
GENESIS AND GEOGRAPHY
OF SOILS

Soil Genesis and Suitability for Viticulture in Zones under Mediterranean Environment

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Abstract—The aim of this study was to analyze and classify the soils of the municipality of Alcubillas (La Mancha, Central Spain) and establish their suitability for vine cultivation. Alcubillas is a traditional location dedicated to vineyards and the production of wine. The pedological fingerprint of this location is the iconic red Mediterranean soil, and a plausible process for the soil formation is discussed. Considering the nature of the soils and the extent and types of natural limitations, as defined by the eight classes of land capability established by the US Soil Conservation Service, the majority of the soils in Alcubillas are suitable for vineyards (i.e., classes 1, 2 and 3) while moderately suitable sites only occupy a small area. The marginally suitable land class is located around a single hill, which occupies only a few hectares of terrain. Given that soil is a major factor in terroir expression, the findings reported here highlight the importance of soil suitability in determining vine performance in vine-growing zones with a Mediterranean environment.

Keywords: vineyard soils, land capability, red Mediterranean soils, terroir, La Mancha

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INTRODUCTION

Due to its economic and social interest, viticulture is expanding in Europe, and the future of wine grape-growing regions in Europe has been analyzed by Tóth et al. [28]. Land use type, which could determine the total level of production from the land, may be defined by the needs of the producer and the environmental conditions (i.e., soil characteristics), with socioeconomic status and political and cultural factors also taken into account [7].

The existence of vineyard areas is generally linked to specific climatic conditions [18, 19]. For example, in the Mediterranean region, the existence of viticulture zones is very common [1] and soil characteristics are among the factors that influence the user's preferences.

In Spain, there are areas with a special designated status named 'Protected Denomination of Origin' (P.D.O.). Other areas are available for viticulture, but these are not formally recognized, i.e., they are undesignated. In fact, when Spanish people (and those from other parts of the world) consider quality wine, many tend to think about those from the Protected Denomination of Origin areas such as Rioja, Ribera del Duero, Jerez, etc. However, designations of origin such as Valdepeñas and La Mancha are not recognized for quality wine but are simply known as major providers for many other quality areas.

The question arises as to why some areas are not considered alongside the best in the Mediterranean region. Are the soils unsuitable for vine cultivation or are they of poor quality? As one would expect, soil features have an impact on vine health, growth and productivity [6, 20, 29]. One location within the La Mancha province (Central Spain), namely Alcubillas, can be considered as a unique place for vineyards and wine production because it is blessed with an excellent climate and remarkable soil that is ideal for growing grapes and the production of supreme wines.

Defining the suitability of a region for viticulture through spatial zoning is a common approach [15, 20] but recently, this suitability has been evaluated based on mesoscale effects [5, 14]. Data requirements for the determination of the suitability of vineyards cover a range of landscape characteristics, such as landform position, slope, drainage and rocky outcrops. Also, it is necessary to address the characterization of certain soil features such as texture, pH, structure, soil structure, salinity, waterlogging and shallow soils. Finally, it is necessary to consider the sustainability of the use and management practices to mitigate risk or degradation. Climatic features, such as average annual rainfall, temperature and sunny days, must also be considered.

The Soil Conservation Service of the US Department of Agriculture (USDA) developed the first land

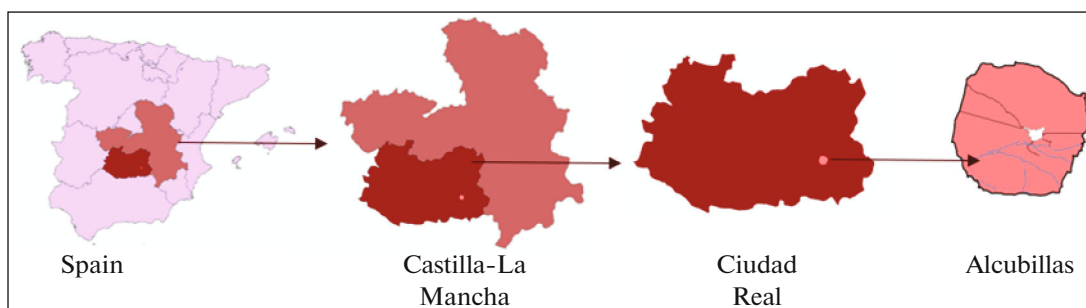


Fig. 1. Location of the study area.

