Soils of the Temperate Humid Zone

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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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J.F. Gallardo (ed.), *The Soils of Spain*, World Soils Book Series,
DOI 10.1007/978-3-319-20541-0_3

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

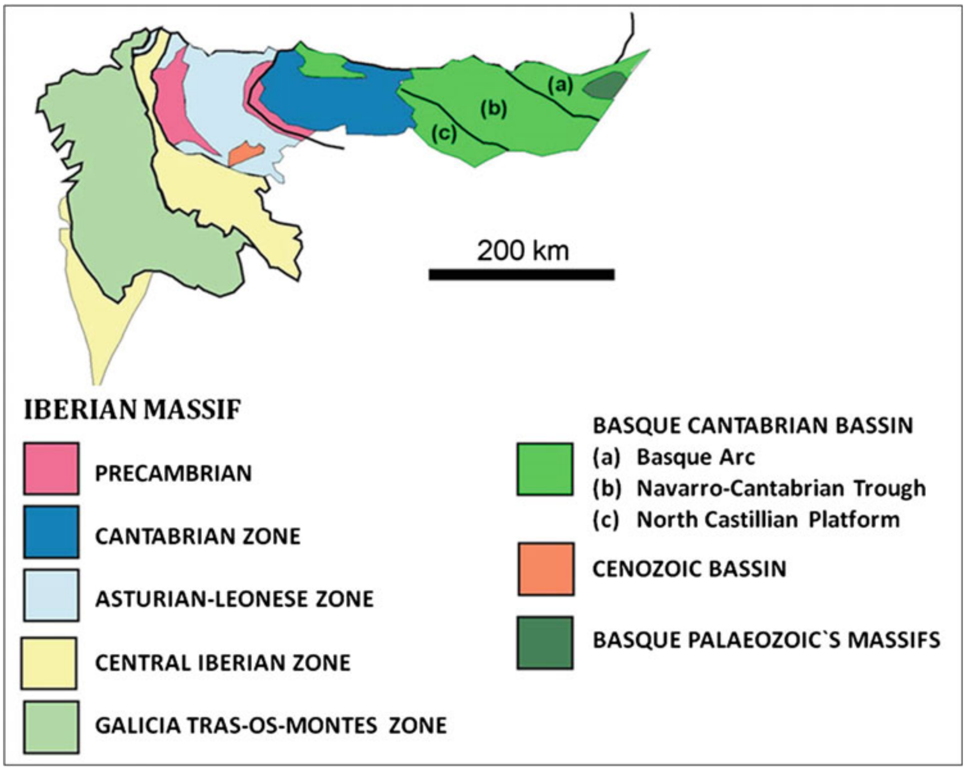


Fig. 3.2 Scheme of the distribution of the various geological units of the study zone, according to the division proposed for the Iberian Massif by Julivert et al. (1972), Farias et al. (1987), and Arenas et al. (1988), and for the Basque-Cantabrian Basin by Barnolas and Pujalte (2004)

(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

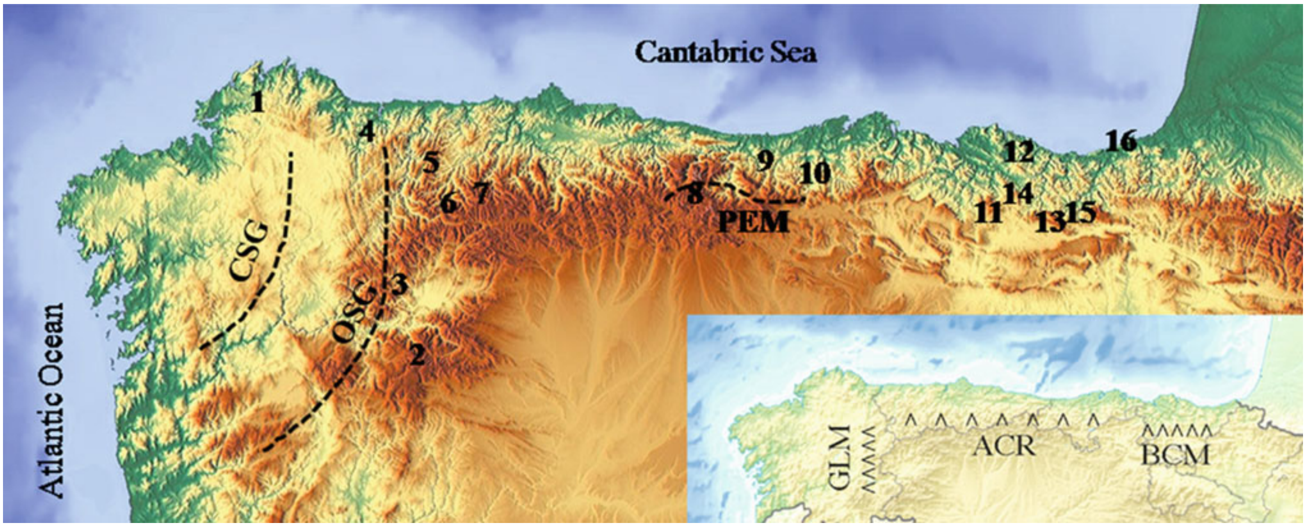


Fig. 3.3 Geographical location of the geomorphological units and some locations described in the text. *GLM* Galaico-Leonese Massif; *ACR* Asturian-Cantabrian Mountains; *BCM* Basque-Cantabrian Mountains; *CSG* Central Sierras of Galicia; *OSG* Oriental Sierras of Galicia; *PEM* Picos de Europa Mountains; *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

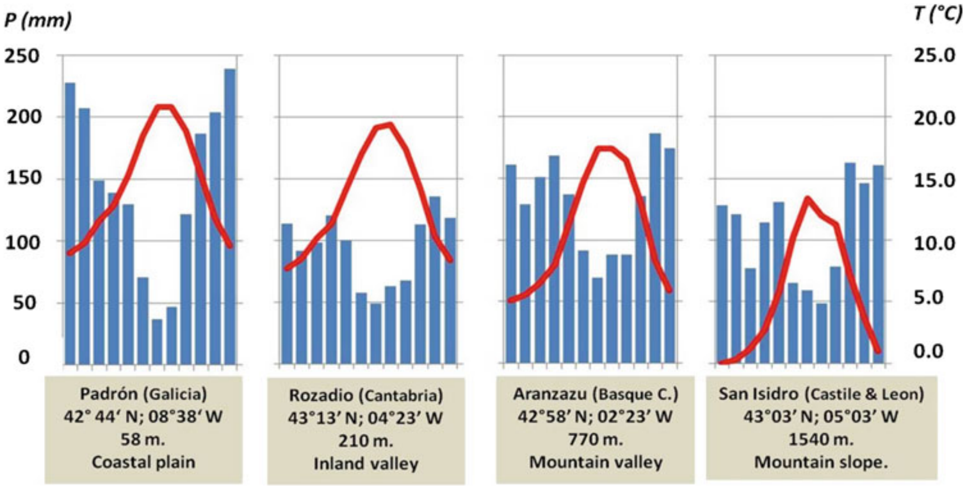


Fig. 3.10 Examples of monthly distribution of temperature and precipitation in four selected meteorological stations in the Spanish Temperate Humid Zone. Data from MAGRAMA (2013)

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).

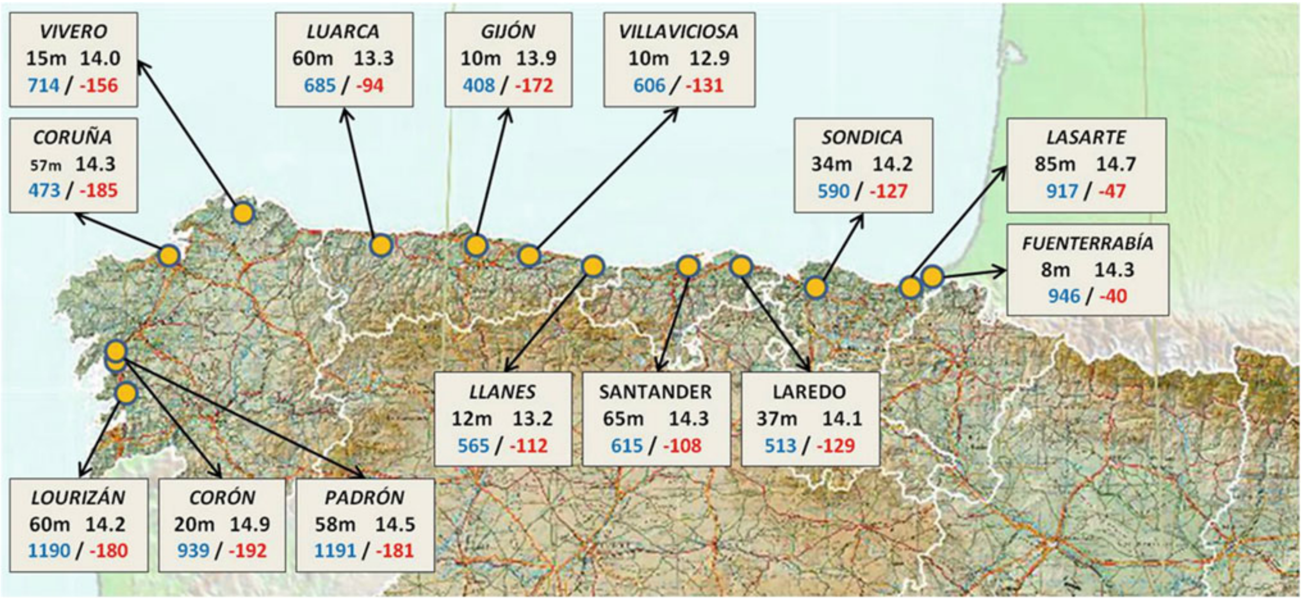


Fig. 3.11 Data from the coastal areas (altitudes below 100 m). Text boxes include: name of the station; altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values ≤ 0, *red characters*). Base map: Instituto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

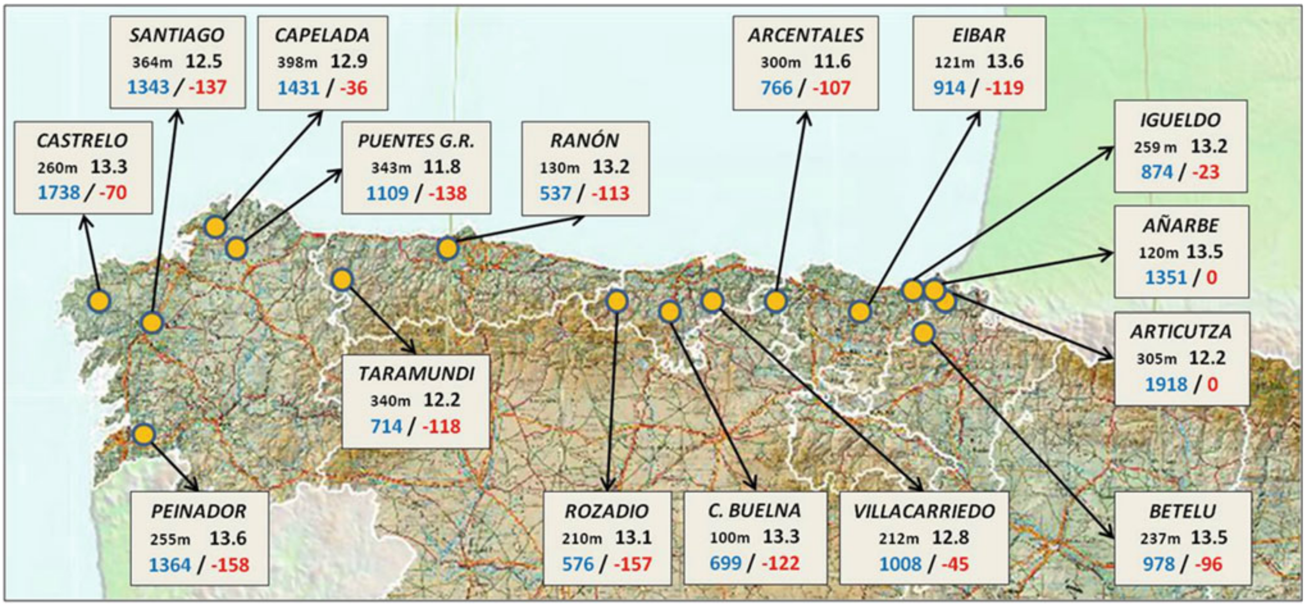


Fig. 3.12 Summarized temperature, drainage and moisture deficit data from meteorological stations in lowlands. Text boxes include: name of the station; altitude (m. asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit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

