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2.1 Introduction

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

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

It should be noted that all the generalizations made here relate only to specific Spanish conditions. The use of a specific toponymy has been carefully considered and the detailed usage decision implies more precise information,

although it can be needed to consult the *Geographic Concise Gazetteer of Spain* (IGN 2006). (For readers who are not familiar with the administrative organization of Spain, please see Fig. 1.6 in Chap. 1 (Appendix)).

2.2 Soil Temperature and Moisture Regimes

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

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

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

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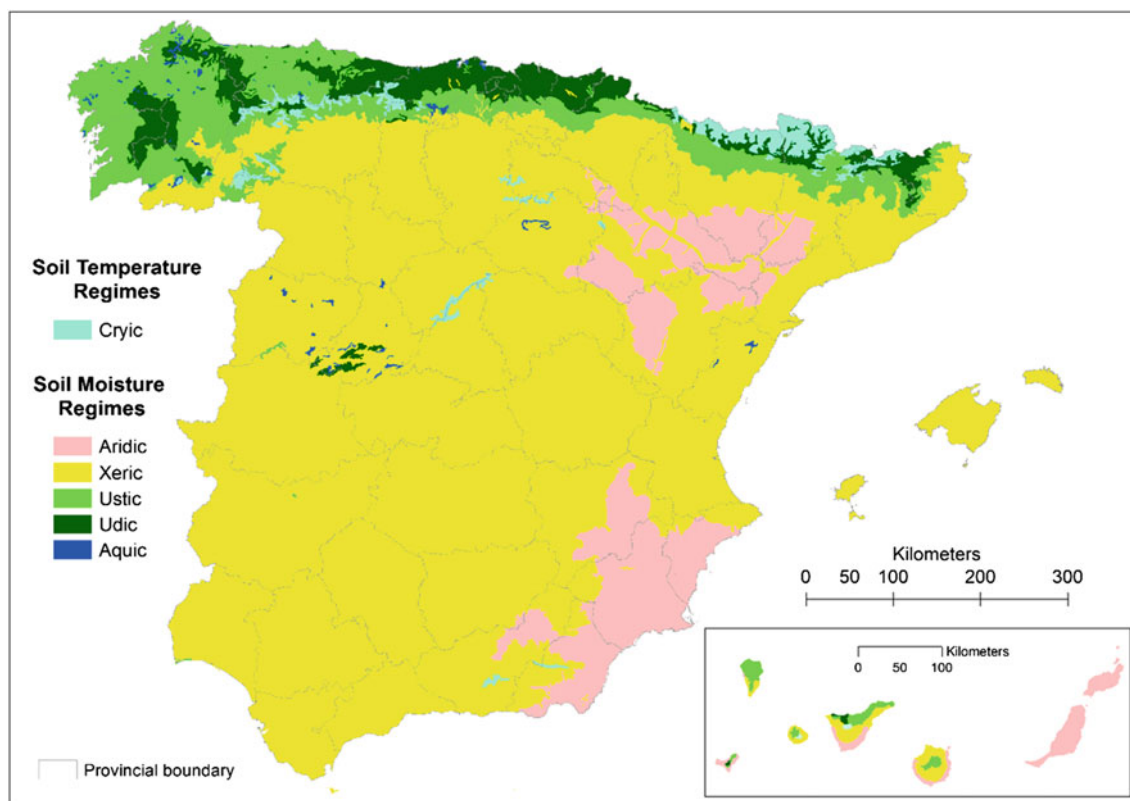


Fig. 2.1 Soil temperature and soil-moisture regimes in Spain: *green* represents wet soils during most of the year; *yellow* shows soils that are completely dry during summer; and *pink* signifies soils that are dry during most of the year (Gómez-Miguel and Nieves 1992)

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

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

The aquic moisture regime is virtually impossible to map at this scale, although it is used in the described taxonomic units. Specifically, hydromorphic areas (aquic conditions),

irrespective of the climatic region in which they are located (azonal character), and aquic and hydromorphy moisture regimes are commonly observed under circumstances of a high water table or heavy water contributions in poorly drained landforms (depressions, watersheds, etc.).

2.3 Soil Geography: Description of Taxonomic Units

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

2.3.1 Alfisols (Photos 2.1, 2.2 and 2.3)

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

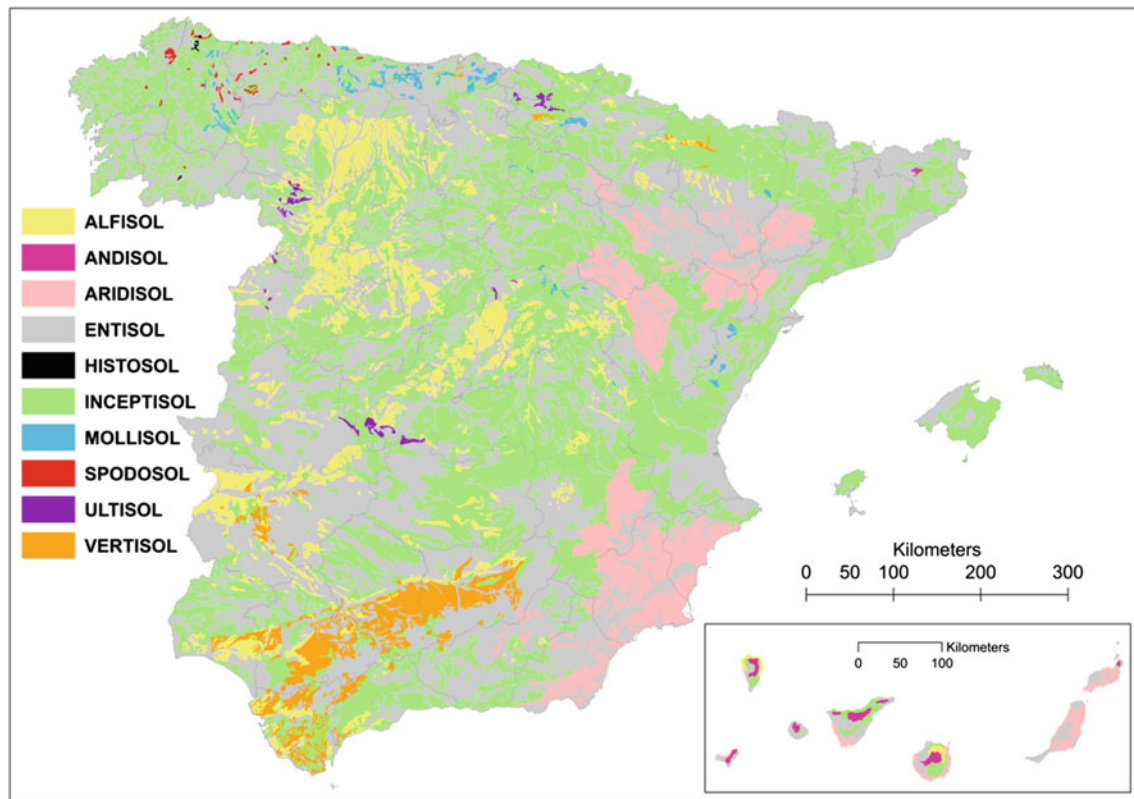


Fig. 2.2 Distribution of soil orders (Gómez-Miguel 2005)

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

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

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

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

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



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



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

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

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

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

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

Alfisols occupy a total of 12.3 % of the country's land (61.9 km²), which puts them in the third order of surface soils (although possibly in first place from an economic and social standpoint). Obviously, not all Alfisols can be included on the map in detail (for example, on the Island of La Gomera). For this reason, an asterisk [*] will indicate the soil units or horizons identified and/or described in Spain that are not mappable due to their minimal surface and/or socio-economic importance. Alfisols are preferably engaged to cultivate short cycle crops and forages. This agricultural potential is limited by other features that define the lesser categories, i.e., hydromorphy (Epiaqualf), very low temperatures (Haplocryalf), abrupt boundary (Paleustalf and Palexeralf), natric horizon (Natrixeralf*) or albic horizon (Albaqualf*) (Table 2.2).

2.3.1.1 Aqualfs: Epiaqualfs

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



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

Therefore, they can be defined as Alfisols (with a genetic horizon Btg) whose water table is near the surface for at least a few weeks of the year, although the water table may fall during the dry season. In some regions, rice is cropped, but when other crops want to be introduced, the excess of water must be eliminated from the profile (artificial drainage). Argillic horizons with an aquic regime are rare in Spain and have only been mapped as secondary soils along 1,472 km² in some flat areas with a specific lithology.

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

soils are associated with Ultisols, in the same way as the *rañas* and *rañizos* of the Province of León, which also coexist with additional associations of Palexeralfs. When Aqualfs have an albic horizon (*E*), they are classified as Albaqualfs*; these are located in specific landforms, such as the *rañas* of the Province of León (which are associated with Epiaqualfs).

2.3.1.2 Cryalfs: Haplocryalfs

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

About 155 km² of Haplocryalfs has been mapped, mainly as inclusions; they are found in the Pyrenees, between the Canfranc and Piedrafita de Jaca locations, including the valleys of Ordesa and Monte Perdido, and Artiés (Provinces of Huesca and Lleida). These soils are covered with conifers and grasses adapted to climatic and soil constraints.

2.3.1.3 Udalfs: Hapludalfs

The Hapludalfs are well-drained Alfisols that, at some point, could have developed under a forest cover. Given the distribution of the udic regime (associated with steep slopes in Galicia, the Cantabrian and Pyrenean mountain ranges), Hapludalfs are not common in Spain, covering an area of 1,187 km², distributed as main soils in northern Cantabria, the Basque Country, Navarra, Huesca and Lleida. In other areas, mainly northern Spain, they appear only as secondary soils and inclusions.

