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DOUGLAS L. KARLEN, SERIES EDITOR

Volume 5

Soil Health and Sustainability in Spain and Portugal

Edited by

Iñigo Virto and Rodrigo Antón

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Soil Health Series: Volume 5 Soil Health and Sustainability in Spain and Portugal

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Soil Health Series: Volume 5 Soil Health and Sustainability in Spain and Portugal

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Soil Health Insights from Spain and Portugal

Douglas L. Karlen, Soil Health Series Editor

Soil Health and Sustainability in Spain and Portugal is the fifth volume in the Soil Health Series being published by Wiley and the Soil Science Society of America (SSSA). Volumes one and two provide background and general methods for assessing soil biological, chemical, and physical properties and processes affecting soil health, while volumes three and four explore those factors, indicators, and management practices affecting soil health in Brazil and India, respectively. This volume, edited by Professor Iñigo Virto and Professor Rodrigo Antón draws upon their research experience in Spain, France and the U.S. on soil health, the soil C cycle, and its response to management to further our global evaluations of the concept. Collaborating with scientists from Spain, Portugal, and other countries, this volume focuses on soil health and sustainability throughout the Iberian Peninsula.

For those not familiar with this geographic area, the Iberian Peninsula, encompasses 583,254 km^2 and is the second-largest European peninsula by area after the Scandinavian Peninsula. It is the westernmost of the three major southern European peninsulas and of the larger Eurasian landmass and has a population of roughly 53 million. There are three dominant climate types (Mediterranean, oceanic, and highland alpine) with a topography that is very contrasting and has uneven relief.[1]

Chapter 1 identifies the most relevant soil health issues and provides a general overview of the natural conditions of the Iberian Peninsula. The diversity and distribution of major soil types, climates, and land uses are examined to evaluate inter-relationships between agricultural management and soil health. Chapter 2 examines different sustainable agricultural management practices for soil carbon

[1] The Iberian Peninsula. https://en.wikipedia.org/wiki/Iberian_Peninsula

sequestration and stabilization, as an indicator of soil health for permanent crops under semiarid conditions. Green manuring or retaining pruning residues are shown to be effective for coping with climate change, but there are no a tailored-made solutions for these semiarid regions. Chapter 3 examines crop diversity in Southeastern Spain with three cash crops (rainfed almonds, irrigated mandarins, and vegetables) by quantifying the variation in different soil physical, chemical and biological indicators of soil health. The results show that crop diversity enhances soil health through the incorporation of plant biomass which creates wider diversity in soil microorganisms with multiple functions.

Chapters 4 and 8 examine soil health in an urban environment and after 25 years of sewage sludge application in Northern Spain. The urban study was done in Santiago de Compostela (Spain) and shows that maintaining and enhancing soil health in those environments can be quite challenging because many soils have been disturbed by anthropic activities and contamination. A study established in 1992 close to Pamplona (Spain) was used to evaluate the impact of sewage sludge recycling, one of the circular economy and European Green Deal goals. The study quantifies several soil physical, chemical and biological indicators, as well as their relation to crop yield and quality in a four-year rotation.

Chapter 5 and 6 examine soil health of highly weathered degraded acid soil and the potential to use irrigation to enhance soil health, respectively. Acid soils are primarily located in the western third of the Iberian Peninsula, on the siliceous domain of the Hesperian massif. They are poor soils that can function to support arboreal plants or arbustive vegetation, which consists of woody plants that are smaller than trees but larger than herbaceous plants but are very vulnerable when cultivated. Chapter 5 examines the long-term effects of integrated farming treatments on a selection of chemical, physical and biological soil properties, measured at different depths, and their relationships with crop development and greenhouse emissions. Chapter 6 is important, since due to climate uncertainty in many areas, including the Mediterranean basin, up to 80% of agricultural production comes from irrigated land. However, the use of irrigation can also increase the environmental footprint of agriculture, which opens questions on the sustainability of irrigation in some areas. This chapter examines soil health during a transition from dryland agriculture to long-term irrigation for different soil and climate conditions within the Iberian Peninsula.