capability rating system, and this led to the publication of the handbook *Land Capability Classification* [21]. This classification focuses on the potential of the land for wide-ranging agricultural use, either with or without specified soil conservation practices. There are eight classes of land capability based on the severity of various limitations and assuming a moderate level of management. Land evaluation processes were further developed by the United Nations Food and Agriculture Organization (FAO), and this work led to the publication of the *Framework for Land Evaluation* [10].

Knowledge of land capability for vineyards in La Mancha (Central Spain) ensures adequate productivity and defines the value of the soil based on the environmental context in which it is found. It is important to establish a successful pathway for areas included in the so-called ‘España Vacía’ (Empty Spain) to promote the potential quality of their wines since the soils meet a series of favorable requirements for the cultivation of the vine. With this aim in mind, and despite the fact that a prescriptive ‘ideal’ set of soil properties does not exist, the main objective of the work described here was to characterize the soil resource and its genesis, as well as to evaluate its suitability for vineyards in a case study on a small and unique local Mediterranean area.

MATERIAL AND METHODS

Alcubillas site. The investigation was carried out on the soils of the municipality of Alcubillas (La Mancha, Central Spain), which is located at latitude 38.7579077 and longitude -3.1412646 . With an elevation of 804 m, Alcubillas occupies a territory that is flat (or nearly flat), with a small undulating hilly area (Fig. 1). The study area has a typical Mediterranean climate that is characterized by hot and dry summers, mild winters and low precipitation, with an average annual rainfall of around 480 mm and an average temperature of 13.5°C . Extended periods without precipitation are common (i.e., 4–5 months).

The area of Alcubillas has traditionally been associated with agricultural activities (mainly vineyards, olives and cereals) and this agricultural use has increased

markedly over the last two or three decades due to the expansion of vineyards. The grape varieties grown in the area are mainly Airen followed by Tempranillo (also called Cencibel).

A crucial requirement for the cultivation of high-quality grapes is sunlight, and this is abundant in Alcubillas. In fact, it is estimated that there is a minimum of 1400 hours of sunshine per year in Alcubillas and the average range is 2600–2800 hours per year, http://www.aemet.es/es/idi/clima/productos_climaticos (accessed 8th January 2020).

Soil identification, sampling and analytical methods.

Several locations were selected, and for each one, a specific geomorphological description, soil profile description and soil sampling were obtained [11, 12, 25]. Eleven profiles were dug out at varying geomorphological positions, and these were studied. Samples were collected from each location, and the common physico-chemical and chemical characteristics were analyzed following the criteria of Soil Survey Staff [26]. Based on the morphological and analytical data, soils were classified by Soil Taxonomy [26] and by FAO-UNESCO-ISSS [13]. The land capability was also assigned for vineyards based on a modification of the Land Capability Class [10] bearing in mind the ecological stability of the area.

RESULTS AND DISCUSSION

The majority of the soils of Alcubillas are red Mediterranean soils, but there are also other types present (Table 1). The soils are characterized by a moderate to deep soil profile that has horizons with clay illuviation (Bt horizon). Another important characteristic is the prominent dissolution and leaching of carbonates, with accumulation at depth (Ck or Ckm horizons) and the development of a characteristic red color matrix (rubefaction). The slope varied from 0–1% (i.e., nearly flat) to 2–6% (gently sloping); only one area with a slope greater than 15% was present, and this corresponded to the palaeozoic sandstone relief (Table 1). The depths of different profiles varied widely, i.e., from >90 cm (deep, being the most common) to around 50 cm (very shallow).