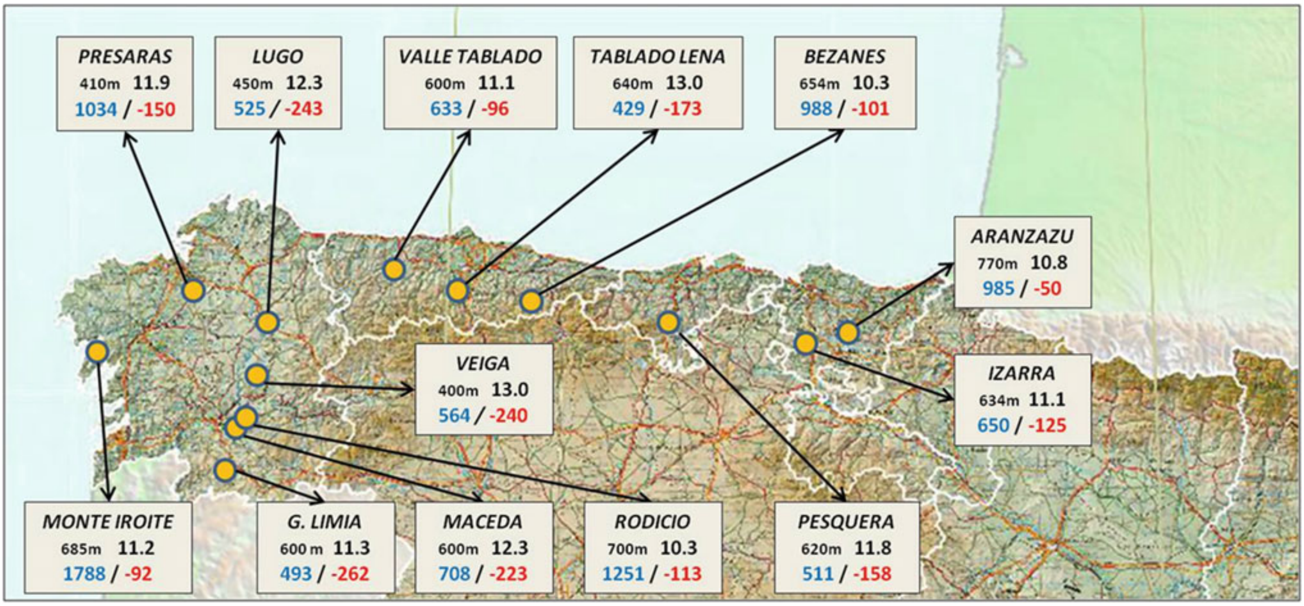


Fig. 3.13 Summarized temperature, infiltration and moisture deficit data from meteorological stations in inland valleys and slopes. Text boxes include: name of the station, altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer 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

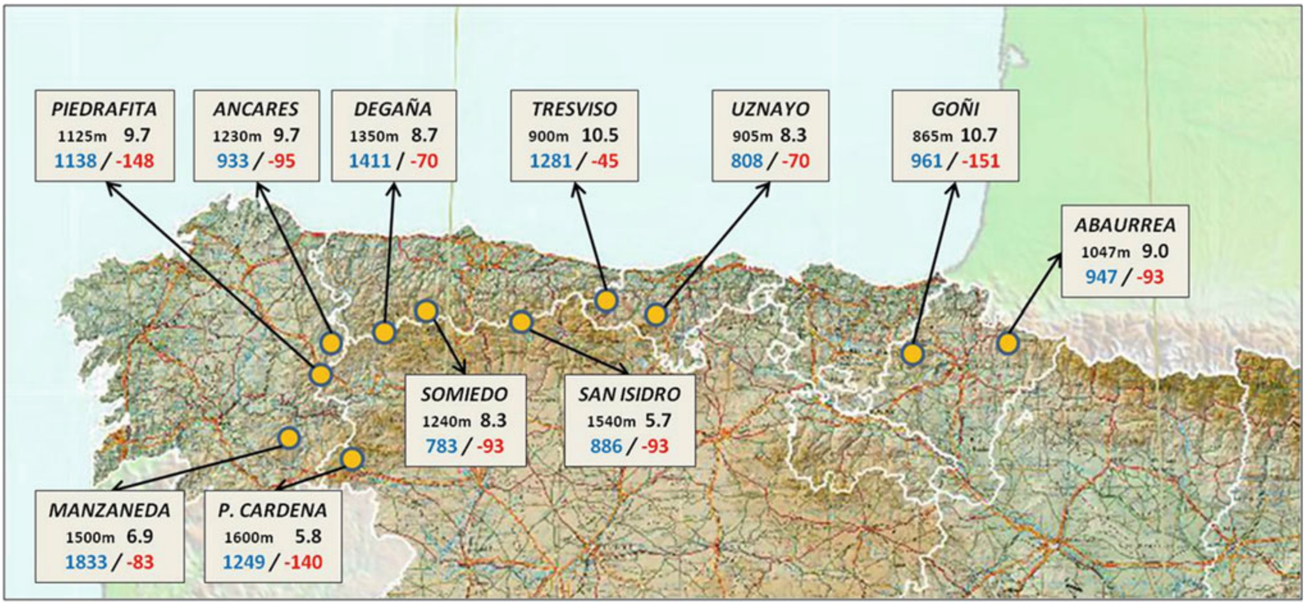


Fig. 3.14 Summarized temperature, drainage and moisture deficit data from meteorological stations in mountains. Text boxes include: name of station; altitude (m asl); average annual temperature °C (*black characters*); average annual drainage (*blue characters*); and average summer moisture deficit (values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

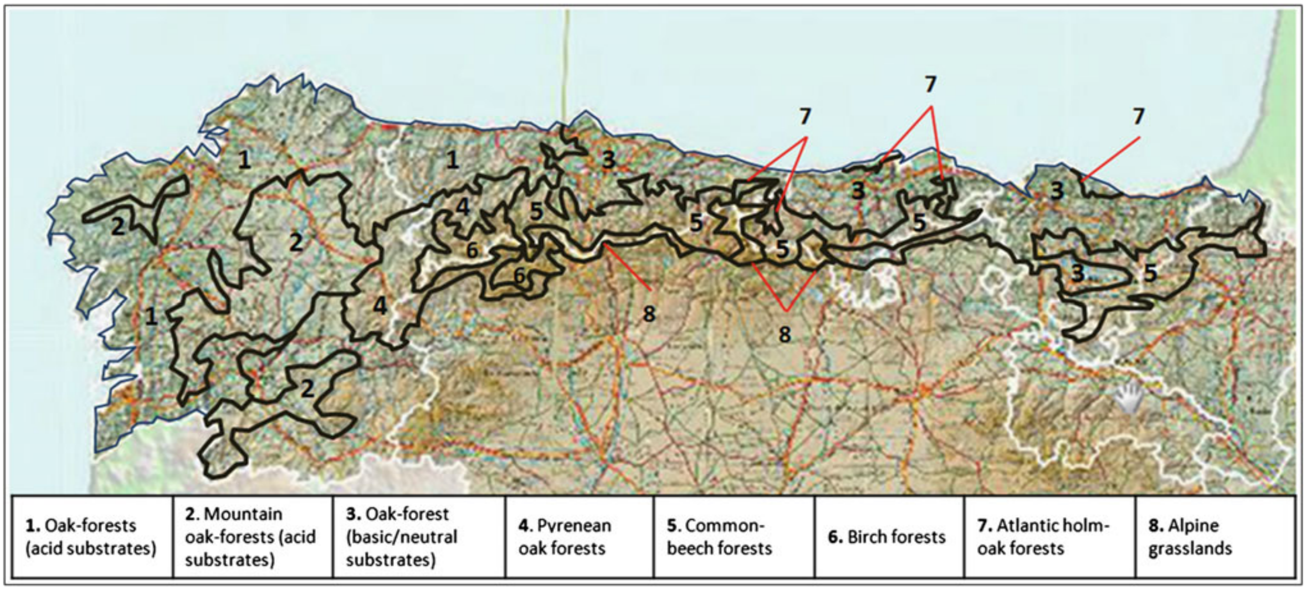


Fig. 3.15 Main climax vegetation formations in the Spanish Temperate Humid Zone. Synthesized and modified from Rivas-Martinez (1987), Spanish Potential Vegetation Map 1:400,000 scale. Base map: Instituto Geográfico Nacional. IGN, Spain

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* I.), 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

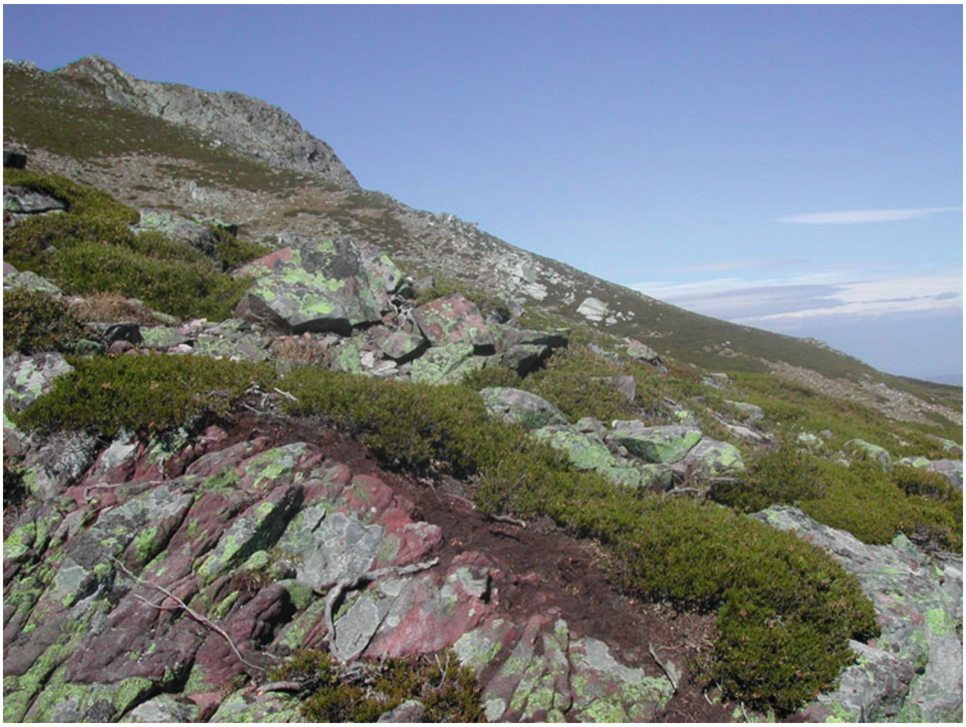


Fig. 3.20 High-mountain scrub. San Isidro, Cantabrian Cordillera. South-Central Asturias