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

2.3.1.4 Ustalfs

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

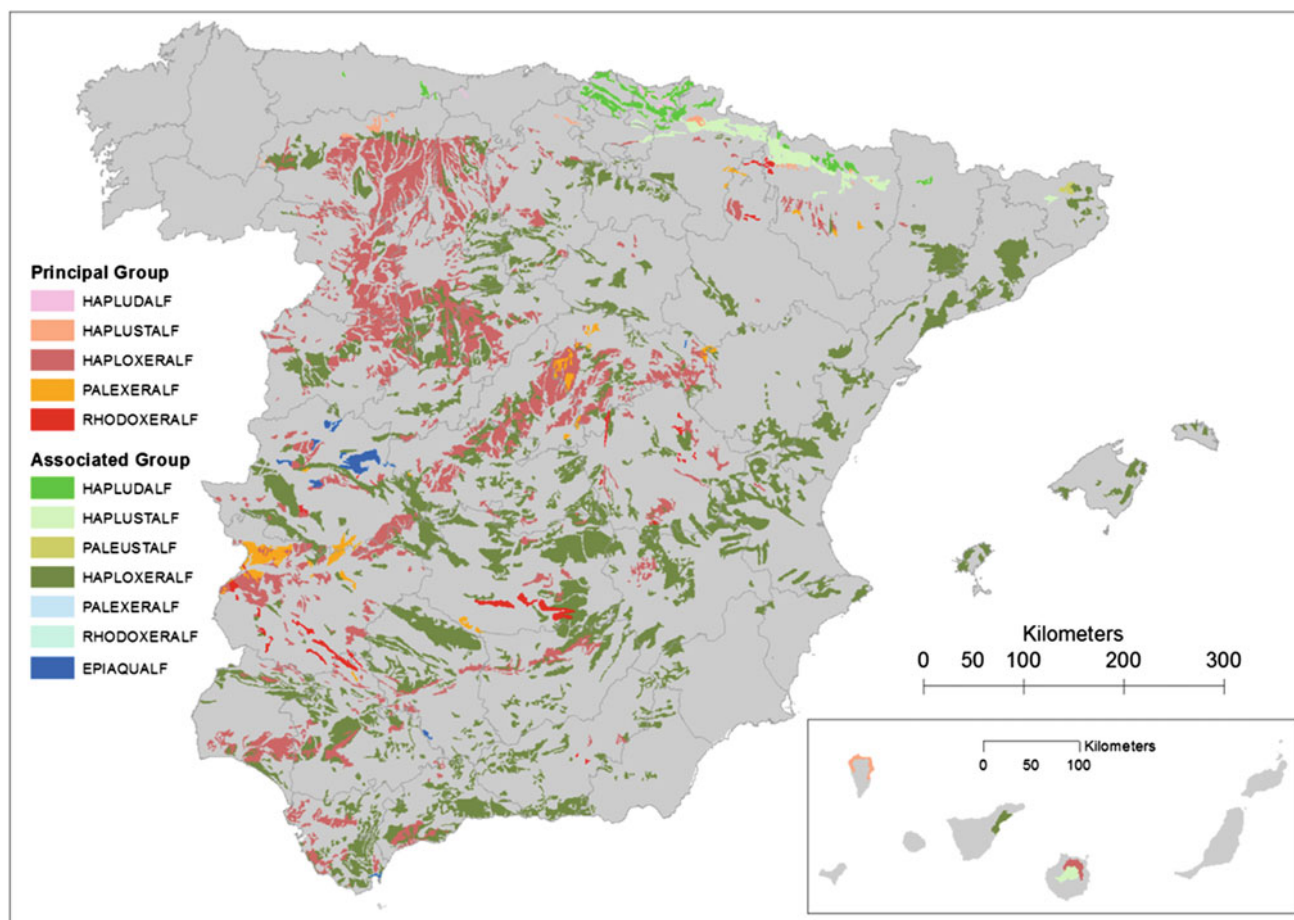


Fig. 2.3 Distribution of Alfisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear associated with various other soils

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

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

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

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

Haplustalfts

The Haplustalfts group is the widest (1,647.6 km²) within the suborder of the Ustalfts, occupying the most stable sites of the ustic border regime. Haplustalfts are present as the major soil types, especially in the northern parts of the Provinces of Navarra and Huesca. Also, they are disclosed between the city of Vitoria and the Montes de Vitoria (Alava) as well as

in the geomorphologically stable surfaces between Santulano and Callezuela in Asturias or the ustic areas of the region north of Aguilar de Campo, Cervera de Pisuerga, Encartaciones (Provinces of Palencia and Burgos), west of Carballo, and areas of the Montes de Castelo and Noreña (Galicia). Between the Aragón River and Jaca (Huesca) there is an ustic central strip in which Haplustalfs are associated with Vertisols (Usterts); with the Ustifluvents, the Usterts can be found as inclusions between the right bank of the Allones River and Malpica, around the Fervenza reservoir, and on the slopes of the Jallas River in Castriz (Galicia).

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

Paleustalfs

Paleustalfs are extremely aged Ustalfs, having required geomorphological stability. The argiluviation is accompanied by other processes, such as the formation of Petrocalcic horizon (Petrocalcic Paleustalfs), rubefaction (Rhodic Paleustalfs), leaching bases (Ultic Paleustalfs), and planosolization. Paleustalfs have only been mapped as secondary associations and represent no more than 27.4 km². These soils have been described only as inclusions in Biescas (north of Huesca). The abrupt boundary is an important condition for the exploration of Argillic material by the plant root system and therefore suited for agricultural use.

Rhodustalfs

Rhodustalfs develop Argillic horizons with a deep red color (≥ 2.5 yr hue, value of 3 or less). Nevertheless, the dry value must not exceed the wet value by more than one unit, a condition that is interpreted as evidence of rubefaction related to a highly evolutionary degree. The rhodic diagnosis character is very demanding (even more than the traditional name of *terra rossa*), and the soil must be very red to conform. Therefore, considering a poor spatial representation of the ustic moisture regime, these soils have been mapped only as inclusions, and they represent barely 251.3 km². Rhodustalfs have been identified in the Canary Islands and in areas associated with the Haplustalfs described above, and in areas associated to Ustepts at medium altitudes of the northern slopes of the Tenerife Island comprising highly evolved ancient volcanic cones (Carboneras).

2.3.1.5 Xeralfs

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

Haploxeralfs

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

In Spain, Haploxeralfs are the most extensively found Alfisols (44,480 km²) and occupy the most stable geomorphological units under the xeric moisture regime. Haploxeralfs abound on the left bank of the Duero River in a wide strip that crosses Madrid from the northeast to the southwest and reaches Extremadura at the foothills of the Sierra de Guadalupe (Extremadura) and the shuttle platforms of the Gadiana Valley. Haploxeralf inclusions appear interspersed with Xerorthents and Xerumbrepts around Villardebós, Oimbra and Monterrey (Orense) and in Villarreal, mixed with Paleoxeralfs Epiaqualfs and even Xeropsamments.

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

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

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

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

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

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

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

and the Marbella ramblas (Province of Granada), and south of Antequera (Province of Málaga).

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

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

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

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

Palexeralfs

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

Palexeralfs have been mapped as main soils, or as associations or inclusions on older surfaces (Plio-Pleistocene) in the Provinces of León and Palencia, Huesca, Madrid and Guadalajara, as well as the central area of Extremadura; these soils occupy a total area of 3,049 km². The Palexeralfs also appear with Rhodoxeralfs and inclusions of Epiaqualfs in the rañas of Salamanca (e.g., Arroyo Serradilla and Cabaco), in the Province of Cáceres (Montehermoso, Monterrubio, Sierras de Guadalupe, Campo Arañuelo), Badajoz (Almendralejo, Albuera, and northern Llerena) and headers of various rivers of the Provinces of Zamora and Palencia. As already mentioned, Palexeralfs have also been described in association with Haploxeralfs in the arid areas of Almería.



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

Rhodoxeralf

Rhodoxeralfs occupy a total area of 9,593 km² in Spain, often in conjunction with Haploxeralfs. Besides having an Argillic horizon with intense rubefaction (typical of Rhodoxeralfs), they may also have either a calcic (Calcic Rhodoxeralfs) or a Petrocalcic (Petrocalcic Rhodoxeralfs) horizon. Derived from topsoil erosion, the Argillic horizon was characteristically intensely red, emerging to the surface as evidenced by the names of places (Almagro, Rubiales, etc.).

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

2.3.2 Andisols (Photo 2.4)

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

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

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

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

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

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

Andisols have been mapped in the Vitritorrands, Haplustands, Udivitrands, Ustivitrands and Haploxerands groups (Table 2.3). The Andisols mapped across Spain occupy a surface close to 533.2 km².

