

Characteristics of vineyard soils derived from Plio-Quaternary landforms (raña or rañizo) in southern Europe

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Abstract

Soil is an essential component in viticulture. The study reported here concerns the assessment of the morphology chemical and physicochemical features of typical, well-developed and representative evolved Mediterranean soils near Anchuras (Spain, southern Europe), a site with soils that developed on old landforms (Plio-Quaternary) called 'raña' and/or 'rañizo'. The soils under study were described and sampled by conducting soil surveys. Selected soil properties, such as texture, bulk density, pH, electrical conductivity (EC), cation exchange capacity (CEC) and contents of organic matter, nutrients, etc., were analysed using standard procedures. The results showed that these landscape surfaces were, linked with specific soil properties such as low pH (from 4.4 to 5.3) and EC (from 0.15 to 0.02 dSm⁻¹), clay contents (20.1%–48.8%), high CEC (26–39 cmol/kg), and low base saturation values (from 11.2% to 17.2%), and have an adequate and singular pedological potential in relation to the 'terroir' or 'terron' concepts that meet suitability criteria. Furthermore, the information provided by this study, fundamentally through the weathering indices, supports the role of soil-forming factors and their influence on soil properties. In addition, as these landforms and underlying materials have abundant and extensive rock fragments, the role of these soils in the context of vineyard growth and development has been investigated.

Highlights

- There are unknown conceptual zones that support production of wine
- This study highlights the importance and uniqueness of vineyard soils linked to old plioquaternary surfaces.
- Pedogeomorphologic vineyard constraints can serve as a basis for implementing a PDO
- The association soils-old surfaces can contribute to the identity and reputation of a viticultural zone

KEYWORDS

acid soils, old soils, Plio-quaternary landforms, soil survey, terroir, viticulture

1 | INTRODUCTION

Soil is an essential component in viticulture and, by extension wine production, since it supplies grapevines with water and nutrients (Coipel et al., 2006; Retallack & Burns, 2016). However, grapevines can adapt to a wide range of soil properties and soil types, which makes it difficult to identify the true influence of soil on the quality of their final product, such as wine (Wang et al., 2015).

The holistic word ‘terroir’ has been widely used as a descriptor of the connection between wines and their origin (i.e. recently White, 2020). Indeed, many authors, such as Vaudour (2002), White (2003), Van Leeuwen et al. (2004), Deloire et al. (2005), Van Leeuwen and Seguin (2006) and White et al. (2007), consider soil to be a key component for wine attributes in relation to this terroir concept. However, this concept has many definitions. According to Vaudour (2003) and Vaudour et al. (2014), terroir lies, in a certain way, at the intersection of several factors, such as terroir-matter or agricultural, terroir-space, terroir-conscience of terroir identity, and terroir-slogan. In general, when the word terroir is mentioned, it is understood in a spatial or territorial context.

According to Costantini et al. (2012), the soil functional properties (i.e., the benefits that people obtain from soils including biodiversity pool, regulation of biogeochemical cycles, filtering and transformation of nutrients and contaminants, etc.) that characterise the terroirs in a Denomination of Origin area are products and witnesses of Quaternary events, natural and human-induced, which happened in those landscapes. Another study considered that it is through the geology-soil binomial that a distinctive influence is exerted on vineyards (Mackenzie & Christy, 2005). The focal point studied by Mercurio et al. (2014) was the characterisation of the whole parent material-soil-vineyard-wine system, while Kodur (2011) and Retallack and Burns (2016) stated that soil pH, nutrient supply and other properties derived mainly from geological rocks are critical for vine growth and wine quality. On the other hand, regarding rock fragment distribution in relation to the recent cultivation pattern, Folain et al. (2006, 2009) demonstrated the effect of previous landscape characteristics on present soil variability.

Currently, the official definition of viticultural terroir according to the International Organisation of Vine and Wine (O.I.V., 2010) refers to an area in which collective

knowledge of interactions between the identifiable physical and biological environment and the applied viticultural practices develops, and provides distinctive characteristics for the products that originate from this area. The current understanding does not address terroir or clod by taking into account human-induced events because they are limited to the nineteenth-century destruction of vegetation cover. Although the term terroir is acknowledged and coined, Carré and McBratney (2005) proposed a new concept: ‘terron’, to help environmental managers to make decisions. This term perfectly matches the objectives of this work because it implies a whole entity that integrates soil properties (pedon) with topographic soil-forming factors (represented herein by landform attribute areas with similar soils), and in such a way the interaction between the two factors is understood. The current study assumed the climate is homogeneous because it is composed of small zonal spaces. In this context, we can state that the term agro-ecozones has been used for those regions with similar biophysical characteristics, such as soil, landform and climate (Anderson et al., 1999).