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

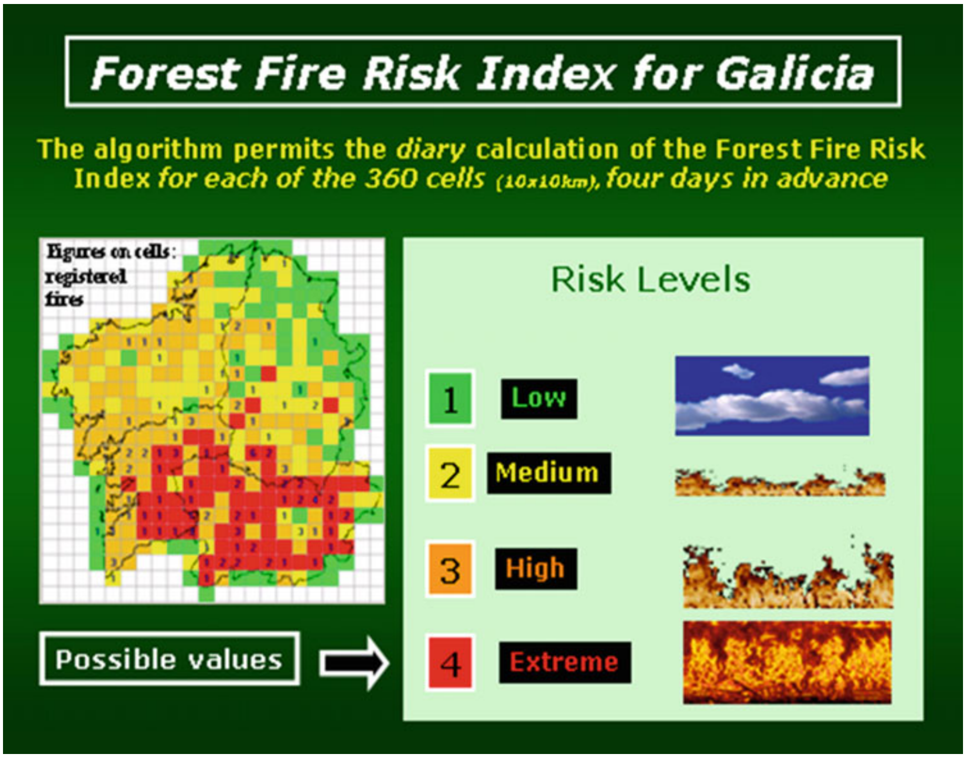
(2) Forest fires 40 years ago that increased at such abnormal rates that they merit additional explanations, bringing about serious processes of post-fire erosion.

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



Forest Fire Risk Index for Galicia

The algorithm permits the *diary* calculation of the Forest Fire Risk Index *for each of the 360 cells (10x10km), four days in advance*

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

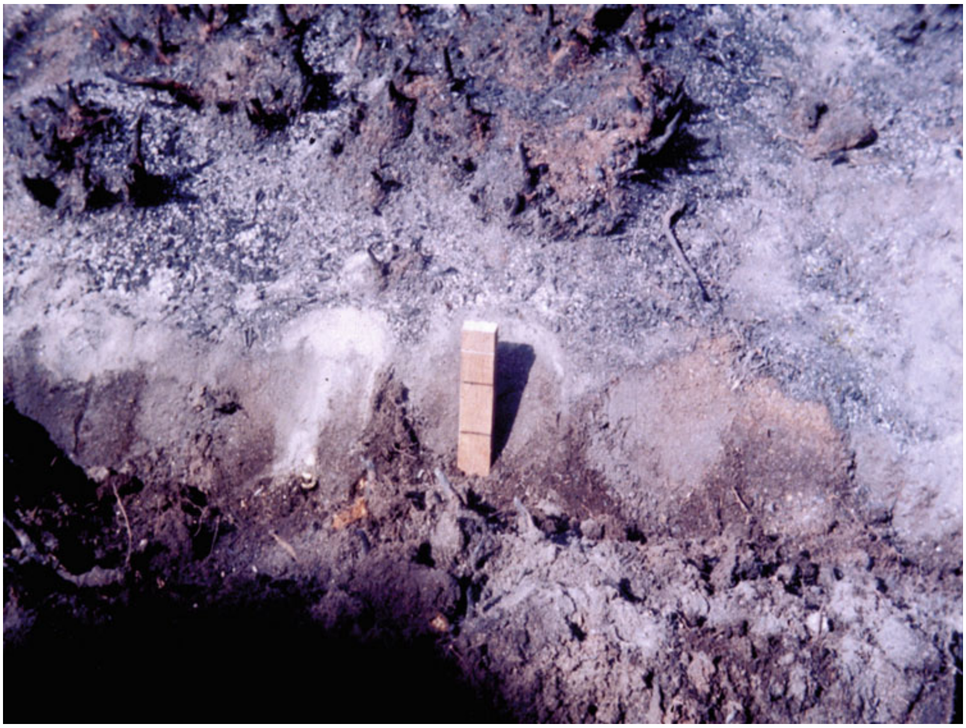


Fig. 3.30 Soil affected by a severe wildfire: detail. Cabeza de Manzaneda, Orense, Galicia

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

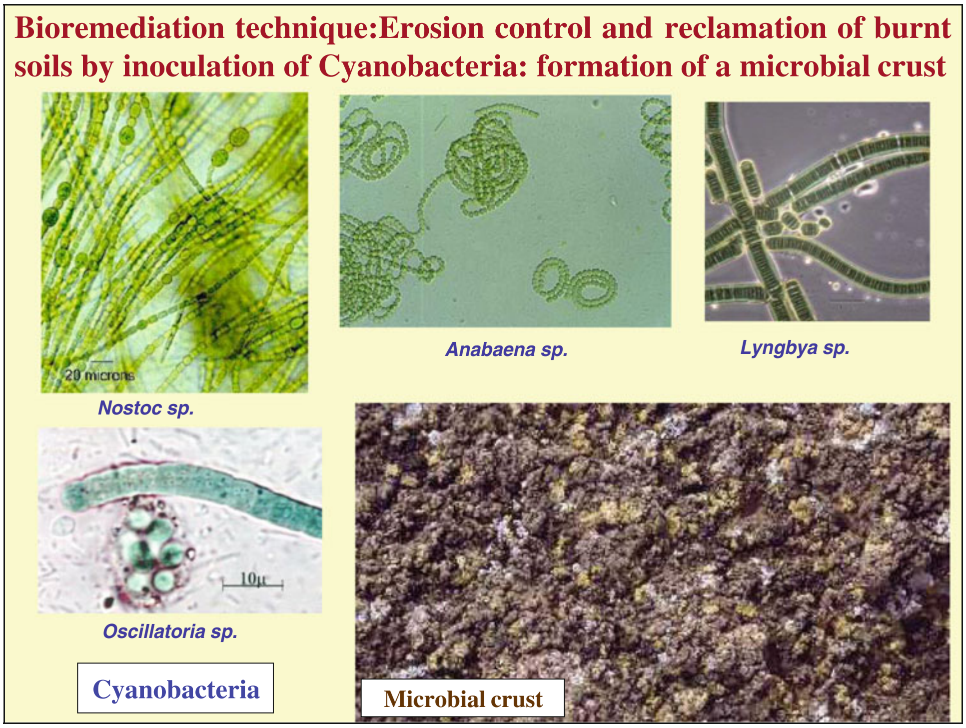


Fig. 3.38 Bioremediation technique for erosion control and reclamation of burnt soils: inoculation of cyanobacteria (*Photo* María José Acea Escrich, IIAG-CSIC)

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 *Eriphorum* 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).

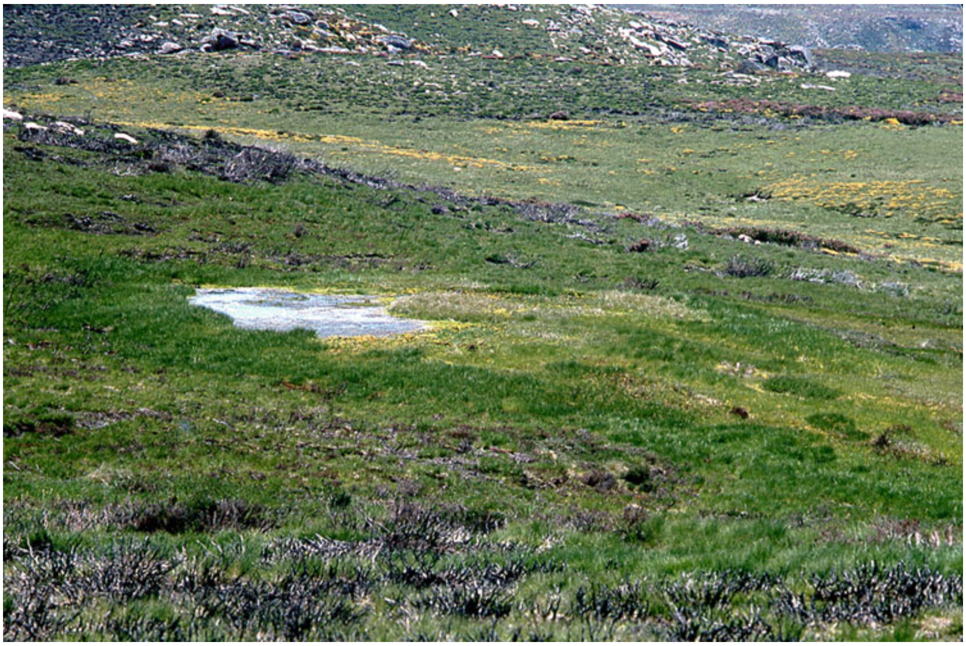


Fig. 3.39 Landscape of Fibric Limnic Histosol (Dystric). Sierra do Xistral, Galicia

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

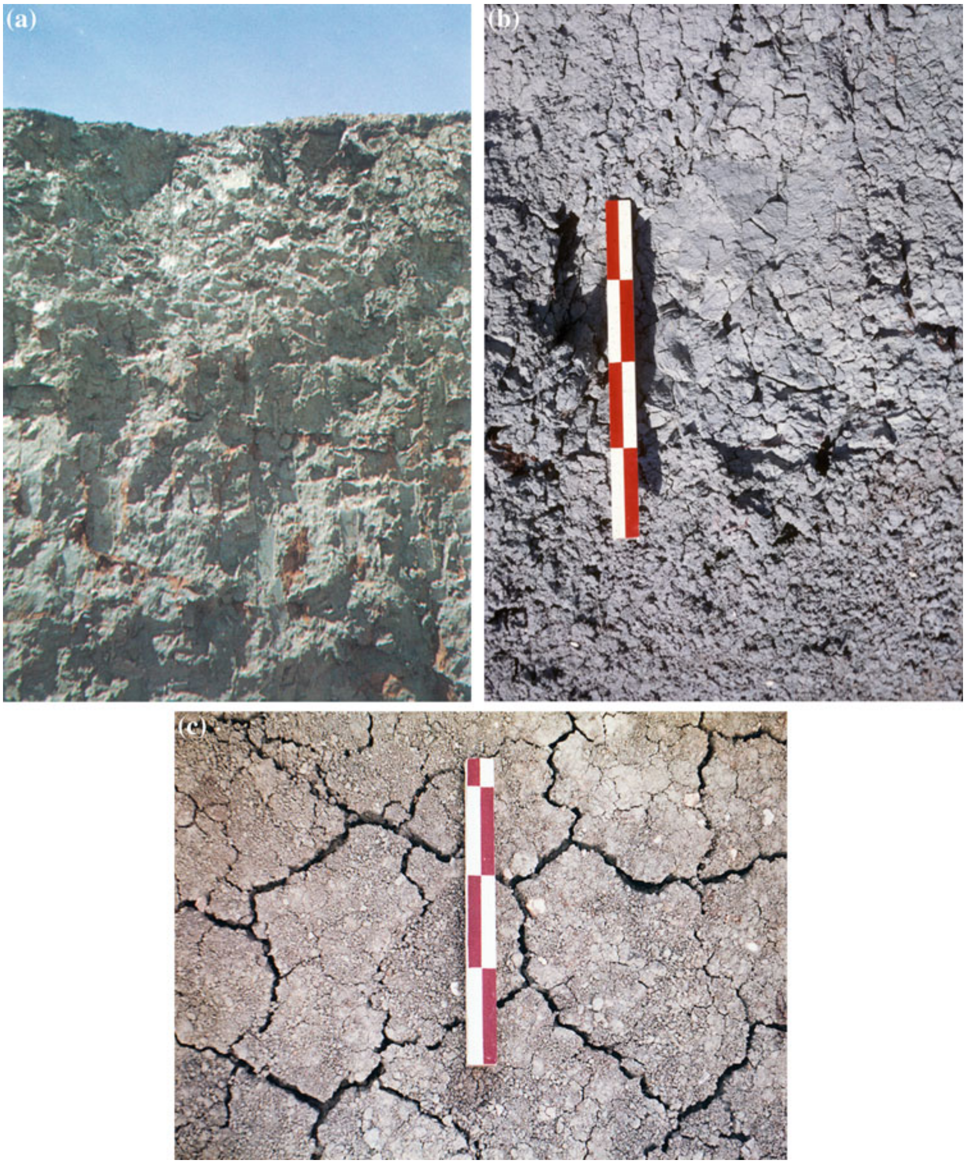


Fig. 3.48 Macic Vertisol (Humic, Hypereutric) on clay sediments: **a** profile; **b** self-mulching and slickensides; and **c** vertical view of the polygonal cracks in the soil surface. Cospeito, Terra Chá, Lugo, Galicia