2.3.2.1 Torrands: Vitritorrands

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

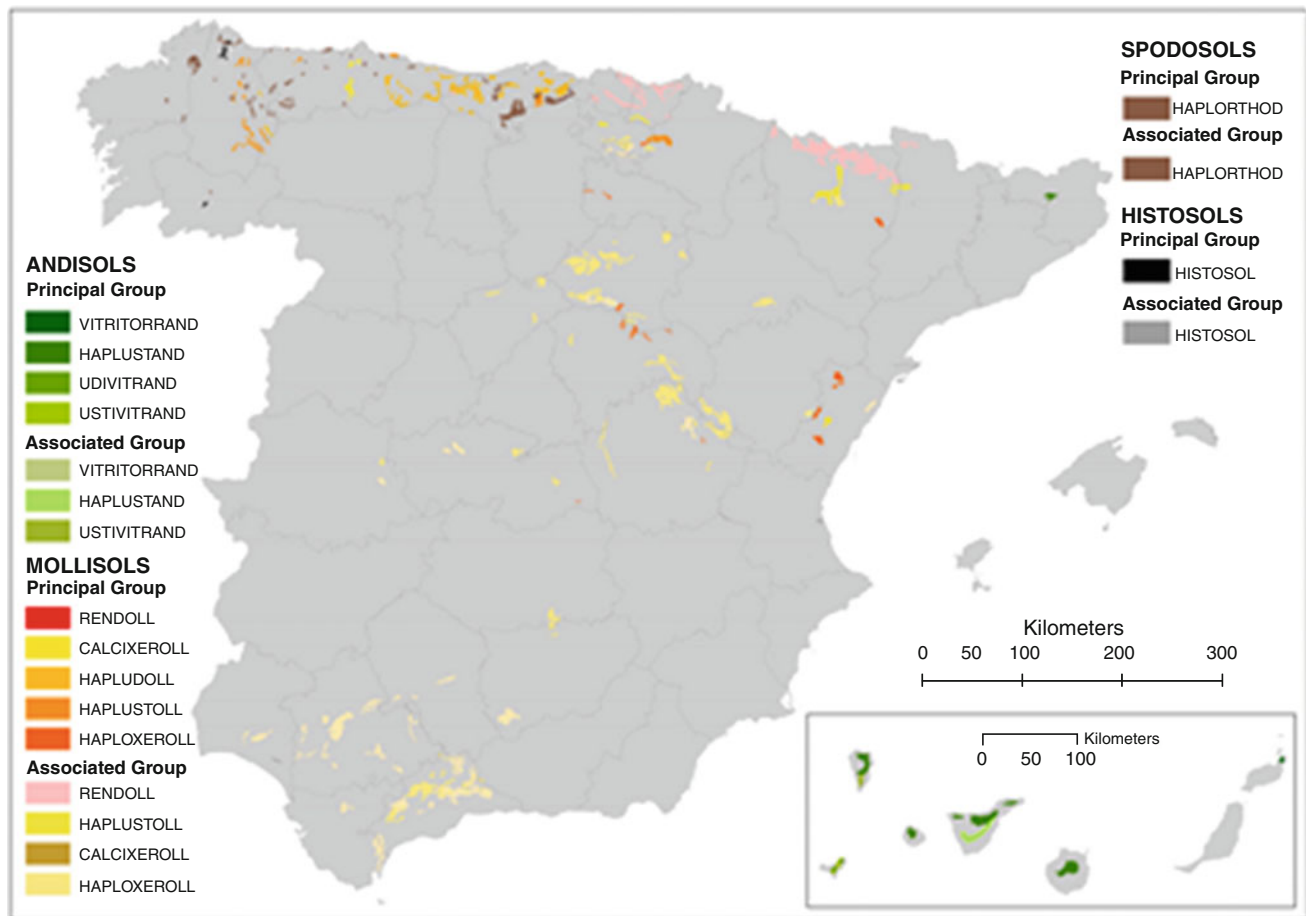


Fig. 2.4 Distribution of Andisols, Histosols and Spodosols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear associated with various other soils

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

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

Vitritorrands have been reported on the Islands of Lanzarote and El Hierro. Specifically, the Island of Lanzarote, under an arid moisture regime, has volcanic materials from many different ages: the Miocene (Ajaches and Famara), Plio-Quaternary (center), recent (north) and historical (eighteenth century), extending over one-third of the island. Vitritorrands have been normally identified on recently found materials (ashes and coladas), consisting of a scarce thickness and sometimes affected by salinity. These soils consist of sandy or silty textures. Vitritorrands are in general developed on a hilly relief and are usually highly erodible

(Teguise-Haria). With regard to the Island of El Hierro, which shows a significant homogeneity of volcanic materials, Vitritorrands are present in the coastal area up to 200 m asl north, 600 m asl south and 700 m asl to the southwest (Guarazona, Isora and Taibique).

2.3.2.2 Ustands: Haplustands

Haplustands are the most widely found; they occupy a surface close to 440 km². They have been mapped in La Garrotxa (Olot, Girona) and especially in the Canary Islands.

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

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

2.3.2.3 Vitrands

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

Udivitrands

Udivitrands represent an area of about 15 km²; they are associated with Hapludands* at an altitude above 1,000 m asl (La Guancha, La Orotava) in Tenerife, east of Sabinosa on the Island of El Hierro, south on the Island of La Palma (the Cumbrecita), etc. Sometimes they are associated with volcanic cones, in which cases they are distinguished by a duripan horizon (Durivitrands*). There are inclusions on the Island of La Gomera.

Ustivitrands

Ustivitrands have been mapped in an area of about 36.6 km². They have been described in association with Haplustands on Gran Canaria Island (Cruz de Tejeda), Tenerife (Sector Icod-Puerto de Santa Cruz-La Laguna, from Anaga to Volcano Negro), on the Island of El Hierro (Valverde South, East Sabinosa), and on the Island of La Palma (Sector Barlovento-Los Catalanes-Puntagorda).

2.3.2.4 Xerands: Haploxerands

Haploxerands have been mapped in an area of only 17.4 km²; their inclusions have been described on Grand Canary Island in the xeric strip between the aridic coastal strip of the south and the ustic regime, as in Tenerife, on the north side (between La Orotava and La Laguna), and to the south (below Punta Oeste-Guía de Isora-Granadilla).



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

2.3.3 Aridisols (Photo 2.5)

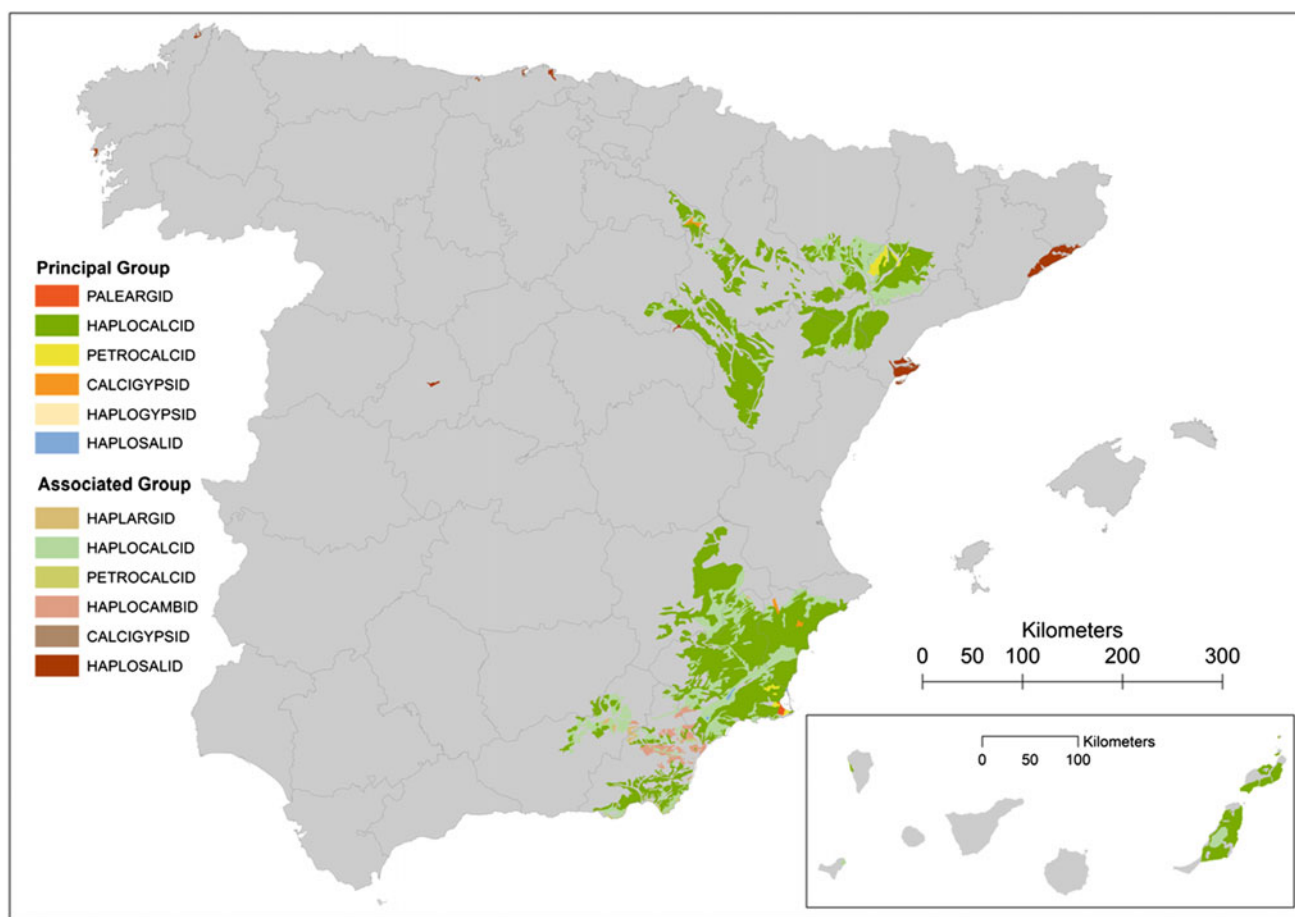
Aridisols constitute the only soil order defined by their aridity degree. These soils have an aridic (torric) soil moisture regime, i.e., they lack water available to plants over extended periods of time. The soil control section has been primarily conditioned by a climatic aridity, which can also influence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

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

In Spain, Aridisols are widely spread out in the Middle Ebro Basin (Huesca, Zaragoza, Lleida), the Calanda Desert (Teruel), southeast of the Peninsula (see Chap. 4) and in the Canary Islands, as well as in saline areas often related to endorheic areas. Aridisols occupy a total of 28.4 km² in Spain, representing more than 5.6 % of the national territory (Table 2.4) and thus constituting the fourth soil order of

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

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

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

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

2.3.3.1 Argids

Argids are Aridisols that contain an Argillic horizon with a relative clay accumulation derived from the upper horizon.