Table 1. General and pedological characteristics of the investigated soils. Drainage class according to ref. [11]. Soil Type, according to Soil Survey Staff [26] and FAO-UNESCO-ISSS [13]

PROFILE		1	2	3	4	5	6
Location (Coordinates)	GPS	38°45'40.0" N–03°08'28.0" W	38°46'30.7" N–03°8'30.1" W	38°45'47.8" N–03°07'27.0" W	38°45'16.9" N–03°09'37.8" W	38°45'05.6" N–03°08'55.0" W	38°44'23.9" N–03°08'29.4" W
	UTM (30s)	0487818x – 4290255y	0487689x – 4291840y	0489226x – 4290512y	0486047x – 4289589y	0487092x – 4289216y	0487710x – 4287936y
Parent Material		Marl/limestone sediments	Marl/limestone sediments	Marl/limestone sediments	Marl/limestone sediments	Red alluvial sediments	Red alluvial sediments
Topography		Karstic flat structural surface	Karstic flat structural surface	Karstic flat structural surface	Karstic flat structural surface	Alluvial surface	Alluvial surface
Slope		Flat or almost flat	Flat or almost flat	Flat or almost flat	Flat or almost flat	Undulating	Gently sloping
Drainage		Well drained	Well drained	Well drained	Well drained	Moderately well drained	Moderately well drained
Stoniness		Fairly stony	No stones or very few stones	No stones or very few stones	No stones or very few stones	No stones or very few stones	No stones or very few stones
Morphology		Ap-Bt-Ck	Ap-Bt-Ckm	Ap-Bt-Ckg	Ap-Bt-Ckm	Ap-Bw-C	Ap-Bw-C
Soil Type	FAO	Calcic Luvisol (Rhodic, Novic)	Calcic Luvisol (Rhodic, Novic)	Calcic Luvisol (Rhodic, Novic)	Luvic Calcisol (Chromic, Novic)	Haplic Cambisol (Rhodic, Novic)	Haplic Cambisol (Rhodic, Novic)
	USDA	Calcic Rhodoxeralf.	Calcic Rhodoxeralf.	Calcic Rhodoxeralf.	Petrocalcic Rhodoxeralf.	Typic Haploxerept	Typic Haploxerept
Vineyard soil class (VSC)		2	1	2	2	3	2
Grape variety		Airen	Airen	Airen	Airen	Tempranillo	Tempranillo
PROFILE		7	8	9	10	11	
Location (Coordinates)	GPS	38°44'21.5" N–03°08'43.0" W	38°44'38.9" N–03°10'56.4" W	38°43'24.4" N–03°0'37.5" W	38°44'39.0" N–03°07'11.2" W	38°45'44.8" N–03°06'25.3" W	
	UTM (30s)	0487374x – 4287857y	0484156x – 4288403y	0488954x – 4286098y	0489591x – 4288394y	0490701x – 4290416y	
Parent Material		Marls	Sandstones/Schists	Limestones	Clay sediments	Marl/limestone sediments	
Topography		Undulating	Undulating	Karstic flat structural surface	Diffuse thrown	Karstic flat structural surface	
Slope		Gently sloping	Flat or almost flat	Flat or almost flat	Gently sloping	Flat or almost flat	
Drainage		Well drained	Moderately well drained	Well drained	Moderately well drained	Moderately well drained	
Stoniness		No stones or very few stones	Stony	No stones or very few stones	No stones or very few stones	No stones or very few stones	
Morphology		Ap-Bw-C	Ap-Ckm	Ap-Ckm	Ap-Bt-C	Ap-Bt-Ck	
Soil Type	FAO	Haplic Cambisol (Chromic, Novic)	Leptic Calcisol (Rhodic, Novic)	Petric Calcisol (Chromic, Novic)	Calcic Luvisol (Rhodic, Novic)	Calcic Luvisol (Rhodic, Novic)	
	USDA	Typic Haploxerept	Lithic Calcixerept	Petrocalcic Cacixerept	Calcic Rhodoxeralf.	Calcic Rhodoxeralf.	
Vineyard soil class (VSC)		3	4	3	2	1	
Grape variety		Tempranillo	Tempranillo	Airen	Airen	Cencibel	