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

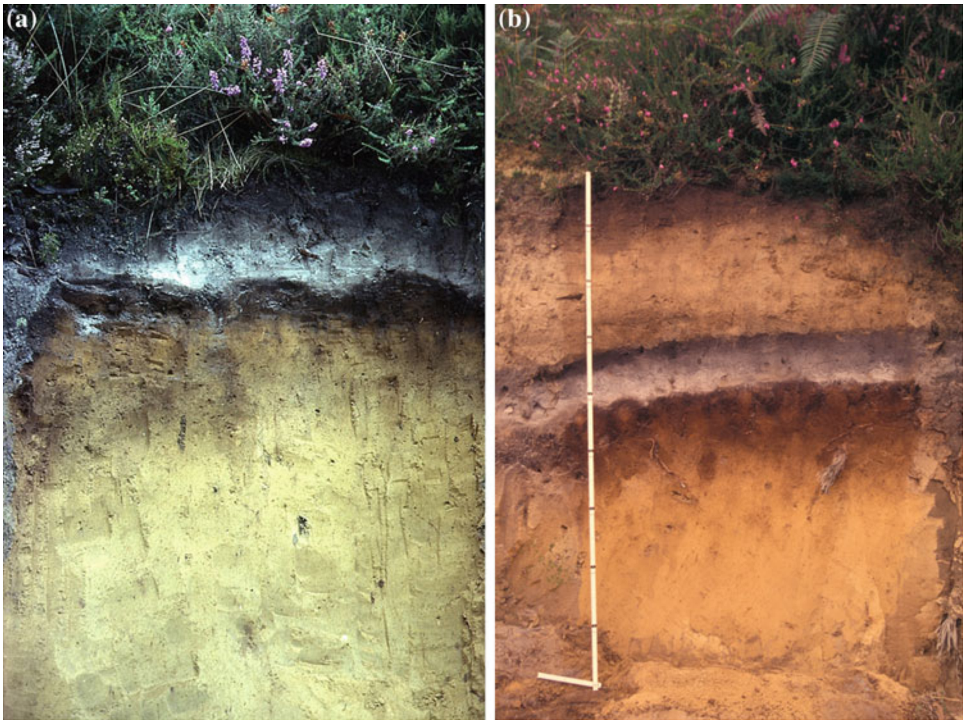


Fig. 3.63 Haplic Podzol on sandstone (**a**); Haplic Podzol buried by a Haplic Cambisol (Humic, Alumic, Dystric) (**b**). Ferreira del Valle de Oro, Lugo, Galicia

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).

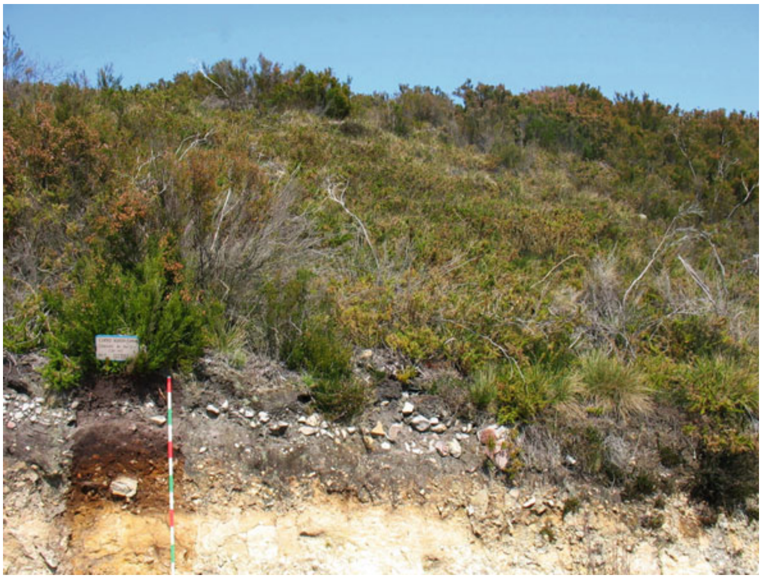


Fig. 3.66 Umbric Podzol in quartzite colluvium, under characteristic vegetation: shrubland with heaths (*Erica sp.*) and gorses (*Ulex sp.*). Onís, Eastern Asturias

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

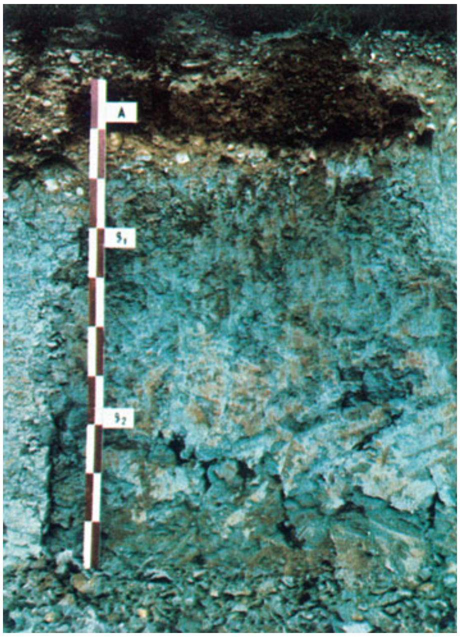


Fig. 3.68 Haplic Stagnosol (Dystric, Clayic) on clayed tertiary sediments. Terra Chá, Lugo, Galicia

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

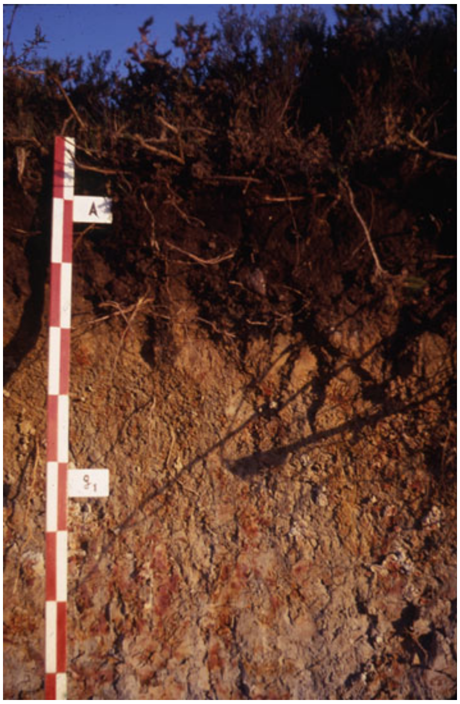


Fig. 3.70 Haplic Stagnosol (Humic, Dystric) on schist. La Castellana, A Coruña, Galicia

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

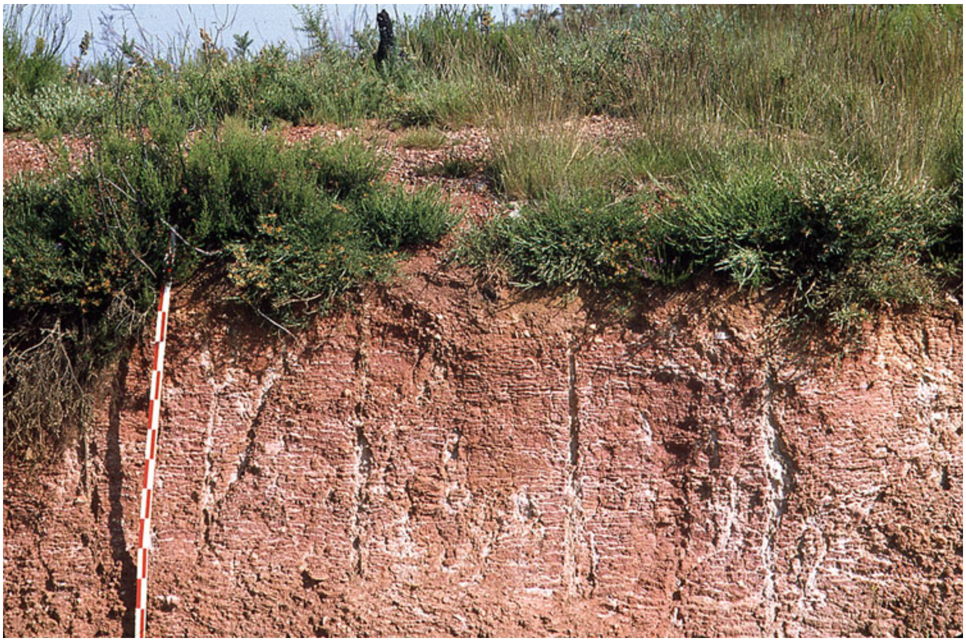
the Latin "*argilla*" meaning white clay), whose main characteristic is a distinct higher clay content than the overlying horizon; this textural differentiation is due to various causes, mainly illuvial processes. Such *argic* horizons must have a base saturation of less than 50 %, in most parts between −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 $\mathrm{cmol_c\ kg^{-1}}$ 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

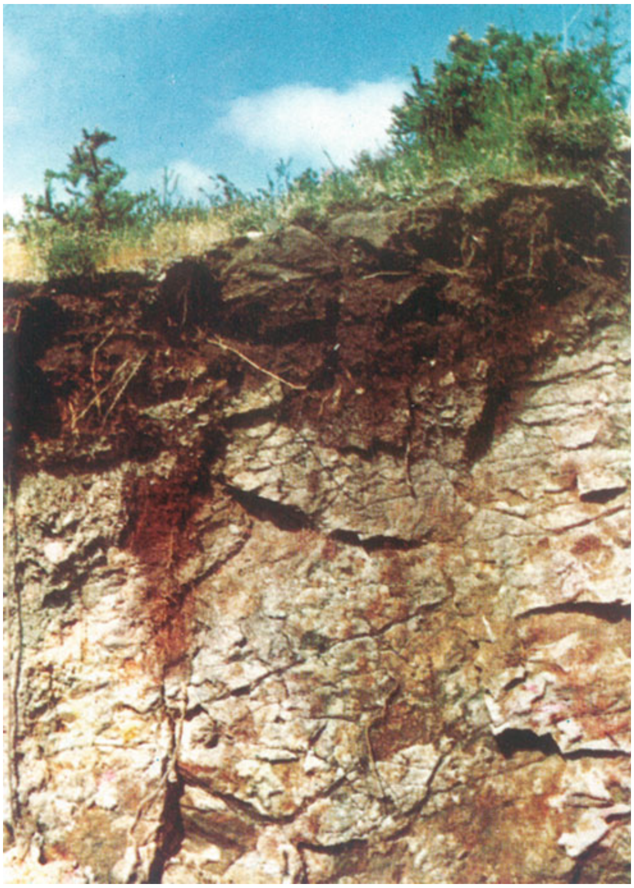


Fig. 3.78 Leptic Umbrisol (Humic, Hyperdystric) on phyllites. Grandas de Salime, Oviedo, Asturias