Castilla-La Mancha is an autonomous community in Spain which covers a wide extension of the Central Iberian plateau, and represents the largest (and probably one of the oldest) delimited wine regions in all of Europe, (MAGRAMA, 2017). In this region, there is the so-called ‘raña’ deposit, which is a flat geomorphic surface formed by quartzite cobbles and pebbles embedded in a clayey matrix that comes from the reworking of Neogene weathering profiles in the Palaeozoic metamorphic rocks within ranges. Mentioning the word ‘raña’ is the equivalent of pointing out a singular and genuine landform, which treasures an iconic geomorphological and edaphic context of the Iberian Peninsula and, by extension, of Europe. Raña was initially identified by Gómez de Llarena (1916) as alluvial landforms that were formed during rainy periods. According to Molina (1975), ‘raña’ is a continental detrital formation with a defined morphological expression, that rests on a surface with a highly developed chemical alteration. This formation is made up of accumulations of quartzite edges and blocks that have a more or less abundant reddish or yellowish sandy-silty matrix. Martín-Serrano (1988) acknowledged other similar deposits but proposed that they should not be called ‘rañas’, but ‘rañizo’. In any case, both ‘rañas’ and ‘rañizos’ stand out singularly on the topographic map, in such a way that their cartographic shape and topography are

FIGURE 1 Location of the study area 'El Rosalejo'

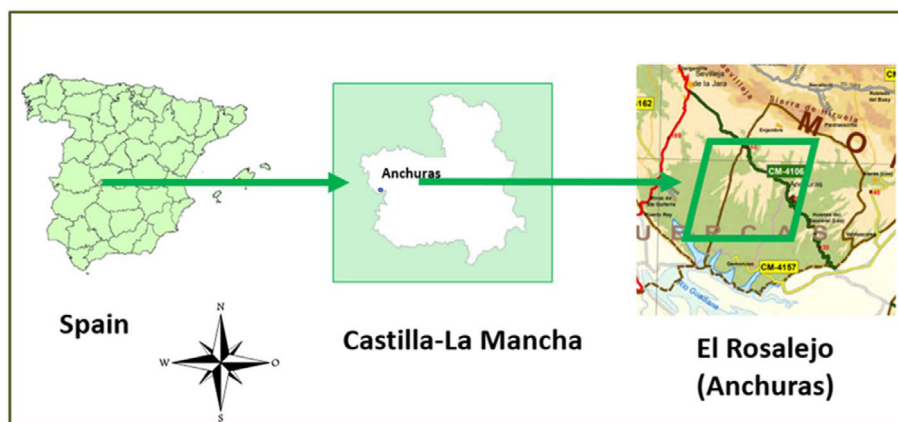
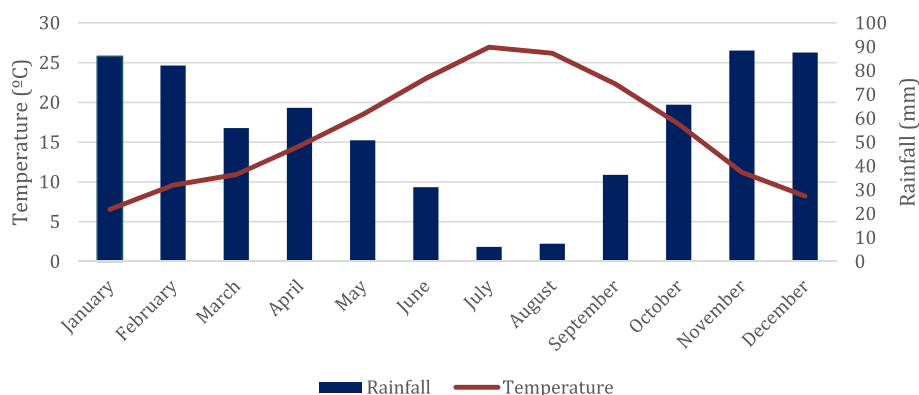


FIGURE 2 Climograph for Anchuras station (Castilla La Mancha)



unmistakable. These conical and finger-shaped platforms have a very low slope.

The specific purpose of this research work is to describe, compare and identify the soil types and their genesis in relation to the landscape characteristics of 'raña' and 'rañizo' as genuine Plio-Quaternary landforms sited in southern Europe. These special landscapes were selected because both are similar in genetic history terms, and they represent some of the oldest formations in Europe that support soils, many of which still persist. To achieve this goal, data from a winegrower on the El Rosalejo farm (Ciudad Real, Central Spain) was attained through field survey and laboratory approaches. Finally, the distribution of rock fragments in topsoil and subsoil, and their influence, were investigated for areas under grapevine cultivation at the study site to improve agricultural sustainability in the zone.

2 | MATERIALS AND METHODS

2.1 | The geomorphic and climate settings of the study area

The study was carried out from June to November 2015 at El Rosalejo farm, which is located near Anchuras, Central-West of Castilla-La-Mancha (43°31 N–3°51 E),

a territory in which an Eldoze winery is located. Vineyards occupy a landscape formed by Plio-Quaternary landforms at 615–635 m.a.s.l. All the vineyards (mainly of the Syrah variety) cover 9 ha. Figure 1 represents the location of the study area in its territorial context.

In geomorphologic terms, two major units should be noted: (a) the Hercynian unit, and (b) the Neogene unit, which forms the tertiary deposits topped by the 'raña' glacia. Tertiary materials are fundamentally detritic and constitute the basin fill, while quaternary deposits are mostly fluvial (Pardo García, 1995).