Finally, Chapters 7 and 9 focus on planted and managed forests in Northern Spain and forest and agroforestry systems in Portugal, respectively. In N Spain and Portugal, *Pinus radiata* and *Pinus pinaster* plantations occupy more than 290,000 ha and 2 million ha, respectively, with rotation lengths between 35 and 40 years. Conventional site preparation consists of the partial removal of logging residues followed by down-slope ripping or blading which pushes logging residues and the humus layer away from the site. This depletes nutrients, increases soil loss, and degrades soil physical properties. Visual assessment is used to evaluate those problems from a soil health perspective.

Overall, Iñigo, Anton and their colleagues have compiled an excellent volume that addresses soil health and sustainability throughout the Iberian Peninsula. Thank you for your excellent contribution to our Soil Health Series.

Preface

This volume in the Soil Health series was written at the invitation of Dr. Douglas L. Karlen and the Soil Science Society of America, and is the fifth in the series, after the first two edited by Dr. Karlen and his collaborators on general perspectives and methodologies.

The objective of this series is to provide a comprehensive overview of experience-based knowledge on soil health assessment under different soil, climate and management conditions globally. Under the umbrella of the first two volumes, the aim is to provide an approach focused on studies developed in different areas of the world, where systematized soil health studies have been conducted. In this case, a selection of case studies in the Iberian Peninsula is offered, which try to be representative of the diversity of natural conditions of our territory, and of the majority uses of the soil that occur in it. Thus, the book includes works of soil health assessment in agricultural (rainfed and irrigated) land, forest and urban soils, in a gradient of climates that corresponds to the most representative conditions of the Peninsula.

Corresponding to this heterogeneity, the approaches to the study of soil health in the different chapters are also diverse. Thus, there are chapters focused on the study of a few selected indicators, and others that use wider ranges, and even a chapter focused on the visual assessment of soil condition in forest management.

This diversity of approaches corresponds to that described in the first book of the series regarding the evolution of soil quality assessment, and even of the concept itself. As described in the first chapter, the definition of Soil Health, and of the methods for its assessment, has changed in recent decades from an approach focused mainly on the productivity of agricultural and forest soils, to an approach that considers soil functions within the (agro)ecosystem, as well as its role in the provision of ecosystem services that contribute to the maintenance of the environment and human well-being. An idea that actually develops in contemporary times, and attempts to systematize, the concern for soil quality that has accompanied humankind since its origin, and in particular since the establishment of sedentary communities whose survival depends on the conservation of natural resources.

This book has also been written in a context of growing awareness on the part of society as a whole, and of the Administration, of the importance of the soil resource for our well-being. In particular, the European Union has developed several initiatives in recent years with the aim of increasing knowledge and regulating the health of Europe's soils (with initiatives such as the European Soil Protection Strategy, the EJP-Soil Joint European Program, the Soil Mission, the C Agriculture Regulation, and above all, the proposed Soil Monitoring and Resilience Directive). In addition, both environmental and agricultural policies include in the Union different mechanisms that try to protect more or less indirectly the health of Europe's soils.

Undoubtedly, all these initiatives have been and are the subject of debate among policymakers, stakeholders, and even within the scientific community itself, so we can speak of a moment of special intensity in our continent in the debate on strategies and tools for soil health assessment, not only among professionals, but even in the regulations themselves. This book is thus more a "state of the art" than a closed work, which attempts to provide quantitative and science-based information on the particular case of some soils of continental Spain and Portugal. For this reason, priority has been given to the search for long-term studies and/or comprehensive assessments of the agricultural or forestry systems considered.

The long trajectory of many agricultural and forestry research and consultancy institutions in our territory would undoubtedly allow the development of several more volumes on this subject. Following the example of the first volume, in this book we have decided to start somewhere, and open to the public some representative cases, instead of embarking on the impossible task of trying to cover all possible situations and approaches.

Iñigo Virto & Rodrigo Antón

1

Soil Health in the Iberian Peninsula

Iñigo Virto, Rodrigo Antón, Miguel Itarte, and Alberto Enrique

Chapter Overview

This chapter summarizes the most relevant geographical and physical characteristics of the Iberian Peninsula including its soils and land uses. It also introduces the general context in which the case studies described in the following chapters have been developed, and their relevance to soil health.