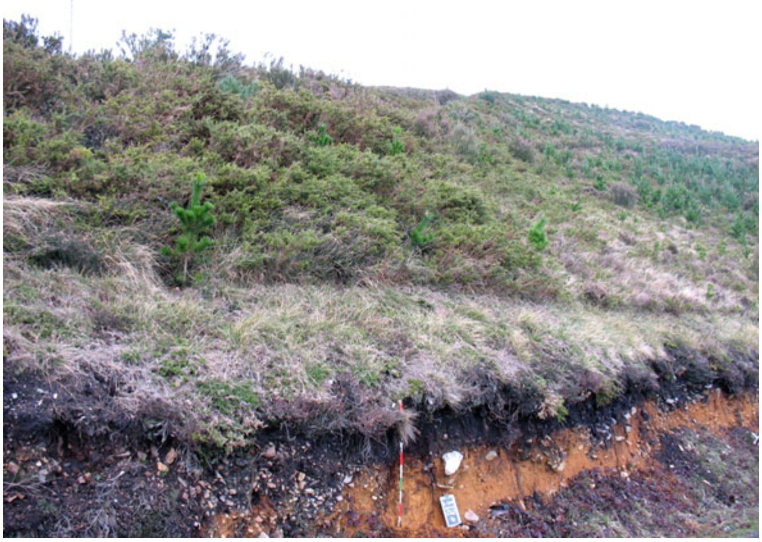


Fig. 3.79 Haplic Umbrisols in quartzite colluvium. Pola de Allande, Western Asturias

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")

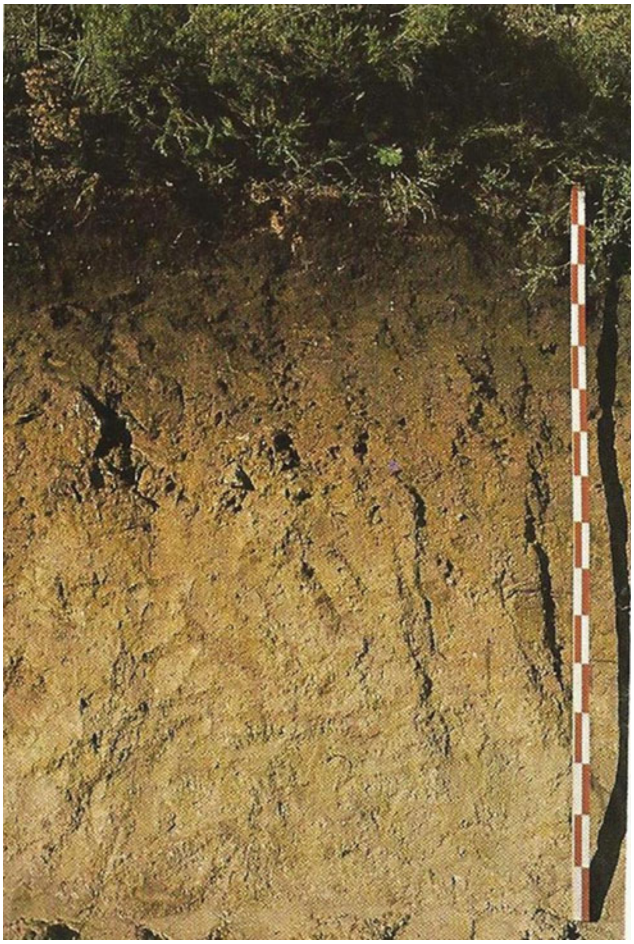


Fig. 3.83 Leptic Cambisol (Humic, Dystric) on porphydic granite. Chantada, Lugo, Galicia

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

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).

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).

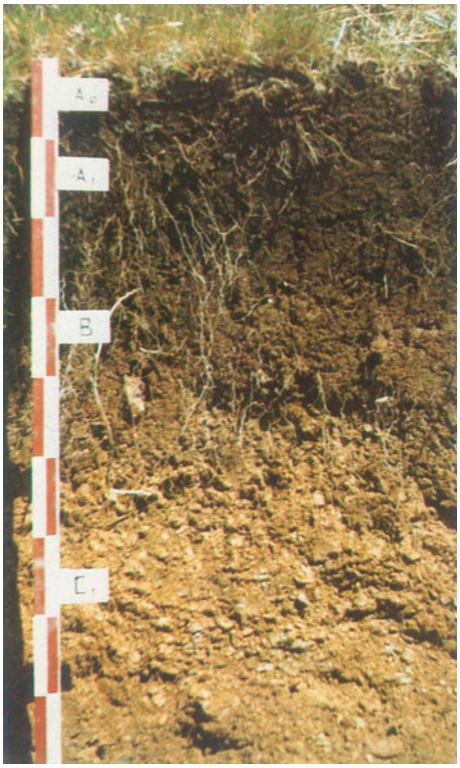


Fig. 3.91 Leptic Regosol (Humic, Dystric) on schist. Santander, Cantabria

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

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 (%)	$\mathrm{pH_w}$	O.M. (%)	C/N	CEC ($\mathrm{cmol_C\ kg^{-1}}$ soil)	CEC ($\mathrm{cmol_C\ kg^{-1}}$ clay)	V (%)	Exch. ($\mathrm{cmol_C\ kg^{-1}}$)	
																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)

References

Abadín J, González-Prieto SJ, Carballas T (1998) Soil N biochemical diversity and numerical taxonomy as tools in the pedogenetic study of a fossil profile. Geoderma 85:341–355

Acea MJ, Carballas T (1986a) Estudio de la población microbiana de diversos tipos de suelos de zona húmeda (N.O de España). An Edafol Agrobiol 45:381–396

Acea MJ, Carballas T (1986b) Distribución de la población microbiana de un podzol férrico húmico. An Edafol Agrobiol 45:399–410

Acea MJ, Carballas T (1987) Distribución y variación estacional de la población microbiana de un suelo humífero atlántico. An Edafol Agrobiol 46:285–300

Acea MJ, Carballas T (1990) Principal components analysis of the soil microbiol population of humid zone of Galicia (Spain). Soil Biol Biochem 23:749–759

Acea MJ, Carballas T (1996) Changes in physiological groups of microorganisms in soil following wildfire. FEMS Microbiol Ecol 20:33–39

Acea MJ, Prieto-Fernández A, Diz-Cid N (2003) Cyanobacterial inoculation of heated soils: effect on microorganisms of C and N cycles and on chemical composition in soil surface. Soil Biol Biochem 35:513–524

AEMET-IM (2011) Atlas Climático Ibérico/Iberian Climate Atlas. Agencia Estatal de Meteorología. Ministerio de Medio Ambiente y Medio Rural y Marino/Instituto de Meteorología de Portugal

Albareda JM (1940) El Suelo. Estudio físico-químico y biológico de su formación y constitución, 486 pp and 58 figs. Editorial Biosca, Madrid, Spain

Alexander M (1977) Introduction to soil microbiology, 467 pp. Wiley, New York

Alonso-Betanzos A, Fontela-Romero O, Guijarro-Berdiñas B, Hernández Pereira E, Paz López A, Paz Andrade MI, Jiménez E, Legido JL, Carballas T (2003) An intelligent system for forest fire risk prediction and fire fighting management in Galicia. Expert Syst Appl 25:545–554

Álvarez García MA (2007) Impacto de los incendios forestales en Asturias (Álvarez García, Director, ed), 201 pp. INDUROT, Universidad de Oviedo, Principado de Asturias, Oviedo, Spain. ISBN:978-84-8367-043-9

Álvarez MA, Díaz-Fierros F (1995) Los suelos. In: Aramburu C, Bastida F (eds) Geología de Asturias. In: , pp 173–186

Arenas R, Farias P, Gallastegui G, Gil Ibarguchi JI, Gonzá1ez Lodeiro E, Klein E, Marquínez J, Martín Parra LM, Martínez Catalán JR, Ortega E, Pablo-Macía JG, Peinado M, Rodríguez--Fernández LR (1988) Características geológicas y significado de los dominios que componen la Zona de Galicia-Trás-os-Montes. II Congreso Geológico de España, Simposios, pp 75–84

Aseginolaza C, Gómez D, Lizaur X, Montserrat G, Morante G, Salaverría MR, Uribe-Etxebarría PM (1988) Vegetación de la Comunidad Autónoma del País Vasco, 361 pp. Viceconsejería de Medio Ambiente. Departamento de Urbanismo, Vivienda y Medio Ambiente. Gobierno Vasco. Vitoria-Gasteiz, Spain

Barnolas A, Pujalte V (2004) La Cordillera Pirenaica. In: Vera JA (ed) Geología de España. IGME-SGE, Madrid, pp 233–343

Barral Silva MT (1987) Estudio de las separaciones de hierro y de manganeso en suelos y sedimentos de Galicia, 680 pp. Universidad de Santiago de Compostela, Spain

Barreiro A, Martín A, Carballas T, Díaz-Raviña M (2010) Response of soil microbial communities to fire and fire-fighting chemicals. Sci Total Environ 408:6172–6178

Blanco E, Casado MA, Costa M, Escribano R, García M, Génova M, Gómez A, Gómez F, Moreno JC, Morla C, Regato P, Sáinz H (2005) Los Bosques Ibéricos: Una interpretación Geobotánica. 4ª ed., 597 pp. Editorial Planeta S.A., Barcelona, Spain

Cabaneiro Albaladejo A (1979) Estudio de los materiales límnico-sapropélicos de los estuarios Gallegos, 37 pp. Universidad de Santiago de Compostela, Santiago de Compostela, Spain. ISBN:84-7191-104-3

Calvo de Anta R, Macías Vázquez F (2000-2005) Mapa de Solos de Galicia, scale 1:50,000, FAO classification 1998. Xunta de Galicia, Consellería de Medio Ambiente. Cartografía digital REVISATLAS, Master's Gráfico S.A., Madrid, Spain. http://siam.cmati.xunta.es/mapa-de-solos

Capdevila R, Corretge G, Floor P (1973) Les granitoides varisques de la Meseta Iberique. Bull Soc Géol France 15:209–228

Carballas M (1982) Estudio de la génesis del Ranker Atlántico (Universidad de Santiago de Compostela, ed.), 63 pp. Imprenta Universitaria, Santiago de Compostela, Spain. ISBN:84-300-7319-1

Carballas M, Acea MJ, Cabaneiro A, Trasar C, Villar MC, Díaz-Raviña M, Fernández I, Prieto A, Saá A, Vázquez FJ, Zëhner R, Carballas T (1994) Organic matter, nitrogen, phosphorus and microbial population evolution in forest humiferous acid soils after wildfires. In: Trabaud L, Prodon R (eds) Fire in Mediterranean Ecosystem, Ecosystems Research Series. Report 5:379–385. EC, Brussels, Belgium

Carballas M, Carballas T, Cabaneiro A, Villar MC, Leirós MC, Guitían Ojea F (1983a) Suelos AC sobre granitos de Galicia (NO de España), con especial referencia al ranker atlántico. III. Fracción orgánica. An. Edafol. Agrobiol. 42:1781–1824

Carballas M, Carballas T, Guitían Ojea F (1983b) Suelos AC sobre granitos de Galicia (N.O. de España), con especial referencia al ranker atlántico. I. Factores de formación y morfología. II. Propiedades químicas. An Edafol Agrobiol 42:1067–1100; 1485–1497, respectively