Table 2. Main physico-chemical and chemical properties of selected soil profiles. (– not determined)

Parameter	Profile Luvisol (Profile 2)			Profile Cambisol (Profile 6)			Profile Calcisol (Profile 9)		
	A _p	B _t	C _{km}	A _p	B _w	C	A _p	C _{km}	
Depth, cm	0–25	25–67	>67	0–21	21–62	>62	0–21	>21	
Coarse fragments, %	27.6	29.2	43.4	53.0	52.2	50.8	29.7	–	
Sand, %	49.4	26.1	52.8	36.8	40.2	56.8	43.5	–	
Silt, %	33.4	44.7	36.0	37.3	35.4	24.3	41.0	–	
Clay, %	17.2	29.2	11.2	25.9	24.3	18.5	15.5	–	
Texture	Loam	Loam–Clay	Loam	Loam	Loam	Loam	Loam	–	
Organic matter, %	2.0	1.5	–	1.0	0.8	–	0.7	–	
Organic carbon, %	0.9	0.7	–	0.5	0.3	–	0.5	–	
Total nitrogen, %	0.07	0.05	–	0.04	0.02	–	0.04	–	
C/N ratio	13.1	12.9	–	12.0	11.8	–	12.1	–	
pH (water 1 : 2.5)	8.2	8.5	8.5	8.4	8.6	8.5	8.7	8.6	
Electrical conductivity (dS/m)	0.29	0.15	0.16	0.19	0.14	0.16	0.22	0.11	
Contents CaCO ₃ , %	19.2	17.8	24.5	34.0	24.6	25.3	38.4	48.7	
Active limestone, %	10.5	10.1	16.3	8.8	8.3	11.8	16.6	16.7	
Cation Exchange Complex (cmol ⁺ /kg)	Ca ²⁺	15.6	17.7	–	14.4	0.4	–	17.9	–
	Mg ²⁺	0.5	0.5	–	16.2	0.5	–	0.5	–
	K ⁺	0.2	0.1	–	0.3	0.2	–	0.1	–
S (Sum of cations)	16.4	18.4	–	15.3	17.0	–	18.6	–	
Base saturation, %	100	100	–	100	100	–	100	–	

The results of the soil characterization revealed the features outlined below (Table 2). The soil pH was moderately basic, and the calcium carbonate content varied between 19.2 and 48.7%. In the top level of the soil, the C and N contents exceeded those at the bottom. The colloidal complex was almost completely saturated by bivalent cations, particularly calcium. The texture of the surface (A_p) and subsurface (B_t or B_w) horizons varied from loam to clay loam, clay sand loam, sandy loam and silty loam (Fig. 3).

Pedons were classified as Calcic Rhodoxeralfs, Petrocalcic Rhodoxeralf, Typic Haploxerept and Lithic Calcixerept [26] (Soil Survey Staff), while according to ref. [13] (FAO-UNESCO-ISSS) these were classified as Calcic Luvisol, Luvic Calcisol, Haplic Cambisol, Petric Calcisol and Leptic Calcisol (Table 1).

Most of the profiles represent good examples of red soils, which are widespread throughout the entire geography of La Mancha. The formation of this type of soil has been observed from varied lithologies such as limestones, slates, shales, basalts and marls, amongst others. The geomorphological positions are generally stable surfaces such as glacis and terraces, floodplains and skirts of the surroundings isolated hills (supported by more resistant rocks such as quartzite sandstones), amongst others. In this study,

the soils appear mainly on limestones and marls or sediments from these rocks. The soils frequently have a stony character due to the surface setting of fragments of petrocalcic horizons after their breakage by anthropic action, although fragments belonging to this rock also appear in the surroundings of the quartzite island.