The chapter also includes an overview of soil health studies in the Peninsula in recent years, and the changes occurred in the topics of interest within these studies.

Finally, the chapter offers an overview of the information explained in the book chapters, grouped in relation to the land use they describe (agriculture, forest and urban soils).

Introduction

Soil health has become a unifying concept, tool, and goal for all kinds of soil-related users, stakeholders, and decision-makers in the past several decades (Karlen et al., 2021a, 2021b). In this book, we aimed to explore and present long-term experiences dealing with different angles of soil health assessment and monitoring in the Iberian Peninsula, home to mainland Spain and Portugal. In this chapter, we introduce first the geophysical and land use context in this corner of Europe, revise the evolution of scientific production related to the topic, and summarize the contributions developed in the book's other eight chapters.

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This work has been carried out in a fast-changing context, both in terms of changes affecting soils, and in terms of the increase in general awareness and regulatory proposals about the protection of soils in the European Union. Indeed, soil health assessment is becoming paramount for understanding the response of soils to the so-called contemporary "global change" due to biophysical planetary-scale changes (e.g., atmospheric circulation and climate, biogeochemical cycles, the hydrological cycle, biodiversity) and changes in the human population, economy, use of resources, land use and cover, urbanization, and other human-related activities. Owing to the key role of soils in terrestrial ecosystems and as the basis of agriculture, and thus the changes in use associated with primary production, soils appear at the center of global change, both in relation to its causes and its effects. This position implies that these changes directly affect the functioning of soils, and require new evaluation systems to assess soils as a resource, determine their responses to changes, and identify possible mitigation and adaptation strategies.

The increase in soil heath studies responds to this need and to the evidence that the role of soils in the face of global change must be approached from a global and holistic perspective. So far, the most widespread trend has been to evaluate the effect of specific soil management measures in isolation. This reductionist approach is common in scientific research and useful in local studies, but it sometimes has limited practical relevance to the wider farming and soil-using community. For instance, the limitation of these approaches becomes clear in the case of agrarian systems, which are based on an interrelated and interdependent complex of options and measures that can only be slightly modified or not modified at all without affecting each other (Faber et al., 2022).

In fact, the basis for the development of concepts linked to soil quality or soil health is that the relationship between soil functioning and the services that soils provide is not univocal (different functions can provide the same service), and vice versa (the same service can depend on several functions), so establishing simple relationships is not easy or, in many cases, adequate. Thus, the definition of the concept of "soil quality" has varied from its first formal conceptions in the 1990s, based specifically on the condition of agricultural soils for production, towards a broader conception, which emphasizes sustainable management of the land and provides a holistic approach (Karlen et al., 2003). Indeed, throughout the history of soil science, concepts such as "soil productivity" (already cited in 1910), "soil conservation," "soil security," or "soil resilience" have been developed and have contributed to increase our awareness of the need to understand and protect the complexity of soil functioning beyond the study of a few or several isolated properties. These new concepts have emerged within the soil science community through multiple actions, such as reflection on the social, cultural, and/or political needs that exist outside this community, or by being progressive and relevant to new emerging interests such as global health or security (Mizuta et al., 2021).

In a recent attempt to compile the different approaches defined in the last years, the Intergovernmental Technical Panel on Soils (ITPS) of the Global Soil Alliance, led by the Food and Agriculture Organization of the United Nations, released a summary definition of soil health: "the capacity of the soil to sustain the productivity, diversity and environmental services of terrestrial ecosystems" (ITPS, 2021). This definition fits the core concept defined by Janzen et al. (2021), who concluded that the multiple definitions of this concept have at least three things in common. First, soil health has at its core the notion of functionality, that is, the ability of a soil to perform its vital functions normally. Second, the soil is considered as a living and dynamic system, with a torrent of connected and intertwined processes. Third, an essential element of the definition of soil health is sustainability or resilience, which acknowledges that a healthy soil maintains the functioning of the ecosystem over time.