Clayey slates and greywacke sandstones appears throughout the Iberian Massif area. Rañas are discordantly arranged on the above-described older materials. According to the Instituto Geológico y Minero de España (IGME, 1985, 1988), a typical conglomeratic Pliocene formation can be found on the Mapa Geológico Nacional (MAGNA 708 and 709 sheets). This Pliocene formation is made up of edges, occasionally blocks, showing subangular and heterometric quartzite and sandstone, generally rubefacted, (reddish or orange clay-sandy matrix).

Furthermore, the IGME (1985, 1988) points out that some conglomerate formations exist that are similar to 'raña', but they are not as thick and do not generally exceed 2 m; they are glacia-terrace, conglomerates, gravel, sand and silt, which are regionally known as 'rañizos'.

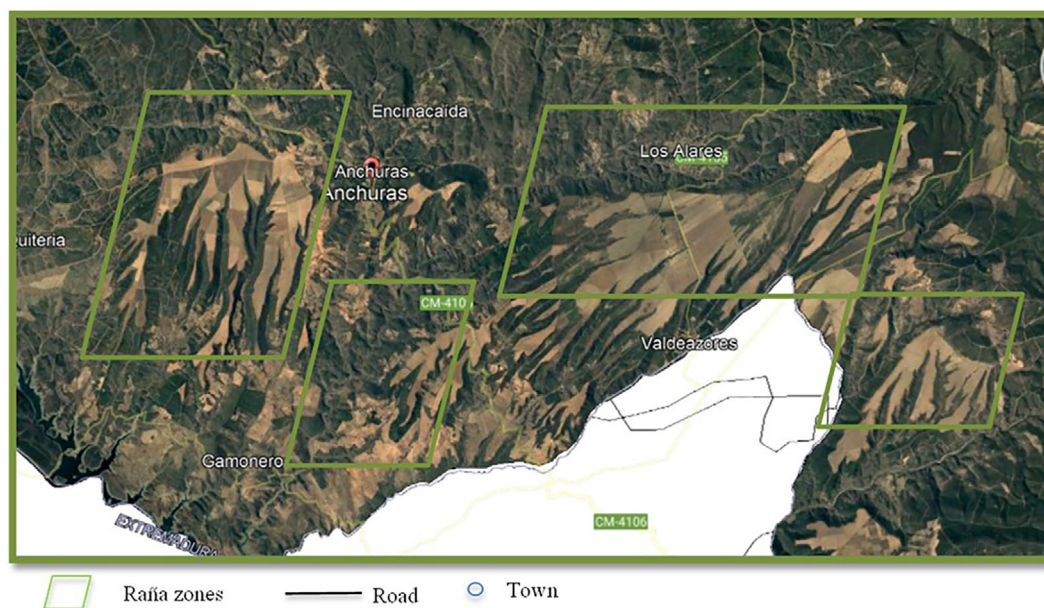


FIGURE 3 Satellite image (Google earth) of the different raña-type surfaces in the center-west of the Iberian Peninsula (Toledo), Spain

The regional climate is a typical Mediterranean semi-arid climate (Figure 2). The average annual temperature is 12.5°C, (AEMET, 2011). The frost period lasts 3–4 months. Significant seasonal moisture deficit occurs in hot summers. The amount of precipitation in the area is 650–700 mm per year, with an average dry period duration of 4–5 months. According to the Köppen-Geiger classification, it is of the Csa type (AEMET, State Meteorological Agency, 2011). If the Papadakis classification is used, the ‘temperate Mediterranean’ climate zone is considered, and the humidity regime in this region is ‘humid Mediterranean’. According to Soil Survey Staff (2014), the soil moisture regime is ‘xeric’, whereas the soil temperature regime is ‘thermal’. In the study region, viticulture is mainly dependent on irrigated cultivation.

2.2 | The original materials of the soils at the Rosalejo: rañas and rañizos

When focusing on the study area itself, according to the IGME (1988) two landforms units appear: (1) One unit can be called ‘rañizo’. It is made up of clayey sands and conglomerate levels, whose dating is simply bibliographic because the only available data indicate that they are covered by ‘raña’. This formation, which is discordant with the Precambrian, Palaeozoic and Lower Miocene, presents variable thicknesses. (2) The other unit is the ‘rañas’ (Gómez de Larena, 1916). It is based on clays, pebbles and blocks, and it is a typical conglomerate formation made up of subangular and heterometric blocks of quartzite and sandstone, with a reddish or orange clay-sandy

matrix. Although these two units are not strictly the same, they are certainly similar because, among other reasons, they are closely related to the altered substrate.

Figure 3 shows an image (taken from Google Earth) of the area and other similar bordering zones, which displays the different raña-type surfaces. Figure 4 illustrates the typical landscape, constituted by flat or almost flat reliefs of raña or rañizo used for intensive agriculture purposes (mainly vine and cereal) or as Mediterranean forest.

2.3 | Soil identification and sampling

In most landscapes the profiles used for soil description and sampling exist hidden beneath the soil surface. However, with raña and rañizo landforms, this difficulty is more evident when terrains are flat or almost flat. Therefore, to describe the soil profile and sample it, it is necessary to open excavations. The five profiles studied were opened using a backhoe machine. Soils were described according to the FAO (2006) guidelines. They were classified following the USDA Soil Taxonomy (Soil Survey Staff, 2014) and FAO (IUSS Working Group WRB, 2015). Some soil samples were collected with a manual drill to determine both soil structure and bulk density.