A small proportion of the red soils of Alcubillas are linked to the crystalline stratum, which is formed mainly by materials of the Palaeozoic era (quartzites and slates) in a hilly topography. These soils are cartographically accompanied by some lithic soils near the ridge of the hill, which coincides with areas of more significant erosion and the absence of forest vegetation. On the slopes, materials are generated from the cracking and denudation of these materials, thus giving rise to more or less colluvial surfaces linked to the starting materials, generally with abundant stoniness.

The characteristic feature of soils developed over limestone and other calcareous materials is the presence of a significant amount of CaCO₃ (Table 2). The soil genesis of red clayey soils developed on limestones (and other calcareous materials) has been widely studied and discussed because these soils differ from those formed on other parent rocks [2, 4, 9]. They usually appear in the form of thick, red and clayed soils known as Terra Rossa or red Mediterranean soils. One of the

most spectacular occurrences in these soils is the presence of argillic and calcic or petrocalcic horizons, which can co-occur.

The most widely known pedological fingerprint of Mediterranean climatic conditions is the so-called red Mediterranean soils, which in terms of Soil Survey Staff [26] present a xeric moisture regime characterized by an extended dry period in the summer, followed by rainfall that occurs after the winter solstice; these solutions also present a thermic temperature regime (with a mean annual soil temperature between 15 and 22°C) or occasionally mesic (8–15°C).

The proposal of a satisfactory process for the formation of the soils in Alcubillas requires consideration of the dominant landforms in this location, which are flat or nearly flat. Over prolonged periods these landforms allowed pedogenic processes that are typical of the Mediterranean area and led to very evolved soils; it is known that clay movement has not been reported in the soils of the youngest landscapes because the formation of argillic horizons is a time-consuming process.

In the Alcubillas landscapes, there are hard substrata in the inselberg and these consist of quartzite sandstone. In other areas, it is not common to find hard substrata of this rock or limestone. In contrast, it is common to see sediments that start from chalky limestone or marl, with coarse fragments that reflect a single landscape on these eroded rocks. This parent material (calcareous sediments) are affected by chemical weathering before the soil material is formed. As a consequence, these sedimentary materials (as for the starting material of the soils) appear with variable carbonate contents. In the Alcubillas area, as in other regions on limestones, a clear-cut differentiation between the red decalcified soil and the white parent material is not observed.

The main period for soil formation and weathering, of these red Mediterranean soils, is during the rainy winter when evapotranspiration is minimal. Under these conditions, the effective dissolution and leaching of calcium carbonate occur and, at this point, the migration of clay can take place. Also, during the hot summer period, soil desiccation occurs, and this causes the development of red dehydrated oxidized iron compounds (mainly hematite) within the profile. In this way, the most widespread horizon generation processes are decarbonisation, argilluviation and rubefaction.

The first step in the pedogenetic evolution of these soils is decarbonisation, i.e., the loss by the washing of the abundant CaCO_3 of the parent material. This process involves the dissolution and leaching of CaCO_3 from the solum, the intensity of which is affected by (1) the dissolution speed of the carbonate fraction, (2) the amount of (rain)water that infiltrates the soil, and (3) the initial CaCO_3 content of the soil and the substratum. Given the limited rainfall in the area, CaCO_3 does not generally disappear from the profile,

and it, therefore, accumulates at depth, thus originating calcic or petrocalcic horizons. The accumulations of carbonates appear as concretions, nodules and pseudo mycelia.

The processes involved in the formation of argillic horizons in this type of area are called argilluviation. It is known that clay migration generally results in the formation of the argillic horizons. Clay migration can be observed in calcareous material [8, 22, 30, 33, 27, 31], and this is attributed to the fact that the soil is decalcified. Argilluviation is a common process in the soils of Alcubillas, and it involves the dispersion of clays, deep mobilization via suspension of the clays in the wash water and their subsequent deposition. Dispersion occurs after decarbonisation and partial desaturation. Flocculation will occur when the wash solution reaches a horizon in which flocculating cations dominate the exchange complex, higher saline concentrations, or the wash water disappears when it enters sub-saturation conditions. When the rains start after summer, calcium carbonate can be leached, and the pH of the surface can become high.