They evidence clay illuviation (slikensides) and their thickness ranges between 7.5 and 15 cm, depending on the profile's case.

Haplargids

Haplargids are modal Argids (that is, they do not have abrupt boundaries, hardpans or petrocalcic, nitric, very thick Argillic, gypsic or calcic horizons); Haplargids cover a total

area of 3,643 km² and have only been mapped as associations or inclusions.

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

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

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

Paleargids

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

Paleargids occupy an area of only 46.4 km² in Spain. They have been identified in very localized points such as east of Algar (Cádiz) and also in the Canary Islands, associated with Haplargids in the plains and hills of lower elevation of the Betancuria Massif (Fuerteventura). However, Paleargids have been identified as the main soil type south of the Mar Menor Lagoon (Murcia).

2.3.3.2 Calcids

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

Haplocalcids

Haplocalcids have a calcic horizon (accumulation of 15 % carbonates or higher in a horizon 15 cm or thicker, and 5 %

or greater than the overlain horizon) and totally lack a petrocalcic horizon. They are the most prominent group among Aridisols; they occupy a total area of 16,194 km² and have been mapped as main soil, associations, and inclusions.

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

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

Petrocalcids

Petrocalcids are Aridisols characterized by a calcic horizon that has been massively cemented, generating a petrocalcic horizon (see Petrocalcic Calcixerept); they cover a total area of 1,224 km² and have been mapped as main soil, associations, and inclusions. Petrocalcids are located, inter alia, on the terraces and glaciis associated with the Middle Ebro River and its tributaries (from Zaragoza to Lleida, throughout Huesca) in northeast Spain (Badía et al. 2008, 2009). In southeast Spain they can be found in Murcia (Campo de Cartagena, Totana, Fuente Alamo, Yecla and Pinoso), Granada (Hoya de Baza), and Almería (Campos de Níjar and Dalias).

In the Canary Islands, Petrocalcids have been found on Miocene materials in Ajarches and Famara (Lanzarote); in the plains and hills located at lower elevations of the Island of Fuerteventura; and in the southern part of Tenerife,

between Los Cristianos and Punta Abona. As already mentioned, Petrocalcids and Haplocalcids can be found along the coast of La Gomera and La Palma.

2.3.3.3 Cambids

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

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

2.3.3.4 Gypsid: Calcigypsid and Haplogypsid

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

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

2.3.3.5 Salids

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

Haplosalids

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

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

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

Aridisol Technology

Using Aridisols for agriculture is limited by the lack of water. In sustainable irrigated agriculture, Aridisols management involves the monitoring and reduction of the profile's salinity, which involves the use of a leaching fraction; this is associated with drainage systems to remove the saline water. Some Aridisols, such as Gypsid, provoke solifluxion and subsidence problems caused by gypsum solubility as well as concrete corrosion. Other Aridisols have a shallow effective soil depth, caused, for example, by the presence of a petrocalcic (Calcids) horizon. When there is a layer of low permeability and contrasting texture (abrupt boundary), as in the case of Argids,

agricultural management problems are related to soil fertility and water infiltration. Regarding chemical components, salts more soluble than gypsums, as for instance NaCl (salids)—can cause several severe crop problems (plant osmotic and specific ion imbalance effects), or on the soil (loss of structural stability by sodicity) (Badía et al., 2011). Also problems arising from the abundance of active limestone such as immobilization of phosphorus and iron chlorosis (affecting sensitive crops such as stone fruits, grapes, etc.), and disadvantages derived from sulfate ions on plant qualities and product processing of specific crops (e.g., vineyards). Overcoming these soil problems and providing irrigation, high temperatures guarantee good agricultural production in Aridisols.

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

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

Entisols are, together with Inceptisols, the most extensive soil class found in Spain. They occupy nearly 40 % of the national surface area (200.4 km²) and are distributed throughout all types of climates and geographical situations (Fig. 2.6).

With regard to Entisols, the following groups have been mapped: Epiaquepts; Fluvaquepts, Hydraquepts, Psammaquepts, and Sulfaquepts; Torrifluvents, Udifuvents, Ustifuvents, and Xerofluvents; Cryorthents, Torriorthents, Udorthents, Ustorthents, and Xerorthents; and finally Quartzipsamments, Ustipsamments, and Xeropsamments (for details, see Table 2.5).

Although the fragmentation and dispersion of Arents* cannot always be mapped, some are of great interest to agriculture or forestry, and, above all, have resulted in great socioeconomic importance. To this suborder of soils belong those particularly modified by human activities: inter alia, terraces for forestry use, agricultural use (e.g., Ribeira Sacra, Galicia), or recovered spaces in opencast mining (Badía et al. 2007) and landfills where urban and industrial



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



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

materials are disposed. A special mention should be made of the *sorribas*, an artificial preparation of soil in particular areas, such as in the Canary Islands for the transportation of materials from other nearby areas, also evident in the changes typical of La Geria and the Island of Lanzarote.

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



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



Photo 2.9 Entisol (Xerofluvent) in Oión (Álava)

2.3.4.1 Aqueunts

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



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

hydrogen sulphide, or have a gray-green color caused by reduction.

Epiaqueunts

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

Epiaqueunts are the most prevalent group among the Aqueunts suborder and have been mapped in an area of 1,503 km². They have been identified in geographically dispersed areas nonetheless, with highly defined geomorphological conditions and an impeded drainage caused by:

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

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

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

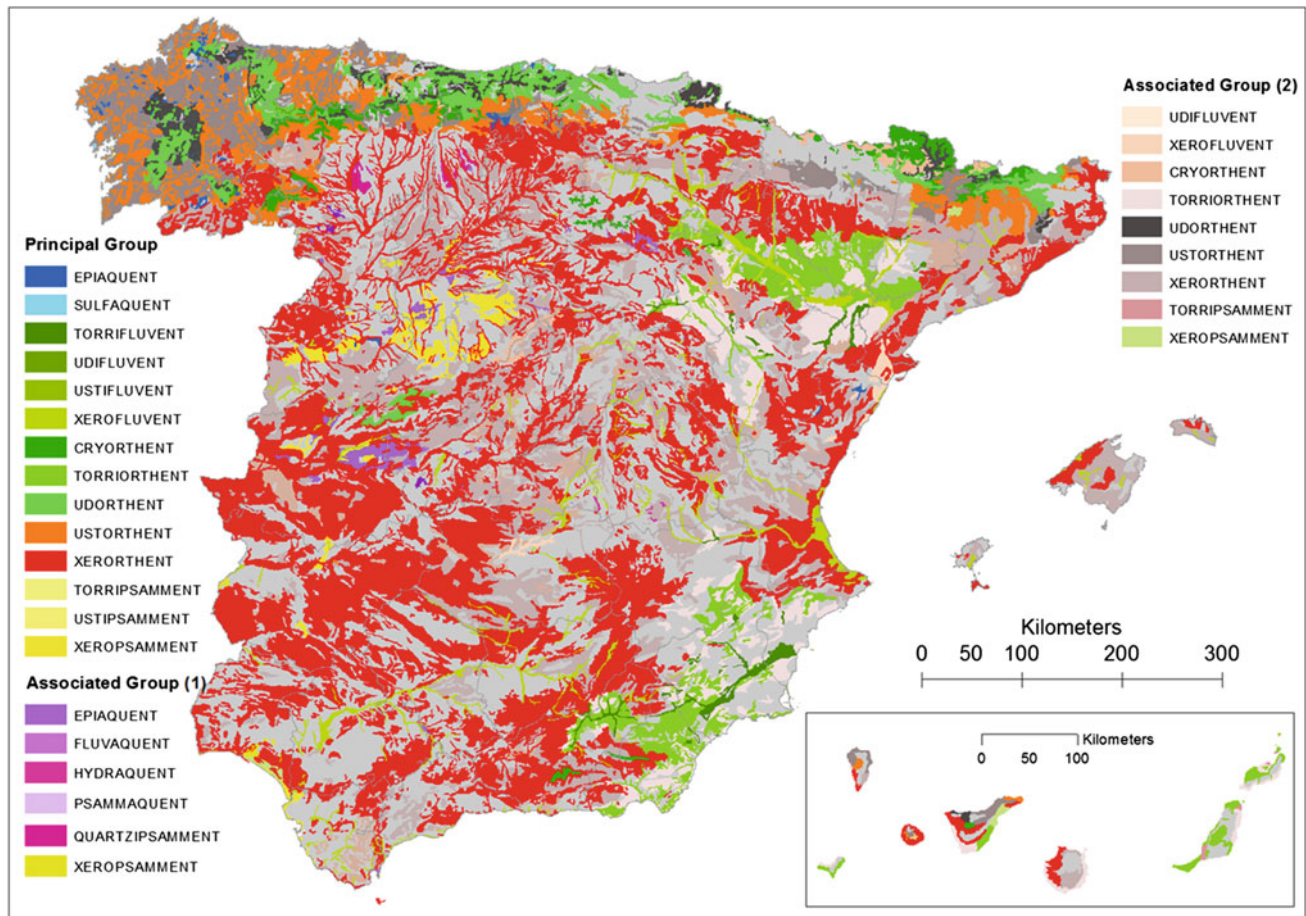


Fig. 2.6 Distribution of Entisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

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

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

There are also Epiaquents in deltas, estuaries and tidal zones of influence together with Sulfaquents, Hydraquents, Fluvaquents and even Haplosalids. These soil mixtures can

be found both in northern Spain (Galicia, Asturias, Catalonia, Cantabria) as well as in the south (Huelva).