Carballas M, Carballas T, Guitían Ojea F (1984) Suelos AC sobre granitos de Galicia (NO de España), con especial referencia al ranker atlántico. IV. Propiedades físicas. An Edafol Agrobiol 43:167–181

Carballas M, Carballas T, Jacquín F (1979) Biodegradation and humification of organic matter in humiferous Atlantic soils. I. Biodegradation. An Edafol Agrobiol 38:1699–1717

Carballas M, Villar MC, Guitián Ojea F, Carballas T (1986) Suelos AC sobre granitos de Galicia (NO de España), con especial referencia al ranker atlántico. V. Mineralogía. An Edafol Agrobiol 45:7–27

Carballas T (1975) Manual de Edafología (Spanish language version of the book of Ph. Duchaufour *Precis de Pédologie*, Masson éd., Paris, 1970), 476 pp. Toray-Masson, S.A., Barcelona, Spain

Carballas T (1977) Atlas Ecológico de los Suelos del Mundo (Spanish language version of the book of Ph. Duchaufour Atlas Ecologique des Sols du Monde, Masson éd., Paris, 1975), 178 pp. Toray-Masson, S.A., Barcelona, Spain

Carballas T (1994) Impact of forest fires on the environment. In: Gallardo-Lancho JF (ed) Biogeoquímica de Ecosistemas. Universidad de Salamanca, Salamanca, Spain, pp 91–100

Carballas T (1997) Effects of fires on soil quality. Biochemical aspects. In: Forest fires risk and management. In: Balabanis P, Eftichides G, Fantechi R (eds) Science research development, pp 249–261. EC, Belgium

Carballas T (2003) Los incendios forestales en Galicia. In: Reflexiones sobre el medio ambiente en Galicia (J.J. Casares Long, coord.), pp 363/545–415/547. (Editions in Spanish and Galician). Xunta de Galicia, Santiago de Compostela, Spain

Carballas T (2004) La materia orgánica del suelo y el cambio climático global. In: Carballas T (ed) 82 pp. Academia de Farmacia de Galicia, Santiago de Compostela, Spain

Carballas T (2006) A rexeneración dos ecosistemas. In: Os Incendios forestais en Galicia (F. Díaz-Fierros, P Baamonde, coords.), pp 189–204. Consello da Cultura Galega, Santiago de Compostela, Spain

Carballas T (2007) Los incendios forestales, un desastre ecológico y económico para Galicia. In: Voz Natura: diez años de compromiso medioambiental (Fundación Santiago Fernández Latorre, ed), Chapter 10.2006. Incendios y gestión forestal, pp 97–106. La Voz de Galicia, A Coruña, Spain

Carballas T (2014) El suelo y los incendios forestales en Galicia (Academia de Farmacia de Galicia, ed.), 82 pp. NINO, Santiago de Compostela, Spain. ISBN:978-84-941537-8-5

Carballas T, Andreux F, Jacquín F (1971) Répartition des principaux constituants d'un végétal marqué au C^{14} dans les composés humiques d'un sol a mull. Bull Ass Franç Etud Sol 3:29–38

Carballas T, Carballas M (1984) Edafología: 1. Edafogénesis y clasificación (Spanish language version of the book of Ph. Duchaufour Pédologie. 1. Pédogènese et classification, Masson éd., Paris, 1977), 493 pp. Masson, S.A., Barcelona, Spain

Carballas T, Carballas M (1986) Manual de Edafología (Spanish language version of the book of Ph. Duchaufour Pédologie. Colection Abregés, Masson éd., Paris, 1984), 220 pp. Masson, S. A., Barcelona, Spain

Carballas T, Díaz-Fierros F, Macías F (2003) 50 Aniversario de la Edafología en Galicia. Universidade de Santiago de Compostela, 379 pp. Imprenta Universitaria, Dep. Legal: C-2611/2003. Santiago de Compostela, Spain

Carballas T, Duchaufour Ph, Jacquín F (1967) Evolution de la matière organique des rankers. Bull. ENSA de Nancy 9:20–28

Carballas T, Guitían Ojea F (1966) Evolución de la composición mineral de los restos vegetales al incorporarse al suelo. An Edafol Agrobiol 25:151–163

Carballas T, Legido JL, Mato MM, Paz Andrade MI (2011) Índices de Peligro de Incendios Forestales específicos para Galicia, Asturias y Cantabria. Investigación, Cultura, Ciencia y Tecnología 3:44–50

Carballas T, Martín A, Díaz-Raviña M (2009a) Efecto de los incendios forestales sobre los suelos de Galicia. In: Efectos de los incendios forestales sobre los suelos en España. El estado de la cuestión visto por los científicos españoles (Artemi Cerdà, Jorge Mataix-Solera, eds.), pp 269–301. FUEGORED. Cátedra Divulgación de la Ciencia. Universitat de Valencia, Valencia, Spain. ISBN:978-84-370-7653-9

Carballas T, Martín A, González-Prieto SJ, Díaz-Raviña M (2009b) Restauración de ecosistemas forestales quemados de Galicia (N.O. de España): aplicación de residuos orgánicos e impacto de los retardantes de llama. In: Gallardo Lancho JF coord, Campo Alves J, Conti ME (eds) Emisiones de gases con efecto invernadero en ecosistemas iberoamericanos pp 49–72. Sociedad Iberoamericana de Física y Química Medioambiental (SiFyQA), Salamanca, Spain. ISBN:978-84-937437-0-3

Carballas T, Muñoz Taboadela M, Guitián Ojea F (1965) Níquel en los suelos de la provincia de La Coruña. An Edafol Agrobiol 24:267–292

Castro A, González Prieto SJ, Carballas T (2006) Burning effects on the distribution of organic N compounds in a 15 N labelled forest soil. Geoderma 130:97–107

Castro A, González Prieto SJ, Carballas T (2007) Effects of two soil reclamation techniques on the distribution of the organic N compounds in a ^{15}N labeled burnt soil. Geoderma 137:300–309

Díaz Fierros F (2003) Antecedentes y primeros trabajos sobre Edafología en Galicia. 50 Aniversario de la Edafología en Galicia. Universidade de Santiago de Compostela, Imprenta Universitaria, Santiago de Compostela, Spain, pp 15–21

Díaz Fierros F, Gil Sotres F (1984) Capacidad Productiva de los Suelos de Galicia. Mapa: 1:200,000, 82 pp + 19 maps. Universidad de Santiago de Compostela, Spain. ISBN:84-7191-341-0

Díaz Fierros F, Gil Sotres F, Cabaneiro A, Carballas T, Leirós MC, Villar MC (1982) Efectos erosivos de los incendios forestales en suelos de Galicia. An. Edafol. Agrobiol. 41:627–639

Díaz Fierros F, Guitián Ojea F (1968) Propiedades físicas de los principales tipos de suelos gallegos. An Edafol Agrobiol 27:533–546

Díaz-Raviña M, Acea MJ, Carballas T (1989) Effects of incubation and chloroform fumigation on the nutrient contents of some acid soils. Soil Biol Biochem 21:1083–1084

Díaz-Raviña M, Acea MJ, Carballas T (1993a) Microbial biomass and C and N mineralization in forest soils. Bioresour Technol 43:161–167

Díaz-Raviña M, Acea MJ, Carballas T (1993b) Microbial biomass and its contribution to nutrient concentration in forest soils. Soil Biol Biochem 25:25–31

Díaz-Raviña M, Acea MJ, Carballas T (1995) Seasonal changes in microbial biomass and nutrient flush in forest soils. Biol Fertil Soils 19:220–226

Díaz-Raviña M, Bååth E (1996a) Development of metal tolerante of soil bacterial communities exposed to experimentally increased metal levels. Appl Environ Microbiol 62:2970–2977

Díaz-Raviña M, Bååth E (1996b) Influence of different temperatures on metal tolerante measurements and growth response in bacterial communities from unpolluted and polluted soils. Biol Fertil Soils 21:233–238

Díaz-Raviña M, Bååth E (1996c) Thymidine and leucine incorporation into bacteria from soils experimentally contaminated with heavy metals. Appl Soil Ecol 3:225–234

Díaz-Raviña M, Benito E, Carballas T, Fontúrbel MT, Vega JA (eds) (2010) Research and post-fire management: soil protection and rehabilitation techniques for burnt soil ecosystems, 346 pp. (Edition in English and Spanish; includes CD). CSIC, USC, UVigo, FUEGORED; Andavira Editora, Santiago de Compostela, Spain. ISBN:978-84-8408-583-6

Díaz Raviña M, Carballas T, Acea MJ (1988) Microbial biomass and metabolic activity in four acid soils. Soil Biol Biochem 20:817–823

Díaz-Raviña M, Martín A, Barreiro A, Lombao A, Iglesias L, Díaz-Fierros F, Carballas T (2012) Mulching and seeding treatments for post-fire soil stabilisation in NW Spain: short-term effects and effectiveness. Geoderma 191:31–39

Diputación Foral de Gipuzkoa (1991) Geomorfología y Edafología de Gipuzkoa, 128 pp. Departamento de Urbanismo, Arquitectura y Medio Ambiente. Donostia, Spain

European Environment Agency www.eea.eu

EUSTAT-Euskal Estatistika Erakundea-Instituto Vasco de Estadística (2007) www.eustat.es

F.A.O.-UNESCO (1974) Soil Map of the World 1:5,000,000, vol I. Legend, ISBN:92-3-101125-1

F.A.O.-UNESCO (1981) Soil Map of the World 1:5,000,000, vol V. Europe. In: FAO-UNESCO (eds), Rome, Italy. ISBN:92-3-201361-4

Farias P, Gallastegui G, González-Lodeiro F, Marquínez J, Martín-Parra LM, Martínez-Catalán JR, De Pablo-Macia JG, Rodríguez-Fernández LR (1987) Aportaciones al conocimiento de la litoestratigrafía y estructura de Galicia Central. Mem. Mus. Lab. Min Geol Fac Ciências Universidade do Porto 1:411–431

Felicísimo AM (1992) El clima de Asturias. In: Tomo I, capítulo (eds) Geografía de Asturias, vol 2, pp 17–32. Editorial Prensa Asturiana, Spain

Fernández I, Cabaneiro A, Carballas T (1997) Organic matter changes immediately after a wildfire in an Atlantic forest soil and comparison with laboratory soil heating. Soil Biol Biochem 29:1–11

Fernandez I, Cabaneiro A, Carballas T (1999) Carbon mineralization dynamics in soils after wildfires in two Galician forests. Soil Biol Biochem 31:1853–1865

Fernández I, Cabaneiro A, Carballas T (2001) Thermal resistance to high temperatures of different organic fractions from soils under pine forests. Geoderma 104:281–298

Fontúrbel MT, Barreiro A, Vega JA, Martín A, Jiménez E, Carballas T, Fernández C, Díaz-Raviña M (2012) Effects of an experimental fire and post-fire stabilisation treatments on soil microbial communities. Geoderma 191:51–60

Fraga Vila M, Reinoso Franco J (1982) A vexetación. In: (A. Pérez Alberti, dir.), Tomo I Xeografía de Galícia: O médio, Cap. 4: Bioxeografía, 4.2. Vexetación natural, pp 128–158. Edicións Sálvora, S.A. O Castro, Sada, A Coruña, Spain. ISBN:84-85779-12-6

Frochoso M, Castañón JC (1997) El relieve glaciar de la Cordillera Cantábrica. Las huellas glaciares de las montañas españolas. Universidade de Santiago de Compostela, Spain, pp 65–137

García-Rodeja E, Macías F, Guitián Ojea F (1984) Reacción con el NaF de los suelos de Galicia. **I**. Característica y significado del test de NaF. Distribución de la actividad en función del material de partida. An. Edafol. Agrobiol. 43:755–776