However, the term soil health continues to appear to some as a theoretical and complex idea, essentially a "popular metaphor" (Janzen et al., 2021). A translation from metaphors into concrete facts and data, possibly applicable to quantitative assessment of soil health relevant for policy-making and to regulations to rule this assessment, is needed to move from the emotional sphere to a political one (Panagos et al., 2022). In this context, the European Union is taking steps towards a concrete formulation for the protection of European soils. The European Commission has thus been preparing a Soil Health Law since 2020. This legal framework will contribute to (a) achieving the objectives of the European Soil Strategy 2030, with the aim of granting soils the same level of protection as water and air, and (b) radically improving the condition of soils to better provide the services that we depend on.

In compliance with this strategy, the European Union Soil Mission proposes that by 2030 at least 75% of the soils of each EU member state will be healthy or will show significant improvement towards compliance of the accepted thresholds of the indicators selected to support ecosystem services. This objective corresponds to an increase in healthy soils with respect to a reference baseline established by each member state. The determination of this reference must be made based on specific indicators. The indicators proposed by the EU Mission for Soil Health (*A Soil Deal for Europe*, European Commission, 2023) cover measurable physical, chemical, and biological soil properties and landscape parameters. At the same time, measurements will have to follow agreed protocols and thresholds that consider the variability of soil types, land use, and climate, with reference points defined by the member states themselves.

In this framework, consensus exists that the assessment of soil health needs to be done in the context of specific geographic, biophysical, and management conditions

(Costantini et al., 2020). The Iberian Peninsula, because of its geographical location, physical characteristics, and long history of land use and land use changes, is home to a great diversity of landscapes, including many based on different uses of soils. A recent compilation of land of soil degradation pathways in Europe (Prăvălie et al., 2024) has shown that the peninsula is also one of the most threatened territories in Europe in this respect, with many areas included as those affected by three or more soil degradation problems. In particular, soil loss by water and wind erosion, soil compaction, nutrient imbalances, or acidification can be identified in different areas. Groundwater decay and aridity at critical levels in most of the southern half of the peninsula are additional relevant threats to soil functioning.

This book therefore presents some of the most representative situations in the peninsula in this respect and highlights the approaches used to assess soil health in each.

General Geophysical Characteristics and Land Uses

The Iberian Peninsula, considered in this chapter as the joint surface of continental Spain and Portugal, is located at the southwestern limit of the European continent, and extends over 582,400 km^2. The peninsula displays extensive landscape and biological diversity owing to its geographical position and its geological, geomorphological, and bioclimatic characteristics. These characteristics also result in a great soil diversity.

From the geological and geomorphological point of view, as described by Maestro et al. (2013), the complex geological history of Iberia reflects its location between the African and European plates and is recorded by rocks ranging in age from Precambrian to Quaternary within a complex and diverse geological setting (Figure 1.1). The peninsula hosts several mountain ranges exceeding 2,000–2,500 m (Cantabrian Mountains, northwestern ranges, Central Range, and Iberian Range) and two ranges with peaks greater than 3,000 m (Pyrenees and Sierra Nevada in the Betic Range).

Despite this complexity, the peninsula can be divided into three main geologic domains based on lithological and hydrologic characteristics (Martín-Serrano et al., 2005; Figure 1.1). These domains include (a) the so-called Iberian or Hesperian Massif (western sector, including most of Portugal), (b) the mountain ranges of the Alpine orogeny (including the Pyrenees and other major chains of the same age) and other Mesozoic formations, and (c) the Cenozoic basins (including the sedimentation basins of the four major rivers: Tajo/Tejo, Duero/Douro, Ebro, and Guadalquivir). In some small areas, relatively recent volcanic complexes are also present, although they represent a minimal surface in the central, northeast, and northwest areas of continental Spain.