Fluvaquents

Fluvaquents occupy a small surface (160 km²) and have only been mapped as associated soils or inclusions. Fluvaquents are found in the Ría de Munguía (Province of Vizcaya), in the river valley of Araguri (Pamplona), and in the depressed and coastal areas of the Province of Tarragona. Epiaquents associated with Fluvaquents appear in the places listed above.

Hydraquents

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

The *n*-value is calculated as:

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

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

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

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

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

Hydraquents occupy a small area of Spain's national territory (19.5 km²) and have only been mapped as associated soils; they are located in marsh and coast areas. Hydraquents have been reported, associated with Salorthids and Sulfaquents, in some areas of tidal influence of the estuaries, such as in the arc formed by the Cabos de Corrubedo, Falcoeiro, and Santa Eugenia (Galicia).

Psammaquents

Psammaquents are sandy Aquent soils that often lack redoximorphic features (iron concentrations and segregations), primarily because the original material—mainly quartz—is very poor in Fe. Psammaquents occupy a small area in Spain (13.1 km²) and have only been mapped as associated soils. Psammaquents appear only at particular points, such as in the littoral spit bars (Perillo, A Coruña), in the Ebro Delta (Tarragona), in Dehesa of El Saler (Valencia), and along barrier beaches and coastal or sandy depressions (Doñana, Province of Huelva).

Sulfaquents

Sulfaquents are Aquent soils that accumulate sulfidic materials between a soil depth of −20 to −50 cm and have an n value

of less than 0.7 or less than 8 % clay, and may have buried histic organic materials. Sulfidic materials (of an organic or mineral origin) contain oxidizable sulfur compounds, have a pH above 3.5, and are permanently saturated with water (predominantly brackish).

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

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

Sulfaquents occupy just a small area in Spain (53.6 km²). They are found in coastal marshes and depressions, having been mapped only as a main soil type in some Galician and Cantabrian territories. Sulfaquents have been described in some of the areas of influence of specific tidal estuaries of Galicia, as in Coruña (Perillo), Betanzos, Ortigueira, south of the estuary of Cedeira, Ferrol, Ría de Viveiro, or in the arc formed by the ends of Corrubedo and Falcoeiro, and Santa

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

2.3.4.2 Fluvents

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

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

Torrifluvents

Torrifluvents are Fluvents that have not been exposed to cold temperatures and have an aridic or torric moisture regime (see Aridisols). Torrifluvents cover a total Spanish surface area of 1,626 km², typical of the alluvium of large rivers and the associated hydrographic network. The Torrifluvents abound in the valley of the Ebro River, southeast of the Iberian Peninsula, and in the Canary Islands. Specifically, Torrifluvents have been identified in northeast Spain, in the central part of the Ebro River Valley and its tributaries (the Martín, Guadalope, Matarraña, Jalón, Cinca, Segre Rivers, etc.), in southeast Spain, i.e., in the Province of Almería (Andarax and Adra Rivers), and in the Provinces of Alicante and Murcia (Segura, Vinalopó, Sangonera, Guadalentín, Almanzora Rivers, etc.).

On the Canary Islands there are Torrifluvents associated with Xerofluvents and Ustifluvents in the valleys of Guimar, Erjos, etc. (Tenerife Island), in San Nicolas and Llanos de

Arinaga (Gran Canaria) and on the Island of Lanzarote, related to Calcids, on the recent glacis of the Miocene massifs.

Udifluvents

Udifluvents are Fluvents distinguished by wet weather, with an udic soil moisture regime (see Udalfs) and typified by warm temperatures. They have been mapped in an area comprising 294 km² of Spain, mostly in siliceous alluvial sediments in udic areas of Galicia, Asturias, Cantabria, the Basque Country, Navarre, and northern Aragon.

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

Ustifluvents

Ustifluvents are Fluvents with an ustic moisture regime, exposed to rain during the warm season and to warm temperatures. They cover a national Spanish area of 441.4 km² and are located in some areas of Galicia, Asturias, Cantabria, the Basque Country, Navarra, Northern Aragón, and Catalonia.

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

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

Xerofluvents

Xerofluvents are Fluvents with a xeric moisture regime (see Xeralfs) subject to rain in the cold season (Mediterranean) and exposed to warm temperatures. They are the group of Fluvents with the highest surface area in Spain, covering a total of 14,172 km², usually located near main rivers.

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

Guadiana, Cigüela, etc.) as well as in those of southern Spain (Guadiana, Guadalquivir, etc.).

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

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

2.3.4.3 Orthents

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

Cryorthents

Cryorthents are Orthents located within a cold climate, whose annual average temperature ranges between 0 and 8 °C and the average summer temperature is below 15 °C to a depth of -50 cm. Cryorthents have been mapped in a total area of 4,784 km², located mainly in high altitude mountain areas across Spain. Specifically, Cryorthents are found in the Central Pyrenees (northern areas of the Provinces of Huesca and Lleida), the Cantabrian Mountains (Picos de Europa,

Sierras de los Ancares y las Omañas, Somiedo y Pajares, Peña Labra), the Massif Galician-Leonese (Cabeza de Manzaneda), the Iberian Range (Sierras of Demanda, Urbión, Cebollera and Cameros), the Betic Range (Sierra Nevada), and on top of the Teide (Tenerife).

Torriorthents

Torriorthents are Orthents characterized by an arid climate (torrid). For agricultural management, it is essential to introduce irrigation and control salinity on specific lithologies. Torriorthents have been mapped in a total area of 20.2 km², mostly in the Middle Ebro Valley from the Rioja Baja, south of Navarra (Bardenas Reales), south of the Provinces of Zaragoza and Huesca (Monegros Desert), Teruel (Desert of Calanda), and around the city of Lleida.

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

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

Udorthents

Udorthents are Orthents with an udic moisture regime (see Udalfs) and are exposed to warm temperatures. They occupy a total area of 9.9 km², found mainly in Galicia, Asturias, the Basque Country, in the Provinces of Avila and Cáceres, in Cantabria (Pesues, Roiz), Navarra (Sierra de Abodí, Isaba), Huesca (Benasque, Aneto), Lleida (Artíés), and the Islands of Tenerife and La Palma.

Ustorthents

Ustorthents are Orthents with an ustic moisture regime (see Ustalfs) and are subject to warm temperatures. They occupy a total surface area of 17,720 km² throughout Spain, with a similar distribution to that of the Udorthents. In addition, it is necessary to highlight their presence in the mountains of Zamora (Segundera, Culebra, Cantadores), Lugo (Sierras de Cadeira in Modoñedo, Lorenzana and in the south and southeast of Becerreá, northeastern Padrairo), or between Cáceres and Salamanca (in the Sierra de Gata and the Rock of France, respectively). They also appear in the westernmost region of the Canary Islands in the highest peaks of the Grand Canary and La Gomera Islands.

Xerorthents

The Xerorthents are Orthents with a xeric moisture regime (see Xeralfs), i.e., with rainfall in the Mediterranean cold season and warm temperatures. The Xerorthent group is the most significant among the Entisols and it occupies more than half of the total proportion of Entisols. Xerorthents have been mapped across a total area of 125.3 km² over most of the Iberian Peninsula and the Balearic Islands, as well as in the areas south of the western Canary Islands.

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

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

2.3.4.4 Psamments

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

precisely because of this sand excess and the consequent alteration difficulty.

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

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

Quartzipsamments

Quartzipsamments are Psamments consisting of over 90 % of resistant minerals (e.g., quartz) in the sand fraction. Quartzipsamments have been mapped as associated soils or inclusions, occupying an area of only 286.3 km², for example in the Cubillas (Province of Granada) and Júcar Zánacara Rivers in the Province of Cuenca.

Torripsamments

Torripsamments are Psamments with an aridic-torric moisture regime (see Aridisols) that are not exposed to cold temperatures. In the case of torripsamments, irrigation becomes more indispensable than for the rest of the Psamments, in view of agricultural use and salinity control. They have been mapped across a total surface of 118.2 km² in the southeast areas of the Iberian Peninsula, e.g., in the Campo de Níjar (Almería) or Manga del Mar Menor (Province of Murcia). Torripsamments are also found in the eastern zones of the Canary Islands: northwest of the Island of Lanzarote and Graciosa, in coastal formations, beaches and dunes, as in Jandia, and dunes of Corralejo, Fuerteventura Island, and the Island of Tenerife north of Medano.

Ustipsamments

Ustipsamments are Psamments with an ustic moisture regime (see Ustalfs). They have been mapped in a total area of 24.3 km² along the ustic coast of Galicia, e.g., Cambados, where they are associated with Psammaquents; moreover, they are also located in the antique Roman gold mining region of las Médulas (Province of León).