García-Rodeja E, Silva B, Macías F (1987) Andosols developed from non-volcanic materials in Galicia. NW Spain J Soil Sci 38:573–591

Gobierno de Asturias (2008) Perfil Ambiental de Asturias 2008. Report nº 3.9 Agricultura y Ganadería. www.asturias.es

González-Amuchastegui M (2000) Evolución morfoclimática del País Vasco durante el Cuaternario: estado de la cuestión. Rev C and G (Cuaternario y Geomorfología) **14**(3–4):79-99. ISSN:0214-1744

González-Prieto SJ, Cabaneiro A, Villar MC, Carballas M, Carballas T (1996) Effect of soil characteristics on N mineralization capacity in 112 native and agricultural soils from the northwest of Spain. Biol Fertil Soils 22:252–260

González-Prieto SJ, Carballas M, Carballas T (1991) Mineralization of a nitrogen-bearing organic substrate model (^{14}C,^{15}N-glycine) in two acid soils. Soil Biol Biochem 23:53–63

González-Prieto SJ, Carballas T (1988) Modified method for the fractionation of organic nitrogen by successive hydrolysis. Soil Biol Biochem 20:1–6

González-Prieto SJ, Carballas T (1991) Composition of organic N in temperate humid region soils (NW Spain). Soil Biol Biochem 23:887–895

González Prieto SJ, Lista MA, Carballas M, Carballas T (1989) Humic substances in a catena of estuarine soils: distribution of organic nitrogen and carbon. Sci Total Environ 81(82):363–372

González-Prieto SJ, Villar MC (2003) Soil organic N dynamics and stand quality in *Pinus radiata* pinewoods of the temperate humid region. Soil Biol Biochem 35:1395–1404

González-Prieto SJ, Villar MC, Carballas M, Carballas T (1992) Nitrogen mineralization and its controlling factors in various kinds of temperate humid zone soils. Plant Soil 144:31–44

González-Prieto SJ, Villar MC, Carballas T (2008) Availability of ^{15}N from pioneer herbaceous plants to pine seedlings in reclaimed burnt soils. Rapid Commun Mass Spectrom 22:1–4

Gran Enciclopedia Larousse (1984) División Administrativa: ESPAÑA. In: Atlas, p 31. Editorial Planeta, 1st. Ed. Barcelona, Spain. ISBN:84-320-6543-9

Guerra A, Guitián F, Paneque G, García A, Sánchez JA, Monturiol F, Mudarra L (1968) Mapa de Suelos de España. Península y Baleares. Scale 1:1,000,000; Map+plates in color. Servicio de Cartografía del CSIC, CSIC, Madrid, Spain

Guerra A, Monturiol F (1959). Mapa de Suelos de la Provincia de Santander. Memoria Explicativa, 110 pp. + VI plates in color. Diputación Provincial de Santander. Instituto de Edafología y Agrobiología. CSIC, Madrid, Spain

Guitián Ojea F (1967) Suelos de la zona húmeda española. I. Tipos principales y sus relaciones genéticas. An Edafol Agrobiol 26:1369–1378

Guitián Ojea F. 1974. *Itinerarios de los Suelos de Galicia*. Monografías de la Universidad de Santiago de Compostela 26, 203 pp. ISBN: 84-600-5991-X. Secretariado de Publicaciones de la Universidad de Santiago. Santiago de Compostela, Spain

Guitían Ojea F, Carballas T (1976) Técnicas de Análisis de Suelos, 2nd edn., 288 pp. Editorial Pico Sacro, Santiago de Compostela, Spain

Guitían Ojea F, Carballas T (1968a) Suelos de la zona húmeda española. III. Ranker Atlántico. An Edafol Agrobiol 27:57–73

Guitían Ojea F, Carballas T (1968b) Suelos de la zona húmeda española. IV. Podzoles. An Edafol Agrobiol 27:747–781

Guitían Ojea F, Carballas T (1969) Suelos de la zona húmeda española. V. Factores de formación: material geológico. An Edafol Agrobiol 28:191–204

Guitían Ojea F, Carballas T (1977) XXV Años de Estudios de Edafología en Santiago 1952-1977, 43 pp. USC, CSIC, Santiago de Compostela

Guitían Ojea F, Carballas T (1982) Suelos Naturales de la Provincia de Orense, 114 pp.+XIV plates in color+Map of soils. CSIC-IIAG, Madrid, Spain

Guitían Ojea F, Carballas T, Díaz Fierros F (1973) Suelos de la zona húmeda española. VII. Suelos naturales del Pirineo oscense. Pirineos 108:5–40+map of soils+4 planches in color

Guitían Ojea F, Carballas T, Díaz Fierros F (1987) Castilla y León. Mapa de Suelos. Escala 1:500,000 FAO. In: Mapa de suelos de Castilla y León (A. García Rodríguez, coord.). Junta de Castilla y León, Spain

Guitían Ojea F, Carballas T, Díaz Fierros F, Macías F (1982a) Mapa de solos de Galicia. Clasificación FAO. In: Atlas de Galicia. Chapter: O Medio Físico, p 59. Edicions Nos-Edicions Sálvora, Santiago de Compostela, Spain

Guitían Ojea F, Carballas T, Díaz Fierros F, Plata Astray M (1985a). Suelos Naturales de Cantabria, 125 pp.+XI plates in color+Map of Soils. CSIC-IIAG, Madrid, Spain

Guitían Ojea F, Carballas T, Muñoz Taboadela M (1982b) Suelos Naturales de la Provincia de Lugo, 151 pp.+XIV plates in color +Map of Soils, CSIC-IIAG, Madrid, Spain

Guitían Ojea F, Carballas T, Pérez Pujalte A (1971) Suelos de la zona húmeda española. VI. Pelosol. An Edafol Agrobiol 30:303–322

Guitián Ojea F, Carballas T, Reyes Pérez J, Souza Castelo P, Carpio Cuellar V, Ayala Leal J (1975). Investigación de Cobre y Níquel por métodos geofísicos y geoquímicos en rocas y suelos de la provincia de La Coruña, 450 pp, Anexos 1, 2 y 3, Mapas. Centro de Edafología y Biología Vegetal, CSIC, Santiago de Compostela

Guitían Ojea F, Díaz Fierros F (1967) Suelos de la zona húmeda española. II. Factores de formación: Clima. An Edafol Agrobiol 26:1467–1485

Guitían Ojea F, Muñoz Taboadela M (1957) El encalado de los suelos de zona húmeda. An Edafol Fisiol Veg 16:1017–1097

Guitían Ojea F, Muñoz Taboadela M, Carballas T (1986) Los Suelos Naturales. In: Sánchez Rodriguez B (ed) Estudio Agrobiológico de la Provincia de Pontevedra, pp 87–171+X plates in color+Map of Soils+Map of Vegetation. Fundación Pedro Barrié de la Maza, Conde de FENOSA, Pontevedra, Spain

Guitían Ojea F, Muñoz Taboadela M, Carballas T, Alberto F (1985b) Suelos Naturales de Asturias, 122 pp+XVI plates in color+Map of Soils. CSIC-IIAG, Madrid, Spain

Gutiérrez-Elorza M (ed) (1994) Geomorfología de España, 526 pp.; Martín-Serrano A. Macizo Ibérico Septentrional, pp 25–62; Ugarte FM, Montes Vasco-Cantábricos, pp 227–250. Editorial Rueda, Madrid, Spain

Iñiguez J, Sánchez-Carpintero I, Val RM, Romeo A, Bascones JC (1980) Mapa de Suelos de Álava, escala 1:200.000, 109 pp. Excma. Diputación Foral de Álava, Vitoria, Spain

IUSS Working Group WRB (2007) World Reference Base for Soil Resources 2006, first update 2007. World Soil Resources Reports No. 103, 128 pp. FAO, Rome

Jacquín F, Carballas M, Carballas T (1978) Interaction entre les ions aluminium et la minéralisation de la matière organique dans les sols humifères atlantiques. CR Acad Sci París 286, Série D: 511–514

Jenny H (1941) Factors of soil formation, 281 pp. McGraw-Hill Book Company, New York

Jiménez M (1996) El glaciarismo en la cuenca alta del río Nalón (NO de España): una propuesta de evolución de los sistemas glaciares cuaternarios en la Cordillera Cantábrica. Rev Soc Geol España 9(3–4):157–168

Julivert M, Fontboté JM, Ribeiro A, Nabais Conde LE (1972) Mapa tectónico de la Península Ibérica y Baleares 1:1.000,000, IGME, 113 pp

Kaal J, Martínez-Cortizas A, Nierop KGJ, Buurman P (2008) A detailed pyrolysis-GC/MS analysis of a black carbon-rich acidic colluvial soil (Atlantic ranker) from NW Spain. Appl Geochem 23 (8):2395–2405

Kubiena WL (1952) Claves Sistemáticas de Suelos, 388 pp. CSIC, Madrid, Spain

Lázaro F, Elías F, Nieves M (1978) El régimen de humedad de los suelos de la España peninsular. Monografías INIA, 20, 15 pp+Anex +Map. Instituto Nacional de Investigaciones Agrarias (INIA). Ministerio de Agricultura. Madrid, Spain

Leirós MC, Gil-Sotres F, Ceccanti B, Trasar Cepeda MC, González-Sangregorio MV (1993) Humification processes in reclaimed open-cast lignite mine soils. Soil Biol Biochem 25:1391–1397

Leirós de la Peña MC, Guitián Ojea F (1981a) Suelos de la zona húmeda española. XI. Contribución al estudio de los suelos hidromorfos de Galicia. 1. Suelos costeros. An Edafol Agrobiol 11:1707–1734

Leirós de la Peña MC, Guitián Ojea F (1981b) Suelos de la zona húmeda española. XI. Contribución al estudio de los suelos hidromorfos de Galicia. 2. Suelos continentales. An Edafol Agrobiol 42:427–461

Loidi J, Biurrun I, Campos JA, García-Mijangos I, Herrera H (2011) La vegetación de la Comunidad Autónoma del País Vasco. Leyenda del Mapa de Series de Vegetación a escala 1:50,000, 197 pp. Ed. Universidad del País Vasco, Spain

Lloveras Vilamanyá J, Alonso Rosano J (1982) Botánica agrícola. In: (A. Pérez Alberti, dir.), Tomo I (eds) O medio Xeografía de Galícia, Cap. 4: Bioxeografía, 4.3, 158–173. Edicións Sálvora, S.A., O Castro, Sada, A Coruña, Spain. ISBN:84-85779-12-6

Macías F, Fernández-Marcos ML, Chesworth W (1987) Transformations mineralogiques dans les podzols et les sols podzoliques de Galicia (NW Espagne). In: Righi D, Chauvel A (eds) Podzols et Podzolization. INRA, France, pp 163–177

Macías Vázquez F (2003) Repercusión de los estudios de la Edafología realizados en Galicia. 50 Aniversario de la Edafología en Galicia. Universidade de Santiago de Compostela, Imprenta Universitaria, Santiago de Compostela, Spain, pp 23–35

Macías Vázquez F, Calvo de Anta R (2001) Los Suelos. In: Atlas de Galicia, pp 173–218. Sociedade para o Desenvolvemento Comarcal de Galicia, Consellería de Presidencia, Xunta de Galicia. Santiago de Compostela, Spain

Macías Vázquez F (Coor), Calvo de Anta R, Pérez Alberti A, Otero Pérez XL, García Paz C, Martínez Cortizas A, Verde Vilanova JR, Pérez Llaguno C, Macías García F, García Ares MT, Saiz Rubio R, Aran Ferreiro D, Díez Rodríguez E, Romero Chouza D, Bolaños Guerrón DR (2013) Complejo Ultrabásico de Capelada-Cabo Ortegal. ¿Un Nuevo Geoparque para el Desarrollo Geoturístico y Cultural de Galicia? 97 pp. Andavira Ed., Santiago de Compostela, Spain. ISBN:978-84-8408-771-7