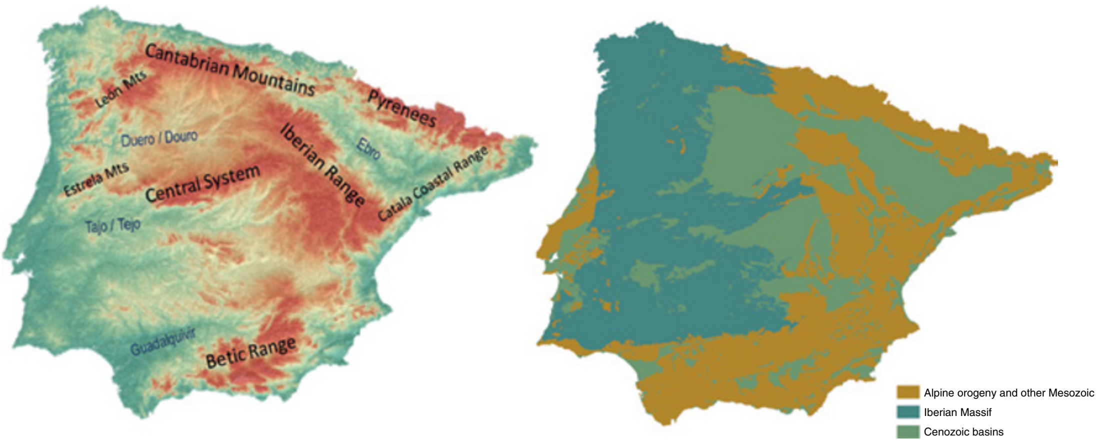

Figure 1.1 Major systems and river basins (left) and main geologic domains (right) in the Iberian Peninsula. Own elaboration from Martín-Serrano et al. (2005) and IGME (2015).

The lithology of these domains can be also summarized in major lithological units (Gallardo, 2016; Figure 1.2). As such, siliceous metamorphic rocks (mainly slates, schists, and quartzites) and intrusive rocks (granites and similar) are the predominant materials in the Iberian Massif (Calvo de Anta et al., 2020). The Cenozoic basins are formed mostly of calcareous materials (limestones, dolostones, marls), and sedimentary rocks, which in most cases also include calcareous materials from their source areas. Major mountain chains display diverse lithologies related to their tectonic and orogeny processes (Vera et al., 2004). In the north, in the Pyrenees and Cantabrian Mountains (Figure 1.1), limestone and other calcareous materials alternate with older, metamorphized materials, especially in the axial zones of the Pyrenees, and pre-Cenozoic materials. Other major ranges in the central and eastern areas (Iberian Mountains, Catalan Coastal Range, Figure 1.1) also contain significant calcareous massifs, and at some points, older metamorphic outcrops. In the south, the Betic Mountains are part of the Alpine ranges surrounding the Mediterranean (Mediterranean Alpine Orogen), with Triasic sedimentary materials in the North, and some metamorphic materials outcropping in the south.

The location and geography of the Iberian Peninsula also results in a multiplicity of climates. Because most wet fronts arrive from the Atlantic Ocean and flow from west to east, all northern and northwestern areas are, in general, rainier than the south and, especially than the east and southeast (Gallardo, 2016). Mountain chains in the north and in northern Portugal (Figure 1.1) also contribute to hinder the entry of these fronts to the inner part of the peninsula. As a result, there is a

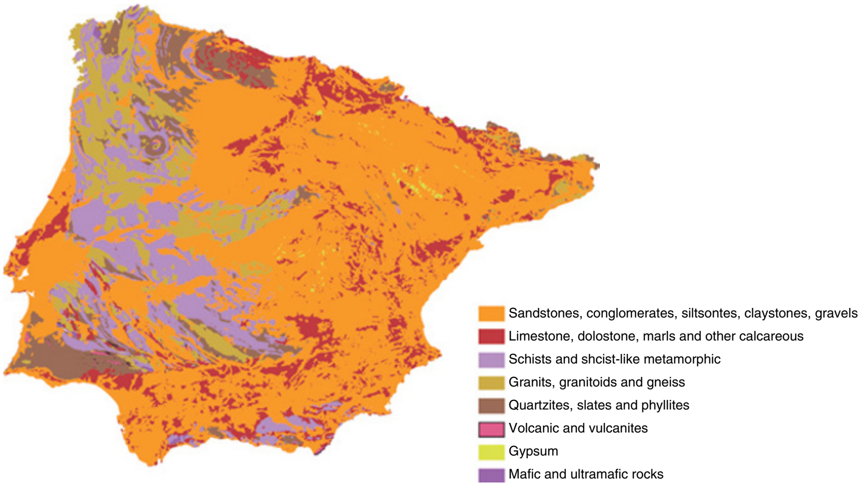

Figure 1.2 Lithologic domains in the Iberian Peninsula. Own elaboration from IGME (2015).