Xeropsamments

Xerosamments are Psamments comprising a xeric soil moisture regime (see Xeralfs). They have been mapped across a total area of 3,886 km², mainly in the central and southwestern parts of the Iberian Peninsula. In fact, the most



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

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

2.3.5 Histosols (Photo 2.11)

Histosols comprise organic soils, colloquially known as “peat.” Their establishment requires specific formation factors such as cold weather and water saturation, concave topography, acid parent material, vegetation adapted to the above factors and, finally, time (from the late Pleistocene). About 85.5 km² of Histosols have been mapped, basically in northern Spain (Table 2.6).

In particular, the most representative Histosols are located in Galicia: Sierras de Capelada, Sierra del Xistral, and south

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

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

of the Montes de Buyo, the Ancares, and Courel, Serpe, Suido, Queixa, Grova Barbanza and also in the Massif of Cabeza de Manzaneda, and the Antela Lagoon.

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

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

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

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

Conceptually, Inceptisols consist of poorly developed mineral soils that are characterized by light-colored surface horizons (epipedion ochre) and subsurface horizons, as, for instance, the cambic, (petro) gypsic, (petro) calcic, hardpan, or fragipan. Inceptisols occupy a large number of landforms, from alluvial terraces to mountain areas; they are also present in most climates, especially in the warm Mediterranean regions (Fig. 2.7). All in all, Inceptisols occupy a large area of Spain, along with the Entisols. They occupy nearly 38 % of the national area (190,517 km²) and are distributed throughout all climates and various geographical situations. Most of the Inceptisols have high agricultural potential, although when located in the xeric and ustic moisture regimes, they require irrigation. In mountain areas, their exploitation is limited to forestry or livestock.

The following soil groups have been mapped: Epiaquepts, Dystricrypts and Eutrocrypts; Dystrudepts, Eutrodepts (or associated); Dystrustepts, Haplustepts (or associated), and, finally, Calcixerepts, Dystraxepts and Haploxerepts (Table 2.7).



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



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

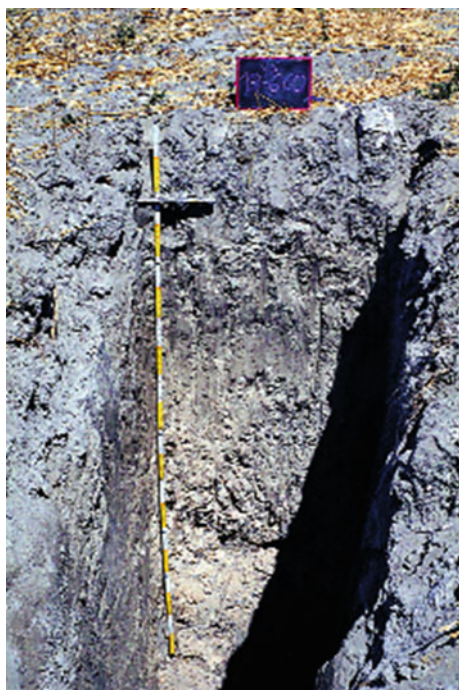


Photo 2.15 Inceptisol (Gypsic Haploxerept) in Villamayor de Santiago (Province of Cuenca)



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

2.3.6.1 Aquepts

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



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



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

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

Epiaquepts

Epiaquepts are found in epi-saturated conditions, characterized by a perched water table. Under these conditions, agricultural use requires the implementation of drainage techniques. In Spain, Epiaquepts cover a total surface area of 806.7 km²; they are located in scattered areas, yet are found under defined geomorphological conditions, in which drainage is impeded by natural or artificial barriers (terraces, moraines, spits, dikes, etc.). Otherwise, they can also be found in places where there is no natural water outlet (endorheic areas, abandoned meanders, wetlands, and lagoon edges), else, water inputs are continuous and the ground has a reduced permeability (marshes, estuaries, deltas, mangroves, etc.).

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

2.3.6.2 Cryepts

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

Cryepts are located in the mountainous areas and at high altitude peaks throughout Spain, in more stable and less eroded zones than Cryorthents. The suborder of the Cryepts is further subgrouped into the Dystrocryepts with a total area of 3,079 km², and the Eutrocryepts are spread over 727.6 km². The Cryepts are found in the Central Pyrenees (Huesca and Lleida), the Iberian Range (Moncayo), Picos de Europa, Manzaneda (Ourense), Sanabria (Zamora), Sierra of Demanda and Urbión (Province of Soria), Somosierra-Navacerrada System (Madrid), Sierra Nevada (Granada), Teide (island of Tenerife), and Garajonay (island of La Gomera).

2.3.6.3 Udepts: Dystrudepts and Eutruudepts

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

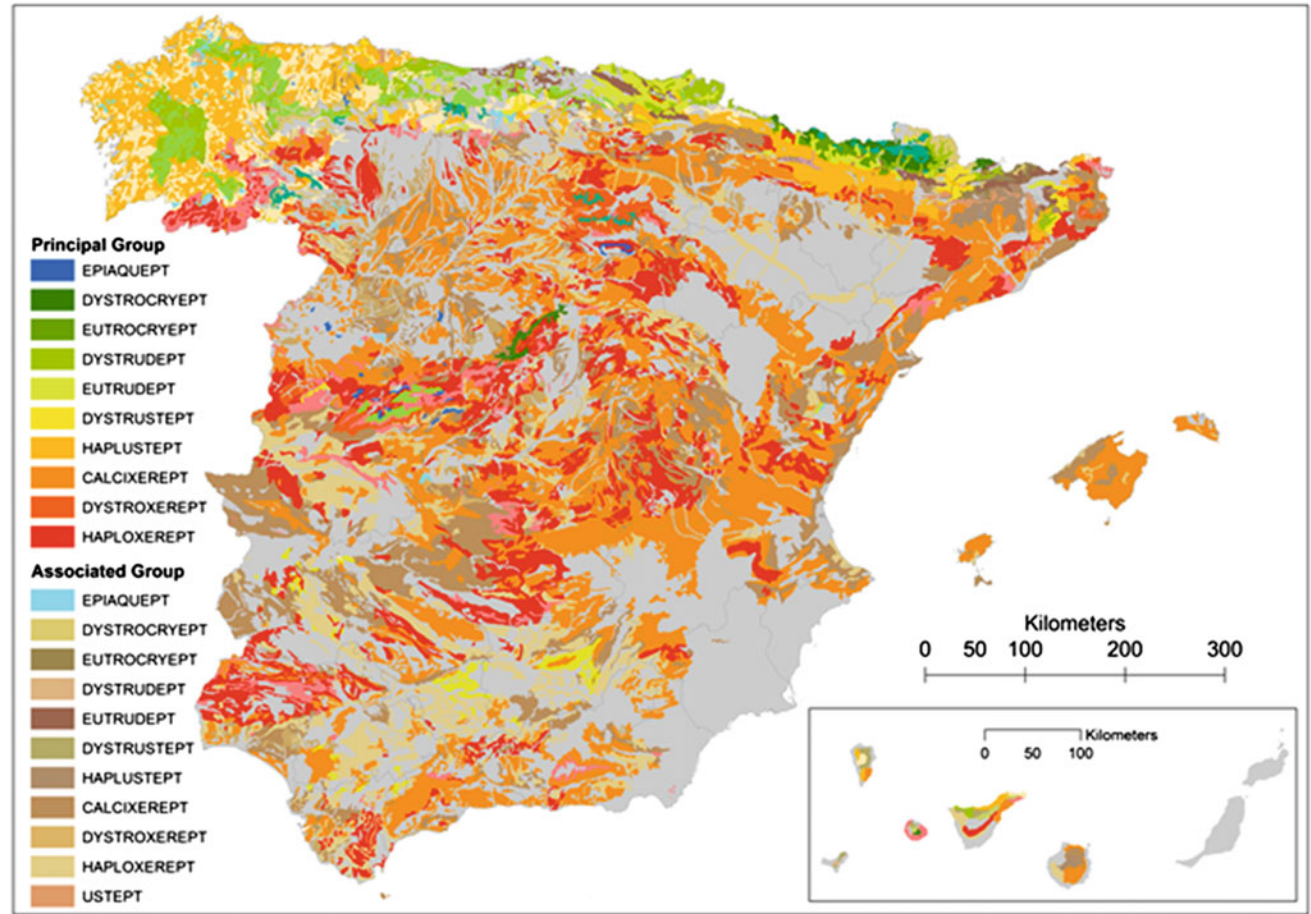


Fig. 2.7 Distribution of Inceptisols (Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

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

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

Udepts are further classified in Dystrudepts and Eutruudepts. Dystrudepts occupy a total surface area of 7,867 km², while Eutruudepts cover 3,177 km².

Given their high moisture availability, Udepts are used for forestry, and if their relief is not marked, also for cultivation. Specifically, Udepts can support intensive

agriculture, although their location may determine the occurrence of erosion and soil truncation. The terracing of Udepts and their subdivision into plots undertaken in these soils with an ultimate prospect to perform intensive agriculture (often smallholders), determines the formation of a very characteristic landscape (such as in the case of certain regions of Galicia). Udepts have been mapped as main, minor and inclusions over wide areas of the wetter zones of the Basque Country, Asturias, Cantabria, Galicia, Navarra, Aragon, and Catalonia.