MAGRAMA (2011) Ministerio de Agricultura, Alimentación y Medio Ambiente. Tercer Inventario Forestal Nacional-Third National Forest Inventory. www.magrama.es

MAGRAMA (2013) Ministerio de Agricultura, Alimentación y Medio Ambiente. Sistema de Información Geográfica de Datos Agrarios. www.siga.es

Mahía J, González-Prieto SJ, Martín A, Bååth E, Díaz-Raviña M (2011) Biochemical properties and microbial community structure of five different soils after atrazine addition. Biol Fertil Soils 47:577–589

Martín A, Díaz-Raviña M, Carballas T (2011) Seasonal changes in the carbohydrate pool of an Atlantic forest soil under different vegetation types. Spanish J Soil Sci 1:38–53

Martín A, Díaz-Raviña M, Carballas T (2012) Main soil properties evolution in Atlantic forest ecosystems affected by low and high severity wildfires. Land Degrad Dev 23:427–439

Martínez Catalán JR et al (12 other geologists) (2010) Geología del Complejo de Cabo Ortegal y de las unidades relacionadas del basamento de Galicia. Guía de campo, 133 pp. Concello de Cariño, Tórculo Artes Gráficas. English versión: The Rootless Variscan Suture of NW Iberia (Galicia, Spain). Galicia Meeting 2007. Field Trip Guide. IGCP Project 497. The Rheic Ocean: its Origin, Evolution and Correlatives. ISBN:978-84606-5205-2

Martínez-Cortizas A, García-Rodeja E (Coords) (2001) Turberas de montaña de Galicia, 254 pp. Colección Técnica Medio Ambiente. Consellería de Medio Ambiente. Centro de Información e Tecnoloxía Ambiental. Xunta de Galicia, Spain

Martínez Cortizas A, Pérez Alberti A (1999) Atlas Climático de Galicia, 207 pp. Xunta de Galícia, Spain

Martínez Fernández ME (1965) Cobre en los suelos de la provincia de La Coruña. Bol Univ Compostelana 73:111–154

Mary G (1985) Niveaux marins du litoral Asturien et Malicien entre San Vicente de la Barquera et Foz. Actas I Reunión del Cuaternario Ibérico, pp 219–228. Lisboa, Portugal

Merino A, Balboa MA, Rodríguez-Soalleiro R, Alvarez JG (2005) Nutrient exports under different harvesting regimes in fast-growing forest plantations in southern Europe. For Ecol Manage 207:325–339

Merino A, Edeso JM (1999) Soil fertility rehabilitation in young *Pinus radiata* plantations from northern Spain after intensive site preparation. For Ecol Manage 116:83–91

Mücher HJ, Carballas T, Guitián Ojea F, Jungerius PD, Krooneenber SB, Villar MC (1972) Micromorphological analysis of effects of alternating phases of landscape stability and instability on two soil profiles in Galicia, N.W Spain. Geoderma 8:241–266

Muñoz Taboadela M (1965) Suelos de Galicia: Análisis y necesidades de fertilizantes con especial referencia al fósforo. Monografías Ecológicas y Agrarias, Nº 1, 109 pp. C.S.I.C. Madrid, Spain

Múñoz Taboadela M, Guitián Ojea F, Labarta JM, Carballas T, Martínez E, Caballo J (1966) Suelos Naturales. In: Viéitez E (ed) Estudio Agrobiológico de la Provincia de La Coruña, pp 169–284+XII plates in color+Map of Soils+Map of Vegetation. Excma. Diputación Provincial de La Coruña, La Coruña, Spain

Olarieta JR, Besga G, Rodríguez R, Usón A, Pinto M, Virgel S (1999) Sediment enrichment ratios after mechanical site preparation for Pinus radiata plantation in the Basque Country. Geoderma 93(3–4):255–267

Olarieta JR, Besga G, Rodríguez-Ochoa R, Aizpurua A, Usón A (2006) Land evaluation for forestry: a study of the land requirements for growing *Pinus radiata* D. Don in the Basque Country, northern Spain. Soil Use Manag 22(3):238–244

Olazábal L (1857) Suelo, Clima, Cultivo Agrario y Forestal de la Provincia de Vizcaya, 114 pp. Imprenta, Fundición y Librería de Don Eusebio Aguado, Madrid, Spain

Pagés JL (2000) Origen y evolución geomorfológica de las rías atlánticas de Galicia. Rev Soc Geol España 13(3–4):393–403

Pagés JL, Vidal-Romaní JR (1998) Síntesis de la evolución geomorfológica de Galicia Occidental. Geogaceta 23:119–122

Parga-Pondal I, Matte Ph, Capdevila R (1964) Introduction à la géologie de l'Ollo de Sapo. Formation Porphiroïde Antesilourienne du Nord Ouest de l'Espagne. Notas y Com Inst Geol 76:119–154

Paz Andrade MI, Mato MM, Varela A, Gago A, Vázquez Galiñanes A, Villaverde J, Carballas T, Díaz-Raviña M, Martín A, Jiménez E, Alonso Betanzos A, Legido JL, Carballo E, Caselles V (2010) Mathematical models and intelligent systems for forest fire fighting and forest ecosystems recovery. In: ViegasDX (ed) 6th International

Conference on Forest Fire Research, CD, Paper 225, pp 1–12. ADAI/CEIF, University of Coimbra, Portugal

Pérez Alberti A (1982) Xeomorfoloxía. In: Tomo I (ed) O Medio (A. Pérez Alberti, dir.). Xeografía de Galicia, vol 1, pp 9–69. Edicións Sálvora S.A., O Castro, Sada, A Coruña, Spain. ISBN:84-85779-12-6

Pérez-Alberti A, Rodríguez M, Valcárcel M (1992) El modelado glaciar en la vertiente oriental de la Sierra de Ancares (Noroeste de la Península Ibérica). Papeles de Geografía 18:39–51

Prieto-Fernández A, Acea MJ, Carballas T (1998) Soil microbial-and extractable C and N after wildfire. Biol Fertil Soils 27:132–142

Prieto-Fernández A, Carballas M, Carballas T (2004) Inorganic and organic N pools in soils burned or heated: immediate alterations and evolution after forest wildfires. Geoderma 121:291–306

Prieto-Fernández A, Carballas T (2000) Soil organic nitrogen composition in *Pinus* forest acid soils: variability and bioavailability. Biol Fertil Soils 32:177–185

Prieto-Fernández A, Villar MC, Carballas M, Carballas T (1993) Short term effects of a wildfire on the nitrogen status and its mineralization kinetics in an Atlantic forest soil. Soil Biol Biochem 25:1657–1664

Saá A, Trasar MC, Gil-Sotres F, Carballas T (1993) Changes in P fraction distribution and phosphomonoesterasa activity immediately following forest fires. Soil Biol Biochem 25:1223–1230

Salgado J, González MI, Armada J, Paz-Andrade MI, Carballas M, Carballas T (1995) Loss of organic matter in Atlantic forest soils due to wildfires. Calculation of the ignition temperature. Thermochim Acta 259:165–175

Sánchez-Rodríguez F, Rodríguez-Soalleiro R, Español E, López CA, Merino A (2002) Influence of edaphic factors and tree nutritive status on the productivity of *Pinus radiata* D. Don plantations in northwestern Spain. For Ecol Manage 171:181–189

Schnitzer M (2000) A lifetime perspective on the chemistry of soil organic matter. In: Sparks DL (ed) Advances in Agronomy, vol 68. Academic Press, Toronto, Canada, pp 1–58

Soil Survey Staff (2010) Keys to soil taxonomy, 11th edn., 338 pp. United States Department of Agriculture—Natural Resources Conservation Service, Washington, DC

Solé-Sabaris L, Llopis N (1952) Geografía física de España. In: Terán M (ed) Geografía de España y Portugal, Chap. I. Montaner y Simón, S.A., Barcelona, Spain, 487 pp

Soto B, Basanta R, Pérez R, Díaz-Fierros F (1995) An experimental study of the influence of traditional slash-and-burn practices on soil erosion. Catena 24:13–23

Taboada Castro MT, Barral Silva MT, Álvarez MA, Díaz-Fierros F (1995) Itinerario de suelos en los alrededores de Oviedo, pp 277–290. Ediciones TREA S.L., Gijón, Spain

Trasar-Cepeda C, Gil-Sotres F, Guitián Ojea F (1990) Relation between phosphorous fractions and development of soils from Galicia (NW Spain). Geoderma 47:39–150

Trasar-Cepeda C, Gil-Sotres F, Zech W, Alt HG (1989) Chemical and spectral analysis of organic P forms in acid high organic matter soils in Galicia (NW Spain). Sci Total Environ 81:429–436

Van Wambeke A, Forbes TR (1986) Guidelines for using Soil Taxonomy in the names of soil map units. SMSS Technical Monograph. Soil Conservation Service. USDA, Washington DC, 75 pp

Varela A, Villaverde J, Mato MM, Salgado J, Paz Andrade MI, Carballas T, Carballo E, Legido JL (2006) Looking for a model for the prediction of the forest fire peaks in Galicia (NW of Spain). In: Viegas DX (ed) CD, Proceedings of the 5th international conference on forest fire research Section B. Fire Prevention, Paper 15, pp 1–14. ADAI/CEIF, University of Coimbra, Portugal. Elsevier

Vázquez FJ, Acea MJ, Carballas T (1993) Soil microbial populations after wildfire. FEMS Microbiol Ecol 13:93–104

Vázquez FJ, Petrikova V, Villar MC, Carballas T (1996) The use of poultry manure and plant cultivation for the reclamation of burnt soils. Biol Fertil Soils 22:265–271

Vega JA, Fontúrbel MT, Fernández C, Orellano A, Díaz-Raviña M, Carballas T, Martín A, González-Prieto SJ, Merino A, Benito E (2013) Acciones urgentes contra la erosión en areas forestales quemadas. In: Xunta de Galícia (ed) Guia para su planificación en Galicia, 139 pp. Tórculo Artes Gráficas, Santiago de Compostela, Spain. ISBN:978-84-8408-716-8

Verde JR, Camps M, Macías F (2005) Expression of andic properties in soils from Galicia (NW Spain) under forest and agricultural use. European J Soil Sci 56:53–63

Villar MC, González-Prieto SJ, Carballas T (1998) Evaluation of three organic wastes for reclaiming burnt soils: improvement in the recovery of vegetation cover and soil fertility in pot experiments. Biol Fertil Soils 26:122–129

Villar MC, Guitián Ojea F (1972) Mineralogía de tierras pardas sobre rocas graníticas de la región occidental gallega. An Edafol Agrobiol 31:243–267

Villar MC, Petrikova V, Díaz-Raviña M, Carballas T (2004a) Changes in soil microbial biomass and aggregate stability following burning and soil rehabilitation. Geoderma 122:73–82

Villar MC, Petrikova V, Díaz-Raviña M, Carballas T (2004b) Recycling of organic wastes in burnt soils: combined aplication of poultry manure and plant cultivation. Waste Manag 24:365–370

Wilding LP, Ahren RJ (2002) Soil taxonomy: provisions for anthropogenically impacted soils. In: Proceeedings 2001 international symposium “soil classification”, pp 35–46. European Communities, Luxembourg

Xunta de Galicia (1992) Plan Forestal de Galicia. Síntesis, 142 pp. Consellería de Agricultura, Gandería e Montes, Dirección Xeral de Montes e Medio Ambiente Natural. Galicia Editorial, S.A., La Grela-Bens, La Coruña, Spain. ISBN:84-453-0402-X

Yaalon H, Yaron B (1966) Framework for man-made soil changes. An outline of metapedogenesis. Soil Sci. 102:272–277