gradient in average annual rainfall from the northwest to the southeast (Figure 1.3). In terms of temperature, latitude, continentality, and altitude all play a role, resulting in a generally warmer southern half (with the highest temperatures recorded in the southeast and the Guadalquivir Basin; Figure 1.1), and milder temperatures in the northern half and mountain areas (Figure 1.3). In addition, the proximity to the ocean or sea makes coastal temperatures less variable throughout the year, whereas a larger contrast between the cold and warm seasons exists in the central area. Altitude also results in colder temperatures corresponding with the major ranges (Figures 1.1 and 1.3). This results in clearly different areas with contrasting annual water balance (moist or dry) and average temperatures (Figure 1.3).

These areas correspond to a large extent to those defined by the global Köppen climate classification (Figure 1.3). Most of the peninsula displays temperate (C-type) climates, with differences in the amounts and distribution of precipitation. While most of the north is under moist C climates (Cf), the central and southern parts and a large area around the east coast display some type of summer drought (Cs). The temperature in the summer is lower in the northern half (Csb) than in the south and southeast (Csa). Csa climate corresponds to the classical Mediterranean climate (mild winters and dry, warm summers, and most rain falling in late winter or in spring or fall). In contrast, relevant areas in the eastern half (mostly corresponding to the Ebro depression and areas in the southeast) are arid enough to be defined as dry climates by Köppen (B-type), in particular steppe-like (Bs), differing owing to whether the annual temperature is milder (Bsk, <18 °C) or warmer (Bsh, >18 °C).

These differences in climate have consequences in land uses, types of natural vegetation, and especially in agriculture. While moist and fresh areas in the north and northwest have been traditionally devoted to forest and grasslands, plains and gentle-slope areas in the central and eastern parts comprise most of the agricultural land. In many cases, irrigation is used on this land as a tool to increase yields and enable the productivity of crops.

In addition, the combination of these diverse soil forming factors results in a high diversity of soil types in Iberia. As depicted in Figure 1.4, major soil types comprise Cambisols of different types and Regosols and Leptosols, also with different qualifiers. Luvisols and Podzols are also present, mostly in the western half of the peninsula (Figure 1.5). Cambisols are relatively young soils, with little or no profile differentiation (either because of limited age, slow pedogenesis, or rejuvenation of the soil material), with at least an incipient subsurface soil formation and evidence of horizon differentiation based on changes in structure, color, clay, or carbonate content (IUSS Working Group WRB, 2022). These soils occur in a wide variety of environments around Europe and under many kinds of vegetation (Soil Atlas of Europe, 2005). The USDA