2.3.6.4 Ustepts: Dystrustepts and Haplustepts

Ustepts are Inceptisols characterized by rain in the warm season (continental characteristics) and with an ustic moisture regime. When located on slopes, Ustepts are normally engaged in forestry or grazing and, more rarely, designated for crops. Specifically, Ustepts can withstand exploitation under a relative performance, yet often they display drought-associated problems. In addition, Ustepts also have active erosion processes that can cause the disappearance of the epipedon (soil truncation), especially if drastic structural changes are made for more intensive agricultural uses. In Spain, two kinds of Ustepts are found: Dystrustepts, covering 8,772 km², and Haplustepts, distributed over 13,974 km² and classified as main soils, secondary and inclusions. They are found in a wide range of areas: Galicia, the Basque Country, north and west of Castile and Leon, north of Catalonia, in the Provinces of Asturias, Cantabria, Navarra and Huesca, between the Provinces of Salamanca and Cáceres, and also in the western part of the Canary Islands.

2.3.6.5 Xerepts

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

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

Calcixerepts

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

one way or another and interact directly with the greenhouse effect.

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

Calcixerepts occupy a total national surface area of 69,691 km², distributed (as main soils, secondary and inclusions) over a nationwide area with the exception of the wettest areas, including high and steep regions.

Dystroxerepts

Dystroxerepts are Xerepts, which have a reduced base saturation. Dystroxerepts cover a total Spanish surface area of 11,775.9 km². Cultivation of these soils requires an input of amendments in order to increase, balance, and activate the cation exchange complex. Dystroxerepts are located throughout the Provinces of Ourense, León and Palencia, Zamora, Toledo, Cáceres, Badajoz, Ciudad Real, Huelva, Barcelona, and in specific areas of the Canary Islands.

Haploxerepts

Haploxerepts have been mapped over a wide area of Spain comprising a total of 70,341 km², distributed as main soils, secondary, and also as inclusions. Prominent among the many places in which they are located, Haploxerepts have been reported in western Grañén (Province of Huesca), in the most stable areas of Sanabria, Aliste, and Sayago (Province of Zamora), on the right riverbank of Valderaduey, on both sides of the Sequillo (North Duero River), also often associated with Xerorthents in the slates of the Dañador Reservoir (Province of Jaén), in Navas del Madroño (Province of Cáceres), in the Sierra de San Pedro (also the Province of Cáceres), west of Fregenal de la Sierra, and northwest of Fuente Cantos (Province of Badajoz), etc.

2.3.7 Mollisols

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



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

Mollisols have been mapped only across 7,490 km², which represents less than 1.5 % of the national surface area, in a very scattered manner and only rarely as main soils (Fig. 2.4). Specifically, the following groups of Mollisols have been observed in Spain: Cryrendolls, Calcixerolls, Haploxerolls, Haplustolls, and Hapludolls (Table 2.8).

2.3.7.1 Rendolls: Cryrendolls

Rendolls are Mollisols that have evolved on highly calcareous materials (>40 %) in cold or wet areas. Of the two groups in which Rendolls are subdivided, only Cryrendolls with a cryic temperature regime appear in Spain. Cryrendolls have been mapped on a total surface area of 714 km² normally associated with Inceptisols or Entisols, or as inclusions in the high altitude limestone massifs of the country. Therefore, Cryrendolls are located in the Pyrenees (West Somport, Huesca), in the Cantabrian Mountains (Picos de Europa Mountains, Cantabria), and also in the Iberian Range (Sierra de la Demanda or Arandio in the Provinces of Burgos, La Rioja, and Soria).

2.3.7.2 Udolls: Hapludolls

Udolls are well-drained Mollisols, comprising an udic moisture regime (see Udalfs). Among the Udolls, only the Hapludolls have been mapped in Spain across a surface area of 972.7 km², specifically in Galicia, the Cantabrian Mountains and the Pyrenees. In general, Hapludolls have been reported on in the northern part of the Province of Huesca (in the wet areas between the Gállego and Cinca Rivers or in the cold areas between Canfranc and Piedrafita

de Jaca). Hapludolls also abound in the Province of Lugo (in the areas of influence of the limestone crags located south and southeast of Becerreá, Doncos, Meira, Mondoñedo, west of Torrelavega, northeast of Padrairo, west of the Sierra San Román, and south of Vilarchao). Hapludolls are also common in the Province of Asturias (between Ribadesella and Nueva), in the Province of Vizcaya (east of Plencia and Kortezubi), in the Province of Guipuzcoa (eastern Zumaraga, Sierra of Aitzgorri, Peña Urdala), or in Navarra (in the Mountains of Aralar). Hapludolls are usually used for forestation activities and occasionally also for crops (e.g., potatoes in the region of Salvatierra, Álava).

2.3.7.3 Ustolls: Haplustolls

Ustolls are Mollisols with rain in the warm season (monsoon). In Spain, only Haplustolls have been mapped, which are preferentially located in Galicia, western Provinces of Zamora and León, the Cantabrian Mountains, and the Pyrenees. Specifically, a total of 1,003 km² of Haplustolls have been mapped, distributed as main, secondary, and soil inclusions developed on base-rich rocks exposed to an ustic soil moisture regime. Haplustolls are usually used for forestation activities and grazing, although occasionally also for crops.

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

2.3.7.4 Xerolls

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

Haploxerolls

Haploxerolls represent more than two thirds of the Mollisol surface in Spain, having been mapped over 4,531 km². There are Haploxerolls in the Provinces of Álava (e.g., Salvatierra), Navarra (Pamplona), Huesca (south of Benabarre), Tarragona (Tortosa), Castellón (Vinaroz), Lleida, Soria, Burgos (Bureba and Belorado), Cuenca, Albacete (Villanueva de Alcardete), Valencia (Llíria), Ciudad Real (Alcaudete-Valdepeñas), Cáceres (Coria, Torrejoncillo and Peraleda), Badajoz (Almendralejo, Santos de Maimona, Fuente del Mestre, between the Entrín and Rivera de los Limonetes Rivers), Huelva (north of Azud de Matavacas), La Rioja (in the region of Tierra de Cameros, between Haro

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

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

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

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

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

Calcixerolls

Calcixerolls occupy a total surface area of 268.6 km² and are found mainly in the Provinces of Barcelona (region of L'Anoia), Castellón (Vinaroz), Lleida, Tarragona (Tortosa), Zaragoza (Fuendetodos, Daroca, Embid, Montes de Zuera), Teruel (Santolea), Huesca (Camporells), Seville (Constantina, Marchena), Segovia, Cáceres, Granada, and Málaga, among others.

2.3.8 Spodosols

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

Throughout Spain, Spodosols occupy only a small area consisting of 645.4 km² (about 0.13 % of the national surface), located in small and widely scattered spots typified by cold and wet environments with acidic lithologies (Fig. 2.4). Only two suborders of Spodosols have so far been mapped in Spain: Humods and Orthods (Table 2.9).

2.3.8.1 Humods: Haplohumods

Only a total surface area of 74 km² of Haplohumods has been mapped across Spain, in all cases as inclusions. In particular, Haplohumods associated with haplumbrepts have been identified in the Montes de Asturias (e.g., in the Sierra de Sobia), Cantabria (north of Roiz), Lugo (north of Puebla and in the Sierra of Navia, Rañadoiro), and also in the Lleida Pyrenees (in the county of Pallars Sobirà associated with Cryods*).

2.3.8.2 Orthods: Haplorthods

About 571.4 km² of Haplorthods have been mapped as main soils, associations or as inclusions, mainly in northern Spain in the autonomous communities of Galicia, Asturias, Cantabria and the Basque Country.