2.4 | Laboratory methods

The collected soil samples were transported to the soil analysis laboratory at Castilla-La-Mancha University. After drying in an open-air space for 6–7 days,

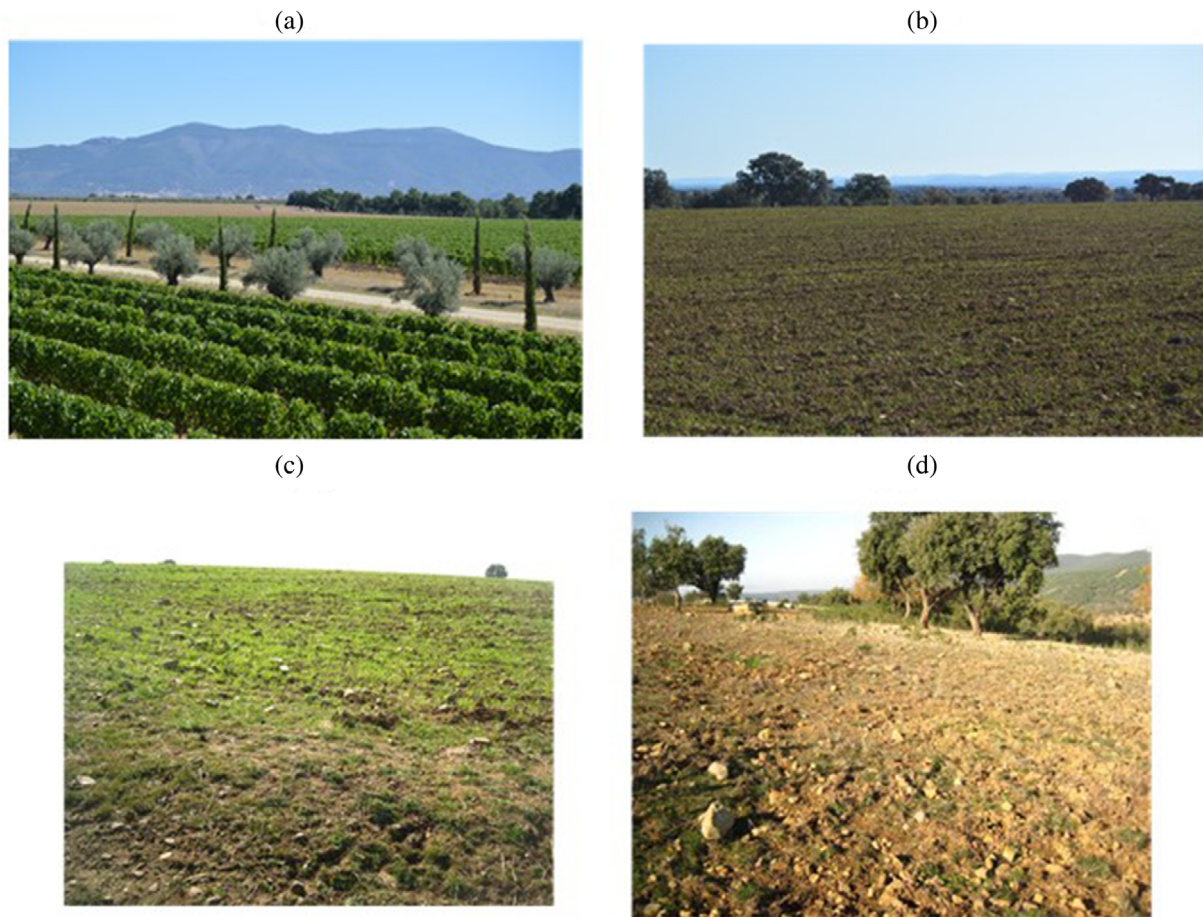


FIGURE 4 Typical relief of raña (a, b) and rañizo (c, d) in the zone

samples were passed through a 2 mm mesh sieve. Physicochemical analyses of fine earth samples were performed by following standard procedures (Table 1). All the samples were collected and analysed in triplicate.

2.5 | Soil indices

Several parametric indices were proposed and used in this research (Table 2). By employing the concentration of Al and base cations Ca, Na and K, weathering indices were used, such as:

a. The Chemical Index of Alteration (CIA) of Nesbitt and Young (1982):

$$CIA = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O + K_2O} \right] * 100 \quad (1)$$

b. The Chemical Index of Weathering (CIW) of Harnois (1988)

$$CIW = \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O} \right] * 100 \quad (2)$$

According to McLennan et al. (1983, 1993) and Cox et al. (1995), the CIW is interpreted with a value of 50 for an unweathered upper continental crust and with a value of about 100 for highly weathered materials with the complete removal of alkali and alkaline-earth elements (Table 2).

3 | RESULTS

3.1 | Soil properties and classification

The 'El Rosalejo' soils developed on materials associated with rañas landform and the environments of raña formation, configured on extensive plains undermined by the interlocking of the quaternary hydrographic network.