As a consequence, the surface charge increases and the possibility of clay deflocculation appears, thus opening the way for clay migration. The clay particles must be dispersed in this way, and at greater depth, the calcium carbonate exerts flocculating power, and the clays become flocculated again. Wetting of a dry soil leads to the dispersion of clay. Once dispersed, the clay moves with the percolating water and stops where the percolating water stops. Wetting and drying processes favor the dispersion of clay and, in dry periods, cracks form and percolation of gravitational water takes place through them. Water moves through material that has pores of capillarity size. Mohr et al. [24] explained the mechanism of clay migration in calcareous materials. They emphasized the role of the end of the summer (dry period) when there are deep cracks in the soil because this is a favorable condition for water movement. Consequently, a common phenomenon in the described soils is that they show a clay 'skin' of illuviation on faces of structural elements, edges and in the pores and root canals.

The third and final evolutionary stage in this color sequence is the result of a slow and prolonged weathering that is expressed by a red color (2.5–5 YR), mainly due to the formation of hematite, which causes a reddening of the soil [3]. The origin of this color must be associated with the weathering of the primary minerals that release Fe. The formation of hematite is related to warm temperatures and low humidity. The almost complete lack of areas with poor drainage corroborates the presence of iron oxides and therefore the red color. Only in the area in which Paleozoic materials appear, mainly with quartzitic sandstones, have ferricrettes been detected and these are related to symptoms of paleohydromorphism [16, 17].

Table 3. Land/soil capability classes for vineyards

VSC class	General definition
1	Extremely high capability land: Soil has no limitations for vineyard use. Special land management practices are not required
2	Very high capability land: Soil has slight limitations for vineyard use. These can be managed by readily available and easily implemented management practices
3	High capability land: Soil has moderate limitations and is capable of sustaining high-impact vineyard use. However, careful management of limitations is required to avoid land and environmental degradation
4	Moderate capability land: Soil has moderate to high limitations for high-impact vineyard use. These limitations can only be managed by specialized management practices with a high level of knowledge, expertise, inputs, investment and technology
5	Moderate–low capability land: Soil has high limitations for high-impact vineyard use. The limitations need to be carefully managed to prevent long-term degradation
6	Low capability land: Soil has very high limitations for high-impact vineyard use. Careful management of limitations is required to prevent severe land and environmental degradation
7	Very low capability land: Soil has severe limitations that restrict vineyard use and generally cannot be overcome. On-site and off-site impacts of land management practices can be extremely severe if limitations are not managed
8	Extremely low capability land: Limitations are so severe that the land is incapable of sustaining any vineyard

Suitability of the land for vineyards. The potential for vineyard production in Mediterranean areas is determined by the length and importance of the rainfall, the tolerance of the vineyard to overcome the summer moisture stress (although this extreme today is easily solved by the winegrower), and the intrinsic soil quality. The climatic characteristics of the Mediterranean area can be considered to be favorable for the growth of the vine.

Considering the nature of the soil and the extent and types of limitations, eight classes of land capability have been defined (Table 3). From the slope point of view, the dominant class in the area in question is flat or nearly flat and, to a lesser extent, undulating or moderately sloping; only near the inselberg constituted by Paleozoic rocks is the slope moderate to strong. The majority of the soils of Alcubillas are therefore suitable for vineyards, while moderately suitable sites occupy only a very small area. Finally, marginally suitable soils are only situated on the slope of the hill.

Soil texture is a crucial factor in relation to soil quality/capability, particularly because it affects the moisture retention and thus extends the period in which moisture is available to the crop. In this respect, the textures of the soils (Fig. 2) and the depths of the soils in question are common favorable factors for vineyards in Alcubillas; and other requirements are used in this sense (Table 4). Stoniness is widespread, and this has a negative effect on crop production because it hinders root development and reduces water retention. However, surface stoniness helps to reduce surface evaporation, protects the soil against

splash erosion and delays runoff. Surface stoniness is associated with the presence of the remains of petrocalcic horizons (and other rock fragments) produced during mechanized agricultural operations, with stones arising from breakage caused by plowing of petrocalcic horizons, which is common on the soils of Alcubillas.