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

2.3.9 Ultisols

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

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

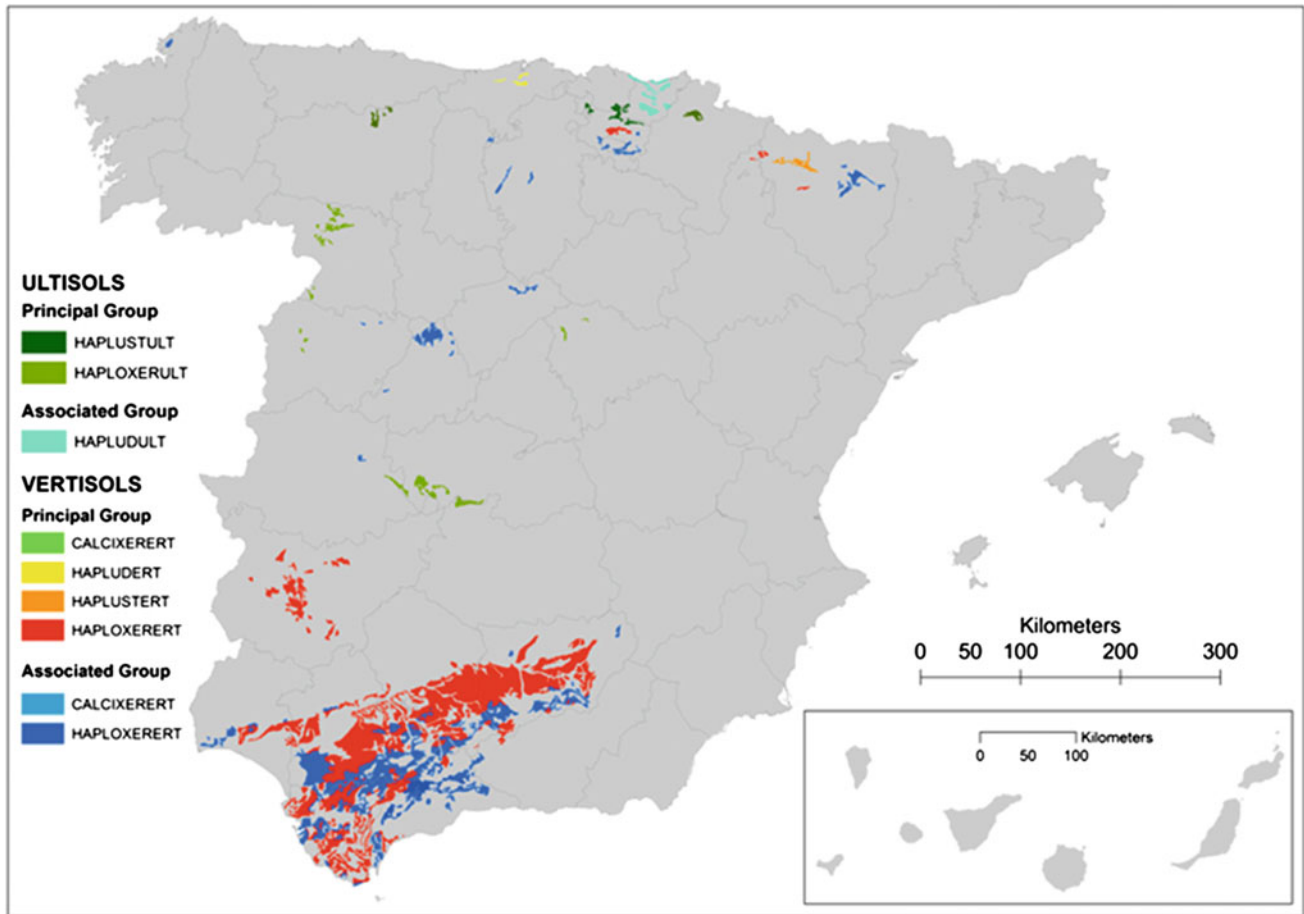


Fig. 2.8 Distribution of Ultisols and Vertisols (excluding inclusions; Gómez-Miguel 2005). Principal groups mean dominant soils. Associate groups are Alfisols that appear assorted with various other soils

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

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

The Ultisols mapped in Spain (Fig. 2.8) constitute only 0.18 % of the total national area (888.6 km²), while only the Haploxerults, Haplustults and Hapludults groups have been mapped across the Spanish territory (Table 2.10).

2.3.9.1 Uduits: Hapludults

The Uduits are freely drained Ultisols found in wet areas and exposed to an udic moisture regime (see Udalfs). In Spain, Hapludults have only been mapped (91.9 km²) as secondary soils and with a very scattered distribution across the national territory.

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

2.3.9.2 Ustults: Haplustults

Ustults are Ultisols exposed to rain in the warm season and encompassing an ustic moisture regime. Only Haplustults have been mapped (194.7 km²) as main soils, minor, or

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

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

**Photo 2.19** Spodosol (Haplorthod) in Roupas-As Pontes (Province of A Coruña)**Photo 2.20** Ultisol (Palexerult) in Paradaseca (Province of León)

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

2.3.9.3 Xerults: Haploxerults

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

Although Palexerults* have been found on more evolved and stable surfaces (such as old *rañas*), they have not been mapped, owing to their scarcity. Therefore, the only Xerults mapped in Spain are Haploxerults (602 km²); they occupy the most stable xeric areas of the Province of León, west of the Provinces of Zamora and Salamanca, north of the Provinces of Guadalajara and Cáceres, and in parts of the Montes de Toledo.

2.3.10 Vertisols

Vertisols are characterized by vertic properties, typified by intense cracking, shrinkage and retraction processes (Photos

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

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

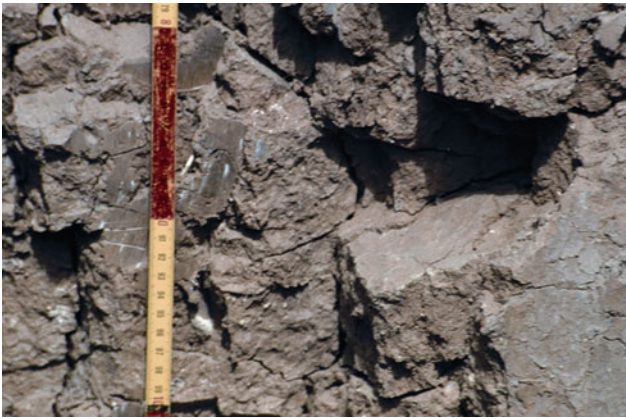


Photo 2.21 Wedge-shaped soil aggregates and slickensides in a haploxerert in Marchena (Province of Sevilla)



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

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

In Spain, Vertisols occupy a total surface area of 11,990 km² and are classified in specific groups: Hapluderts, Calciusterts and Haplusterts, and Calcixererts and Haploxererts, all of which occupy less than 2.4 % of the nation's total area and distributed over all types of climates and situations (Table 2.11).

2.3.10.1 Uderts: Hapluderts

Uderts are Vertisols seen in areas with an udic moisture regime (see Udalfs). In Spain, only Hapluderts have been mapped (37.3 km²); these soils comprise an electrical conductivity higher than 4.0 dS m⁻¹ or a pH above 5.0. Hapluderts are normally used in forestry or grazing and, to a lesser extent, in crops. Hapluderts have been mapped as main soils in Cantabria; thus, they have been described in association with Entisols and Inceptisols in locations south of the villages of Liaño, Solares, and Cartes (Province of Santander). In addition, Hapluderts are also found in the Province of Alava, in the upper Teno volcano (Island of Tenerife), north of Fagayesto-Santa Brigida (Gran Canaria Island), as well as in the northern part of the Island of La Palma (between Barlovento and Los Franceses).

2.3.10.2 Usterts: Calciusterts and Haplusterts

Usterts are Vertisols exposed to rainfall in the warm season, i.e., ustic moisture regime (see Ustalfs). In Spain, they are used for forestry or grazing, and only under very specific conditions for crops. There are only two groups of Usterts: Calciusterts (with a calcic horizon) and Haplusterts (modal one). The Haplusterts have been mapped only as a main soil type in the northwest of the Province of Huesca, over a total surface area of 87.6 km². In addition, Haplusterts have been occasionally described on the Islands of La Gomera, Tenerife, and El Hierro. With regard to Calciusterts, a total of 17.5 km² have been mapped, yet only as inclusions. Specifically, Calciusterts have been identified with Haplustalfs on the Island of La Palma (between Barlovento and Los Catalanes).

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

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

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

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

2.3.10.3 Xerert: Calcixererts and Haploxererts

Xererts are Vertisols exposed to rain in the cold season (Mediterranean); they constitute the suborder that occupies the largest surface area of Vertisols. Xerert management is conditioned by drought; the irrigation of crops cultivated during the summer can seriously affect soil mechanisms and

vertic properties, inclusive trigger all the unwanted effects described for the order.

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

Haploxererts have been mapped as main soils, secondary, or inclusions north of the Iberian Peninsula (Provinces of Burgos and Álava, Navarra and Huesca), in central Spain (Provinces of Ávila, Segovia, Guadalajara and Toledo, Cáceres), in southern Spain, both in the Gadiana River Basin (Provinces of Badajoz and Huelva) and in the Guadalquivir River Basin (Andalusia). Haploxererts occupy a total surface of about 7,317 km².

On the other hand, a total national surface area covering 4,531 km² of calcixererts has been mapped. They can be found, associated with Haploxerert, in the Andalusian countryside (where they are called “black soils” or “*tierra de bujeo*”), i.e., south of the Guadalquivir River, mainly in the Provinces of Seville, Jaén, Córdoba, and Cádiz and, to a lesser extent, in the Provinces of Huelva, Málaga, Granada and Almería. They have a multipurpose dedicated crop (cereals, cotton, sugar beet, grass, sunflower, etc.).

Appendix

See Tables 2.12 and 2.13.

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

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

(continued)

Table 2.12 (continued)

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

(continued)

Table 2.12 (continued)

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

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

Order	Suborder	Groups (2003)	FAO units (1998)
Alfisol	Aqualf	Epiaqualf	Gleyc Luvisol Gleysol
	Cryalf	Haplocryalf	Gelisol
	Udalf	Hapludalf	Luvisol
	Ustalf	Haplustalf	
		Paleustalf	Planosol Nitisol Luvisol
		Rhodustalf	Cromic or Rhodic Luvisol
	Xeralf	Haploxeralf	Luvisol
		Palexeralf	Planosol Nitisol Luvisol
		Rhodoxeralf	Cromic or Rhodic Luvisol
Andisol	Torrant	Vitritorant	Andosol
	Ustant	Haplustant	
	Vitrand	Udivitrand	
		Ustivitrand	
	Xerant	Haploxerant	
Aridisol	Argid	Haplargid	Luvisol
		Paleargid	Planosol Nitisol Luvisol
	Calcid	Haplocalcid	Calcisol
		Petrocalcid	Petric Calcisol
	Cambid	Haplocambid	Cambisol
	Gypsid	Calcigypsid	Gypsisol
		Haplogypsid	
	Salid	Haplosalid	Solonchak
Entisol	Aquent	Epiaquent	Gleysol Gleyic Leptosol
		Fluvaquent	Gleysol Fluvisol
		Hydraquent	Gleysol Gleyic Leptosol
		Psammaquent	Arenic Gleysol
		Sulfaquent	Thionic Gleysol
	Fluvent	Torrifluent	Fluvisol
		Udifluent	
		Ustifluent	
		Xerofluent	
	Orthent	Cryorthent	Gelic Leptosol

(continued)

Table 2.13 (continued)

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

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