The morphological features of the soil profiles generally show a sequence of types Ap-Bw-C, Ap-Bt-C or Ap-C (Table 3). The soils with a Bw or Bt horizon have a high clay content, which implies a distinctive characteristic of the soils in this area. The presence of Bw or Bt horizons with high clay content can sometimes limit root development at greater depths due to physical limitations and relative lack of oxygen. Based on the morphological and

TABLE 1 Methods used for measuring soil parameters

Soil property	Methods	Reference
pH	Potentiometrically measured in 1:2.5 soil/water suspension, pH meter	Peech et al., 1947
EC	Salinity measured in 1:5 soil/water suspension, EC meter	Richards, 1954
Texture	Hygrometer	Gee & Bauder, 1986
Bulk density	Cylinder	Blake & Hartge, 1986
OM	Determination by dichromate digestion (Walkley and Black)	Nelson & Sommers, 1982
CEC	Percolation with ammonium acetate solution, pH = 7	Thomas, 1982
P	Olsen	Olsen et al., 1954
N	Kjeldahl	Bremner & Mulvaney, 1982
Al, Ca, Mg, Na, K	Determination by FRX	

Abbreviations: CEC, Cation exchange capacity; EC, Electric conductivity; N, Nitrogen (total); OM, Organic matter; P, Available phosphorus.

analytical data of the studied soils, and according to the Soil Taxonomy (Soil Survey Staff, 2014), the identified soil orders were Inceptisols, Alfisols and Ultisols, which correspond to soil groups Cambisols, Luvisols and Acrisols according to the IUSS Working Group WRB (2015). Table 3 shows the classification and properties of investigated soils.

The soils in this area generally have moderate fertility, a very low pH and some nutrient imbalance problems (Table 3). In relation to coarse fragments, a large proportion of them is observed in all the profiles. Textural classes: silty clay, clay, silt loam, clay loam and loam were predominant in the study area, and such textures (with a high clay content) are among the commonest in the viticultural soils of this region (Amorós et al., 2015). A clear increase in clay content is seen in all of the soil profiles in B horizon (Table 3). Although the increase in clay in the Ap to B transit is notable, it is not observed in the other properties of the argillic horizons in all the soil profiles. This means that they qualify as cambic horizons. Soil pH values varied from 4.4 to 5.3. As the ideal pH for vines lies between 6.0 and 8.0 (Amorós et al., 2015), soil profiles can be classified as 'very strongly acidic' (Soil

Survey Staff, 1993). Hence, the degree of acidity is not adequate for vine production. However, this property confers a specific and special character to these viticultural soils because the soils traditionally used for growing grapes in Castilla-La Mancha largely develop on calcareous materials (Amorós et al., 2011) and, in practice, generate excellent wine.

When examining other properties (Table 3), we found that electrical conductivity (EC) values were low and ranged from 0.02 to 0.15 dSm⁻¹. Organic matter content varied between 1.3% and 3.2% in soil surface horizons and decreased with depth. These values can be considered adequate for vine cultivation. The carbon-to-nitrogen ratio (C/N) was around 10–13 indicating that these soils have good humification. Total N in soil ranged between 0.01% and 0.11% and therefore had no optimal value for viticulture. The available phosphorus (P) contents varied from 1.8 to 6.8 mg/kg P₂O₅, which means that the studied soils are poor in P content. All of the soils were desaturated with cations because their base saturation values were less than 35% (Soil Survey Staff, 2014). The base saturation values were higher in the soil surface horizons than in the subsurface layers. Cation exchange capacity (CEC) was always high (about 40 cmol/kg) and, exceptionally, some values are below 30 cmol/kg. The exchangeable cations content appeared in the order Ca>Na>Mg>K, but with much less Ca than in soils from Castilla La Mancha (Amorós et al., 2015). Based on field test, no carbonate was present in the studied soils. Finally, iron and manganese concretions occur, which are typical of a pseudogleyisation process due to temporary hydromorphy and poor permeability.

4 | DISCUSSION

4.1 | The Rosalejo soils: the identity of a singular substrate 'raña' and rañizo'

The base from which terroir or terroir applies to the zone to be identified lies in the so-called raña, understood as those fluvial formations of the alluvial fan type associated with slate-quartzite reliefs under more contrasting and warmer conditions than current ones, and by presenting flat surfaces with little slope and evolved soils with marked hydromorphic characteristics. This definition was proposed during a specific meeting on raña, held in 1987 at the Consejo Superior de Investigaciones Científica (Higher Council for Scientific Research) in Madrid (Spain).

Flooded extremely tiny areas arise because of drainage difficulties due to the surface flatness and the nature of their semipermeable deposits. Consequently, in the

TABLE 2 Soil categories criteria of the chemical indices of weathering (CIA and CIW)

Chemical index of alteration (CIA)		Chemical index of weathering (CIW)	
Value	Category	Value	Category
50–60	Very slightly weathered	50	Unweathered
60–70	Slightly weathered	100	Highly weathered
70–80	Moderately weathered		
80–90	Highly weathered		
90–100	Extremely weathered		

soils on raña and rañizos, iron segregations are frequently detected, as are ferruginous gravels, which are formed with pinkish edges derived from iron oxides content (haematite), which are loose and dispersed, or cemented by the same iron oxides to generate ‘ferruginous pseudo-crusts’ to a certain extent (Figure 5). For these accumulations to form, it is necessary to invoke pedogenetic processes, including intense weathering processes (Figure 5) with consequent clay synthesis and the release of iron (Espejo, 1987). The acidity generated at the same time would cause the mobilisation and migration of iron throughout the length of the soil profile. Finally, discolouring and sandblasting processes were also detected, along with nodular concretions and micro-aggregates (Figure 6). All these processes have been related to paleoclimate conditions (Espejo, 1987), which we believe are still active today.