Cation exchange capacity and base saturation are generally medium to high (Table 2). Most of the Alcubillas soils are also responsive to fertilization with P, are well supplied with K because of their high illite content, and contain adequate levels of Ca and Mg. The soils are not irrigated with salinized water, and therefore salinization processes are not possible.

The VSC Class 1 presents a very high potential for vineyard production, and it encompasses productive soils on flat surfaces with slopes <1%, good drainage, balanced texture, and water holding capacity to supply growing vineyards. The soils generally have good buffering capacity against soil acidity and specific management practices to control soil acidity are not required. However, any minor limitations can be very readily managed by adding organic matter.

The VSC Class 2 includes fertile soils and short gradual slopes (1–3%). These areas have a high potential for vineyard production on fertile soils similar to Class 1, but there are some restrictions on land use due to slight limitations, which can be controlled by readily available management practices involving the addition of organic matter and fertilizers.

The VSC Class 3 includes fertile soils with good drainage, balanced texture, and water holding capacity to supply growing vineyards. Low organic matter

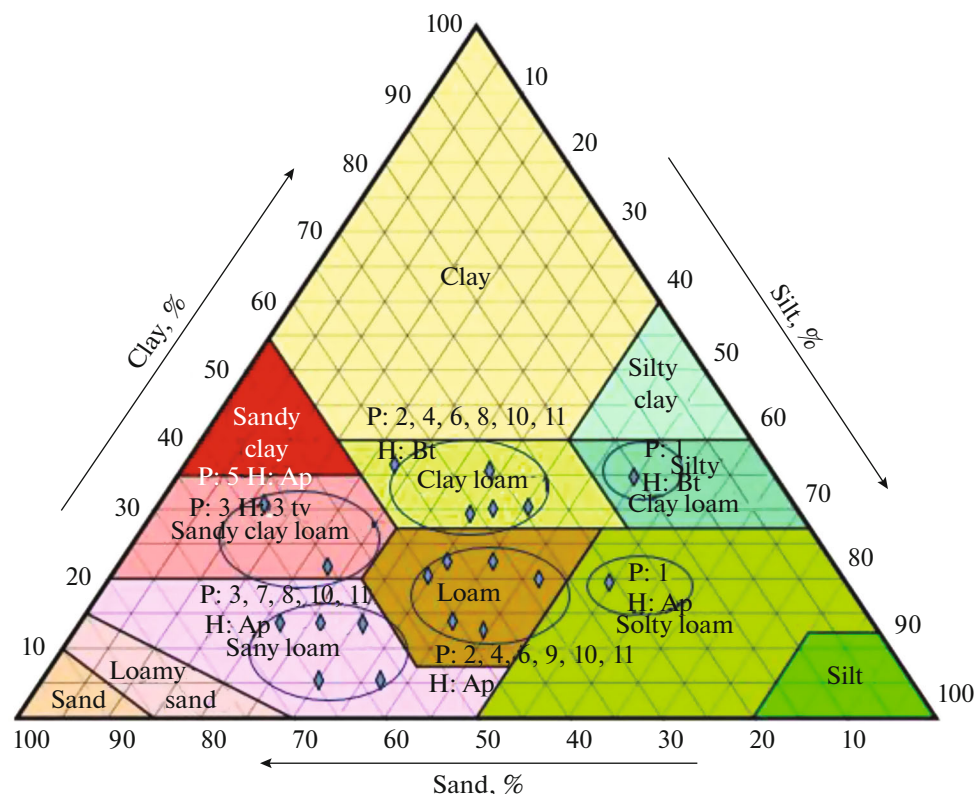


Fig. 2. Textures found in the surficial and subsurficial horizons (Ap and Bt or Bw or C) of the eleven soil profiles. (P: profile; H: Horizon).

contents and excessive active calcium carbonate can cause some problems. The soils generally have good buffering capacity against soil acidity and specific management practices to control soil acidity are not required. Low organic matter contents can be a moderate drawback. Active calcium carbonate can be a moderate problem, and this aspect needs to be managed. Some management of soil fertility is required, and the addition of organic matter or chemical fertil-

izer is recommended in order to improve productivity. Under long-term land use, soil active calcium carbonate levels should be monitored. This land is free of rocky outcrops and large stones that would restrict the operation of farm machinery.