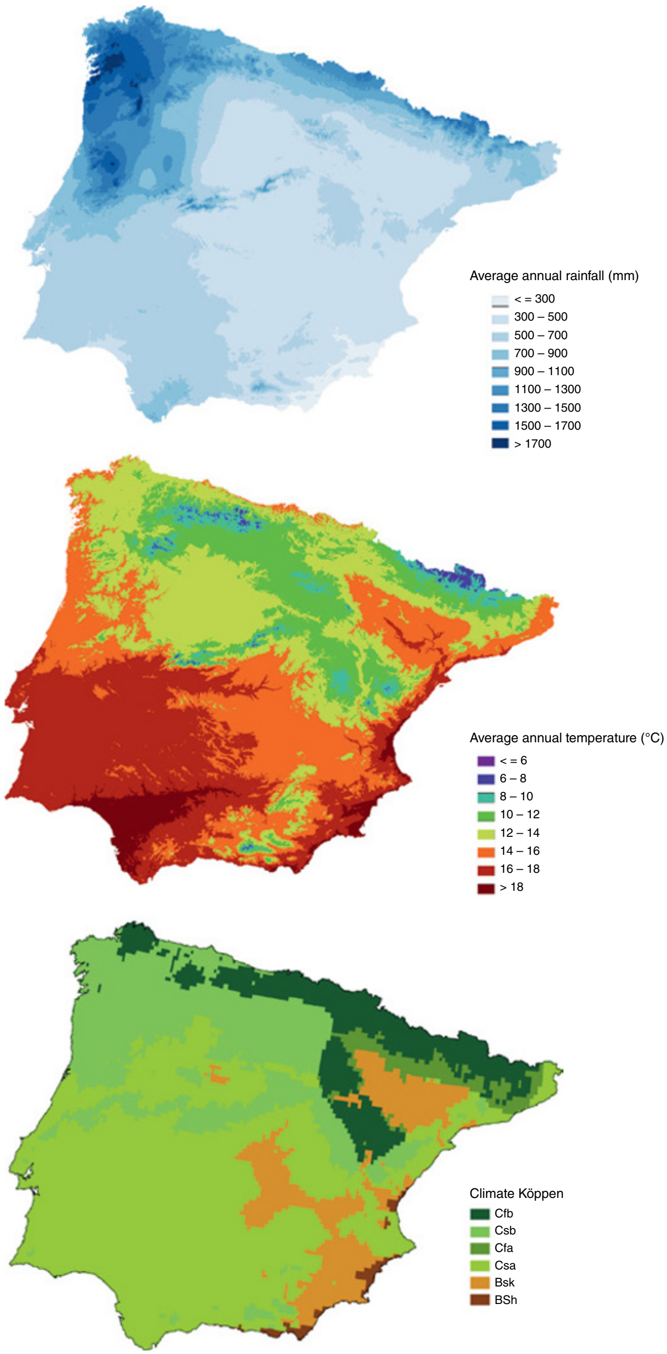

Figure 1.3 Distribution of average annual rainfall (top), and temperature (center), and Köppen climate areas (bottom) in the Iberian Peninsula. Own elaboration from E-OBS (Cornes et al., 2018), CRU-TS 4.06 (Fick & Hijmans, 2017), and World Map of Köppen-Geiger Climate Classification (https://koeppen-geiger.vu-wien.ac.at/).

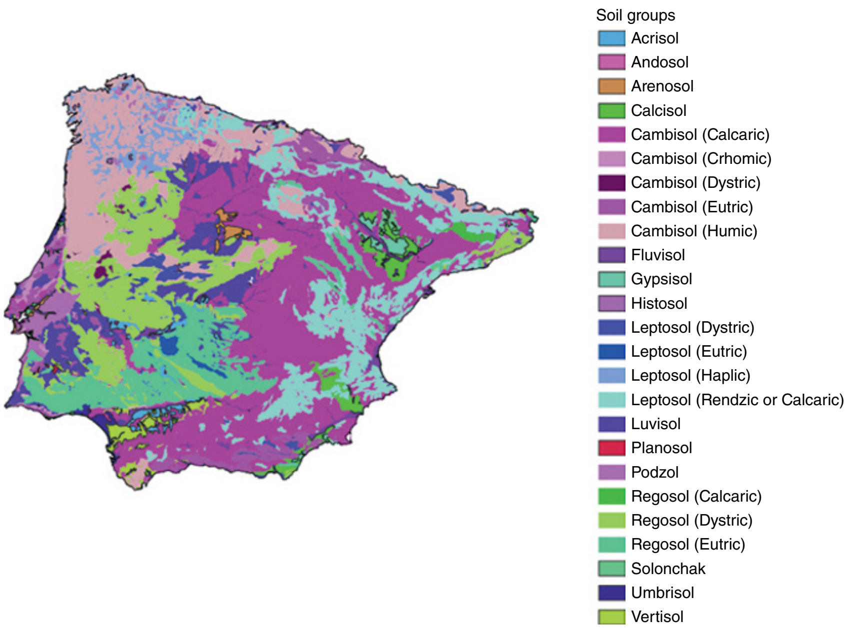

Figure 1.4 Distribution of soil groups of the World Reference Base in the Iberian Peninsula (IUSS Working Group, 2015). Own elaboration from ESDAC, ESDB v2.0, 2004.