In light of all the above, we devised the following sketch of the soils in the raña and rañizo landscapes of our area (Figure 7).

Soil genesis and development in arid and semi-arid areas are strongly affected by geological formations, and geomorphic surfaces (Bayat et al., 2016; Khresat et al., 2004). Thus, morphological, physical and geochemical soil properties at different geomorphic units are usually attributed to different soil-forming factors, including parent material and climate (Selmy et al., 2020; Selmy, Abd El-Aziz, et al., 2021; Selmy, Al-Aziz, et al., 2021).

One of the vineyard landscape structure features of the Plio-Quaternary surfaces ‘raña and rañizo types’ is that they are flat or almost flat. This characteristic allowed the formation of developed soils. Using the so-called ‘natural terroir units’ (Laville, 1993; Priori et al., 2014), it can be stated that one of the oldest natural terroir units has been generated on rañas and the like in the Anchuras area.

Deloire et al. (2005) stated that beneficial water deficit (a typical process in vineyards of Mediterranean regions, like that herein studied) delays shoot growth without notably affecting photosynthetic activity. This process also facilitates the distribution of sugar in berries and perennial organs during ripening (Deloire et al., 2005). So

these drought processes are not considered intense for the studied soils, which present on flat surfaces with little drainage. Furthermore, this water regime strongly impacts nitrogen dynamics (Celette & Gary, 2013).

4.2 | Soil indices

The soil development and the evaluation of the fertility status of these soils are related to chemical and physical parameters

4.2.1 | Soil geochemical weathering index

Concentrations (in molecular proportions) of major elements have been used by several authors (Darmody et al., 2005; Harnois, 1988; Ruxton, 1968) to determine the degree of weathering along soil profiles because they provide a quantitative measure of the depletion of mobile (Ca, Na, K) versus immobile (Al) elements during chemical weathering. The literature contained several index. Herein, we have considered two indices of geochemical weathering: the CIA and CIW.

The CIA can vary from around 35–55 (for unweathered rocks) to 100 (highly weathered). In particular, Nesbitt and Young (1982) classified the CIA values as very slightly weathered (50 to 60), slightly weathered (60 to 70), moderately weathered (70 to 80), highly weathered (80 to 90) and extremely weathered (90 to 100).

The elemental concentrations (Ca, Na, K and Al) and the weathering rates obtained were shown in Tables 4 and 5, respectively. The CIA values varied from 87.2 to 98.1, which are markedly high according to Fedo et al. (1995), Ao et al. (2010) and Özyetkin et al. (2012). The CIW values ranged between 97.2 and 99.4. The CIA and CIW indices exhibit similar behaviour with values ranging from 90 to 100, indicating intense weathering of the studied soils (McLennan et al., 1993, 1983). The weathering index values of the five soil profiles investigated showed no significant differences. This may be because those soil profiles were

TABLE 3 Physical, chemical, and morphological properties and classification of the investigated soil profiles

