and season, hindering further implantation of tree species, but runoff from lateral zones can provide an additional source of water for certain patches (forming adjacent bare inter-patches), determining the development of a sparse woody system in drier areas (Cammeraat et al. 2010).

The use of organic wastes in dry areas, such as sewage sludge or urban refuse, usually increases the water availability by increasing water storage capacity, modifying the soil structure, and changing the infiltration rate (Bastida et al. 2007). These organic amendments improve soil properties related with nutrient availability while spurring microbial activities and fungal diversity (Alguacil et al. 2009).

Querejeta et al. (2000), Bocio et al. (2004), and Palacios et al. (2009) showed that deep subsoiling had significant positive effects on water infiltration and root development. Espelta et al. (2003) concluded that subsoiling in uncleared or lightly grazed areas, before planting, was the best alternative among different soil-preparation techniques (or mixed alternatives), because of its low economic cost and low ecological impact, promoting reasonably good seedling survival and growth; other forest actions are significantly more expensive despite better plant survival.

Intensively managed soils, especially those devoted to annual crops, are particularly susceptible to soil erosion because of high soil erodibility and the lack of a protective plant cover (Murillo et al. 2004; Solé Benet 2006; García-Ruiz and Lana-Renault 2011). Due to the consequent lower SOM content, high erosion rates are usually recorded with respect to scrublands, grasslands, or forests (Cerdá 2003). Associated with the loss of SOM (and concomitant soil compaction and erosion), a reduction of CEC, total soil N (Nt), available P and K, and SWC values have been reported, for example, in cultivated soils in the Pyrenees (Navas et al. 2008), as well as in cultivated oak woodlands near Salamanca (Nunes et al. 2012). In addition, rainfall impact and low aggregate stability usually lead to the formation of surface crusts that reduce the infiltration capacity of the soil.

Severe problems of overland flow, rill, and even gully erosion are often found in abandoned areas. Terraced fields also have a high risk of severe gully erosion due to terrace collapse (Rey Benayas et al. 2007); badly designed or mismanaged terraces can moreover act as points where flow concentrates, resulting in further erosion and terrace collapse. For this reason, terracing has been criticized because it leads to physical soil degradation and additional soil erosion (Querejeta et al. 2000; Nunes 2011). Nevertheless, some positive cases have been reported (e.g., significant increase of fine-particle retention and water-holding capacity).

However, land degradation after farmland abandonment in arid and semi-arid areas depends on several factors and can usually be reversed under suitable conditions (e.g., aspect, orientation, parent material, soil stoniness, etc.). For example, Cerdà (1997) found that runoff and erosion reached low rates only 10 years after abandonment under various stages of vegetation cover.

Overgrazing, combined with periodic fires (which is a common management practice) has been shown to have strong effects on soil degradation, especially by inducing changes in C, N, and P cycling as well as soil compaction (Pausas et al. 2004; Pereira et al. 2004; Moreno and Pulido 2009). Specific problems of land degradation caused by livestock grazing, such as impoverishment of the pasture cover, accelerated soil erosion caused by physical soil degradation (low SOM content, low porosity, and reduced infiltration rate), and excess of N inputs have also been reported for Iberian *dehesas* (Coelho et al. 2004; Murillo et al. 2004; Fernández-Rebollo et al. 2008; Schnabel et al. 2009; Shakesby et al. 2011; Morillas et al. 2012). Moreno and Obrador (2007) and Tárregas et al. (2009) reported improved soil physical and chemical properties in shrub-encroached *dehesas* a few decades after livestock grazing ceased. By contrast, Peco et al. (2006, 2012) found lower contents of SOM, organic N, available K, and readily available water in abandoned soils as opposed to grazed zones, explained by the lack of input of organic wastes (feces).

In addition to the CO_2 release caused by SOM mineralization, intensive agricultural management involves far-reaching implications in two powerful greenhouse gases, i.e., CH_4 and N_2O. Apart from the effects on the SOM pool and quality, the effect of soil management on microbial communities should be taken into account. In relation to this, agricultural management results in greater N_2O emissions and less CH_4 uptake. Thus, transformation of agriculture lands into forests reduces soil N_2O emissions (e.g., cultivated vs. forest soils, near Madrid; Sánchez-Martín et al. 2010) and boosts CH_4 uptake rates (Inclán et al. 2012). A review from Aguilera et al. (2013) on soil N_2O emissions from Mediterranean soils shows that they are especially important when mineral N fertilizers are used. Due to the involvement of soil in global warming, this effect of agricultural soils on the dynamics of the greenhouse gases should also be taken into consideration. Some studies (e.g., Merino et al. 2004; Sánchez-Martín et al. 2010) show that agricultural soils have low rates of CH_4 uptake and that they can even act as a source of this gas during rainfall.

A near-future shift from aggradation to steady-state, warming, increasing drought, continued N deposition, and usually high ozone levels have been cited as potential drivers of changes in the biogeochemistry of Mediterranean forests. Situations of nutrient (mainly N) saturation in forest soils have also been reported in Catalonia, near Barcelona (Rodá et al. 2002). Any temperature rise would likely increase SOM mineralization while, by contrast, a decrease in mineralization rates by a slowdown of microbial activity and by changes in humus quality (e.g., sclerophylly) could promote drought in Mediterranean ecosystems (Casals et al. 2000). Drought could also diminish plant uptake of P and K (Sardans and Peñuelas 2007), and aridity could negatively affect the concentration of SOC and total N (associated with biological processes such as litter decomposition), but positively affect the concentration of inorganic P (associated to physical processes such as rock weathering (Delgado-Baquerizo et al. 2013)). Hence, many uncertainties remain concerning how the atmosphere and climate change would affect nutrient availability and net nutrient cycling in Spanish and other Mediterranean soils, an issue that should be addressed by research programs in the coming years.

Another pressing issue involves the subsidies of the European Union to agriculture. Some issues could be not fully addressed—for example, economical support of cows can result in overgrazing, i.e., increased soil erosion.

Lastly, it is of fundamental importance to ascertain the position of Spain as a mining country. Iron, gold, silver, and mercury have been mined since Roman times. During many European and world wars, Spain also exported strategic minerals such as wolfram, profiting—either legally or illegally—from the country's neutrality. Therefore, contaminated areas are common throughout the mainland. In addition, abandoned coal mines are common in northern Spain, raising serious dilemmas; also, the entire country is contaminated by lead because of hunting with lead shot (Guitart and Mateo 2006). Soil restoration and decontamination is, then, an important issue in Spain, as promoted by Macías and others (e.g., Otero et al. 2012) in Galicia (northwestern Spain).

6.3 Future Subjects in Soil Science

From the above, we can conclude that the following scientific issues are important concerning soils in Spain:

- Time course of soil properties after land abandonment
- Soil responses to afforestation

- Biogeochemical cycles in transformed and abandoned soils
- Nutrient imbalances in agricultural and forest soils
- C sequestration in abandoned soils
- Pollution and balances of gases with greenhouse effect from soils
- Soil-water efficiency in intensive agriculture
- Soil-water efficiency in rangelands
- Soil salinization is semi-arid and arid areas
- Soil acidification and impoverishment in soils submitted to percolation
- Effectiveness of forests for soil protection
- Soil contamination in areas supporting intensive agriculture (greenhouses)
- Soil reclamation and decontamination of contaminated areas.

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