Soil Taxonomy classifies most Cambisols as Inceptisols. Depending on their parent material, climate, and landscape positions, Cambisols can be differentiated in soils that have contrasting characteristics and behavior in terms of their response to management or potential use. In the Iberian Peninsula, two types are dominant according to the European Soil Data Center (ESDAC, ESDB v2.0, 2004, Figure 1.4). In the eastern part, corresponding to the areas with calcareous and sedimentary dominating lithologies, Calcaric Cambisols dominate (Figure 1.5). These are Cambisols having calcaric material between 20 and 50 cm from the surface, or between 20 cm and the bedrock, or a cemented layer (IUSS Working Group WRB, 2015). Other soils with calcaric or calcium-rich features (such as Calcaric Leptosols and Regosols, and of course Calcisols) are also widespread in this part of the peninsula (Figure 1.5). In fact, in the Soil Atlas of Europe, these areas appear as occupied mostly by Calcisols (with substantial secondary accumulation of carbonates). These areas correspond to soils with a Mediterranean type of climate, including Calcixerepts and Haploxerepts according to the USDA Soil Taxonomy, which together cover more than 140,000 km^2 in Spain (Gómez-Miguel and Badía-Vilas, 2016). These findings imply that the presence of carbonates in different forms in the soil

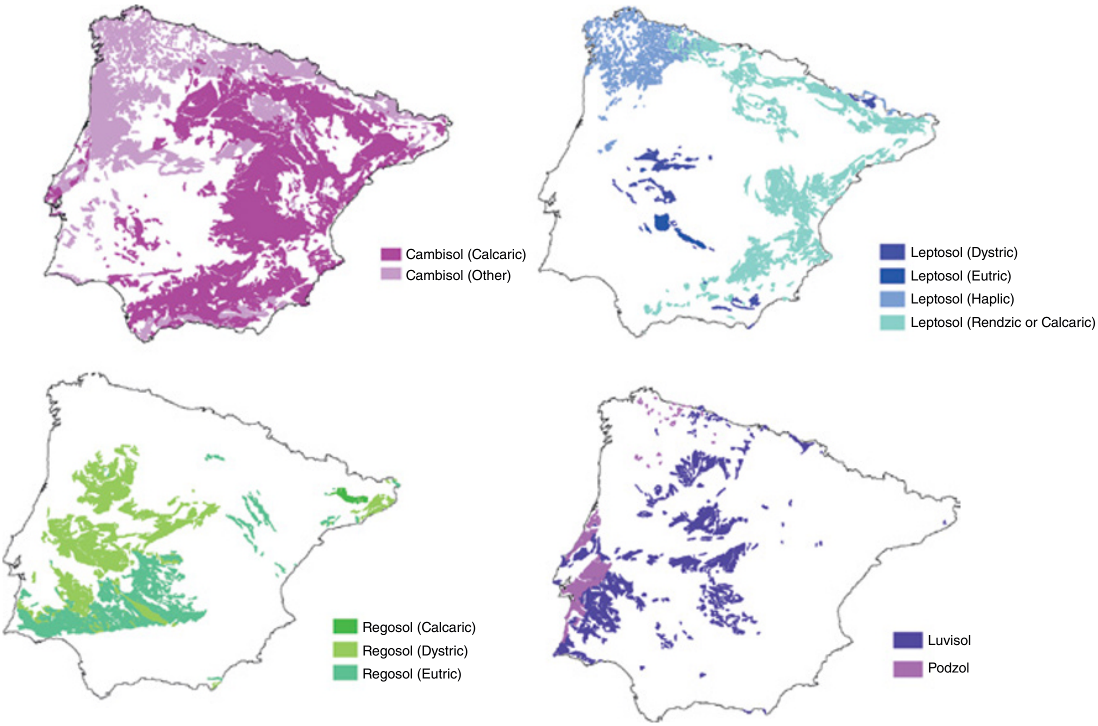

Figure 1.5 Distribution of Cambisols, Leptosols, Regosols, Luvisols, and Podzols in the Iberian Peninsula (IUSS Working Group, 2015). Own elaboration from ESDAC, ESDB v2.0, 2004.