Soil classification	FAO: Haplic Acrisol (ferric, chromic)			FAO: Haplic Cambisol (ferric, chromic)			FAO: Haplic Cambisol (ferric, chromic)			FAO: Haplic Cambisol (ferric, chromic)			FAO: Haplic Cambisol (ferric, chromic)			FAO: Haplic Cambisol (ferric, chromic)		
	S.T.: Typic Haploxerult			S.T.: Oxyaquic Dystroxept			S.T.: Oxyaquic Dystroxept			S.T.: Oxyaquic Dystroxept			S.T.: Oxyaquic Dystroxept			S.T.: Oxyaquic Dystroxept		
Soil horizons	Ap	Bt	C	Ap	Bw1	Bw2	Ap	Bw	C	Ap	Bw	C	Ap	Bw	C	Ap	Bw	C
Depth (cm)	0–16	16–67	>67	0–24	24–99	>9	0–32	32–67	>67	0–14	14–77	>77	0–28	28–75	>75	0–28	28–75	>75
Coarse fragments (%)	51.3	44.8	61.8	53.0	51.0	65.0	55.1	53.0	61.2	48.2	55.8	56.4	45.7	50.5	53.7	45.7	50.5	53.7
Sand (%)	35.4	32.2	40.5	29.9	22.4	21.9	30.7	24.9	25.9	13.4	1.2	12.5	28.1	17.6	20.6	28.1	17.6	20.6
Silt (%)	41.0	31.4	35.2	50.0	54.9	58.1	33.9	28.5	31.4	48.2	43.4	43.1	33.5	37.3	36.8	43.4	37.3	36.8
Clay (%)	23.6	36.4	24.3	20.1	22.7	20.0	35.4	46.8	42.7	38.4	45.4	44.4	38.4	45.1	42.6	45.4	45.1	42.6
Texture	Loam	Clay loam	Loam	Loam	Silt loam	Silt loam	Clay loam	Clay loam	Clay	Silty clay loam	Silty clay	Silty clay	Clay loam	Clay loam	Clay	Clay loam	Clay loam	Clay
Bulk density (g/cc)	1.23	n.d.	n.d.	1.19	1.3	0.7	1.36	n.d.	n.d.	1.32	n.d.	n.d.	1.33	n.d.	n.d.	1.33	n.d.	n.d.
Organic matter (%)	2.7	0.9	n.d.	1.3	0.7	n.d.	3.2	0.9	n.d.	2.8	1.3	n.d.	n.d.	0.5	n.d.	n.d.	0.5	n.d.
P Olsen (mg/kg)	4.2	1.9	n.d.	6.0	1.8	n.d.	5.2	1.9	n.d.	6.8	1.9	n.d.	6.0	1.9	n.d.	6.0	1.9	n.d.
Total Nitrogen (%)	0.11	0.04	n.d.	0.05	0.05	n.d.	0.09	0.04	n.d.	0.11	0.05	n.d.	0.05	0.01	n.d.	0.05	0.01	n.d.
C/N ratio	10.9	9.4	n.d.	11.0	11.1	n.d.	14.4	11.3	n.d.	11.3	10.6	n.d.	11.3	13.5	n.d.	11.3	13.5	n.d.
pH (water 1:2.5)	5.1	4.4	4.5	5.1	4.6	4.7	5.1	4.9	4.9	5.35	4.4	4.5	5.2	4.5	4.4	5.2	4.5	4.4
pH (KCl 1:2.5)	4.4	3.09	3.9	4.6	4.1	3.9	4.6	4.2	4.1	4.81	3.9	3.8	4.8	4.0	3.9	4.8	4.0	3.9
Electrical conductivity (dS/m)	0.06	0.02	0.02	0.05	0.02	0.03	0.15	0.03	0.03	0.04	0.04	0.03	0.12	0.02	0.03	0.12	0.02	0.03
Cation Exchange (cmol ⁺ /kg)																		
Ca ²⁺	2.1	1.8	n.d.	3.5	2.4	n.d.	3.2	1.9	n.d.	4.7	2.9	n.d.	3.8	2.6	n.d.	3.8	2.6	n.d.
Mg ²⁺	0.8	0.6	n.d.	0.7	0.4	n.d.	0.5	0.2	n.d.	0.3	0.1	n.d.	0.6	0.4	n.d.	0.6	0.4	n.d.
K ⁺	0.5	0.3	n.d.	0.4	0.3	n.d.	0.4	0.3	n.d.	0.5	0.3	n.d.	0.5	0.3	n.d.	0.5	0.3	n.d.
Na ⁺	0.8	0.7	n.d.	1.0	0.9	n.d.	0.7	0.6	n.d.	0.7	0.8	n.d.	0.9	0.8	n.d.	0.9	0.8	n.d.
C.E.C (cmol ⁺ /kg)	35.2	30.4	n.d.	34.6	28.3	n.d.	30.3	26.7	n.d.	n.d.	39.6	n.d.	33.7	25.7	n.d.	33.7	25.7	n.d.
Base saturation (%)	11.9	11.2	n.d.	16.4	14.3	n.d.	15.8	11.6	n.d.	n.d.	12.0	n.d.	17.2	16.7	n.d.	17.2	16.7	n.d.

Abbreviations: n.d., not determined; S.T., Soil Taxonomy classification.

FIGURE 5 (a) Weathering with ferruginisation. (b) Iron oxides cemented by the same iron oxides



FIGURE 6 Discolouring and sandblasting processes

derived from the same parent material and developed on same environment.

The interpretation of all these data is that intense weathering is a consequence of these soils' old age; that is, soil age promotes an intense weathering process. Consequently, alkali and alkaline-earth elements have been largely removed.

4.2.2 | The soil organic carbon/clay ratio

The chemical composition of the parent material and intense weathering are responsible for some distinctive soil properties, such as high CEC and clay content. The high clay content detected in the studied soils can be a key factor in its effects on soil organic carbon (SOC) protection (Dungait et al., 2012; Six et al., 2002). In this way, the SOC/clay ratio index allows soils to be evaluated on a scale from degraded to good soil conditions (Prout et al., 2021). A SOC/clay ratio above 1/10 should be achieved for all the managed soils with different textures (Prout et al., 2021)

According to Johannes et al. (2017), SOC/clay ratio thresholds of 1/8, 1/10, and 1/13 indicate the boundaries between the 'very good', 'good', 'moderate' and 'degraded' structural condition levels. On this scale, the obtained values (Table 5) showed that they are lower than the 1/13 ratio and thus, the studied soils are degraded. Like many other soils in Mediterranean regions, the Rosalejo soils show an evident SOC deficit, a circumstance that the farmer is aware of, which is why he adds organic waste; for example, pruning material from the same vineyard to increase SOC storage to improve soil conditions and carbon sequestration.