The VSC Class 4 has moderate to severe limitations for vineyard use. This class includes sloping lands (10–15% slope), and there are cropping limitations due to the presence of highly active calcium carbonate, the

Table 4. Some requirements for determining land/soil capability for vineyards

Profile	Erosion	Acidity	Salinity	Waterlogging duration	Sallow soil depth	Rock outcrop
1	Sheet erosion	No	No	Only days	No	No
2	Sheet erosion	No	No	Only days	No	No
3	Sheet erosion	No	No	Only week	No	No
4	Sheet erosion	No	No	Only days	No	No
5	Sheet erosion	No	No	Only weeks	No	No
6	Sheet erosion	No	No	Only weeks	No	No
7	Sheet erosion	No	No	Only days	No	No
8	Sheet erosion	No	No	Only days	Yes	Yes
9	Sheet erosion	No	No	Only days	Yes	No
10	Sheet erosion	No	No	Only days	No	No
11	Sheet erosion	No	No	Only weeks	No	No

shallowness of soils, or a combination of these factors. This class is particularly problematical if surface parts of the soil profile become petrocalcic in character. The VSC Class 5 has severe limitations for high impact land management uses such as vineyards. There are only a few management practices generally available to overcome these limitations. Class 5 land includes sloping lands (>15% slope) with highly erodible soils and/or lithic contact (shallow soils). Fertility is generally lower than for land in Class 4. The VSC Class 6 also has severe limitations, with very highly erodible soils and very low fertility. The VSC Class 7 has extreme limitations for vineyard use. This type of soil is unsuitable for any type of vineyard as it may be too steep or rocky. The VSC Class 8 is not suitable for vineyard production due to its extremely severe limitations. Class 8 land includes precipitous slopes (>50% slope) and cliffs or areas with a large proportion of rocky outcrop (>70% area).

The soils of Alcubillas were found to be suitable for vineyards as the wine industry is based on soils with apparent production capacity, and the soil in question is capable of producing quality wines. If soil is a major factor in terroir expression, the results obtained highlight the importance of soil suitability in determining vine performance in undesignated vine-growing areas with a Mediterranean environment.

CONCLUSIONS

The morphological characterization of the most important soil types from the Alcubillas wine-making area has been carried out. The landforms have allowed prolonged periods for pedogenic processes (decarbonisation, argilluviation and rubefaction), which are typical soil-formation processes of the Mediterranean area that lead to very evolved soils. In fact, it is common to see sediments beginning from chalky limestone or marl, with coarse fragments that reflect a single landscape on these eroded rocks. The parent material (calcareous sediments) had suffered chemical weathering before the soil material had formed. As a consequence, these sedimentary materials, which are the starting materials for the soils, appear with variable carbonate contents. In the Alcubillas area, as in other areas on limestones, a clear differentiation between the red decalcified soil and the white parent material is not apparent.

Considering the nature of the soil and also the extent and types of limitations, as defined by the eight classes of land capability established by the USA Soil Conservation Service, the majority of the soils of Alcubillas are suitable for vineyards (classes 1, 2 and 3), while moderately suitable sites occupy only a very small area. Finally, a marginally suitable soil class is situated around a single hill, which occupies only a few hectares of terrain.

Therefore, the Alcubillas area was found to be suitable for vineyards. It can be concluded that the wine industry is based on soils with apparent production capacity and this area is certainly capable of producing quality wines. Further work is required in order to draw conclusions about these soils for the cultivation of several grape types.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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