4.3 | Stoniness in vineyards: origin and effects

Figure 8 shows a series of photographs in which a profuse stony phase (mainly thick quartzites) was detected, covering the soils that developed on raña and rañizo. In many semi-arid regions, such as in central Spain,

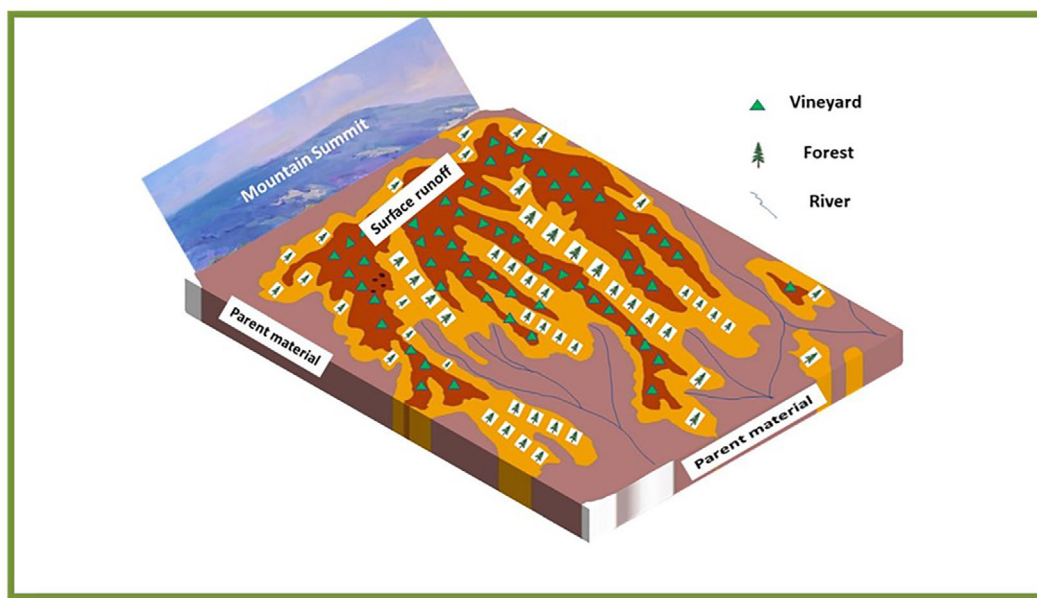


FIGURE 7 Soil-landscape architecture in the study area showing finger-shaped platforms with a very low slope. Landform and parent material were two important soil forming factors affecting soil formation in the area

	Hor.	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
%Na ₂ O	A	0.18	0.20	0.18	0.13	0.15
	B	0.09	0.10	0.08	0.07	0.07
	C	0.08	0.10	0.09	0.07	0.11
%K ₂ O	A	1.73	2.01	1.29	1.29	1.32
	B	1.00	1.57	1.13	1.04	1.10
	C	0.29	1.50	1.13	0.93	1.48
%CaO	A	0.17	0.22	0.17	0.26	0.18
	B	0.29	0.10	0.09	0.05	0.07
	C	0.07	0.07	0.12	0.05	0.08
%Al ₂ O ₃	A	19.05	16.67	12.71	12.62	12.86
	B	19.42	20.89	17.72	21.27	19.66
	C	23.40	22.54	20.78	19.97	25.71

TABLE 4 Soil content of Na, K, Ca and Al elements

	Hor.	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
CIA	A	90.07	87.20	88.51	88.15	88.56
	B	93.30	92.15	93.08	94.78	94.02
	C	98.12	93.02	93.84	94.96	93.87
CIW	A	98.11	97.46	97.27	96.90	97.43
	B	98.04	99.02	98.97	99.41	99.26
	C	99.33	99.18	98.91	99.36	99.39
SOC/clay ratio	A	0.066	0.038	0.052	0.042	0.021
	B	0.014	0.018	0.001	0.016	0.006

TABLE 5 Soil index scores of CIA and CIW

Abbreviations: CIA, Chemical Index of Alteration; CIW, Chemical Index of Weathering.

FIGURE 8 Stony phase of 'El Rosalejo'



pedological landscapes appear to be covered by these rocky mantles (Jiménez-Ballesta et al., 2021; Pérez-de-los-Reyes et al., 2020). These mantles have a natural origin since they were formed by natural transport activities such as gravity and climate factors on gentle slopes (e.g. glacis) from mountains adjacent to fields.

On the other hand, stoniness resulted from the remobilisation that farmers have carried out since immemorial times. These rocky surface mantles are considered as 'gravel mulches' because they protect the soil surface against high evaporation, extreme temperatures, water erosion, and runoff, among other effects. Rock fragments have various positive effects on soils, including reduced runoff, increased infiltration and water storage, and lower evaporation rates. Above all, its impact on soil protection against rain splash compaction and erosion has been emphasized by Pérez-de-los-Reyes et al. (2020). Field observations confirmed these impacts in the study area, but other recognised effects are masked by being a Mediterranean mountain climate and, thus, for not being very extreme.

Generally, shallow stony beds provide a series of benefits for vineyards and other crop types (Brakensiek & Rawls, 1994; Pérez, 1998; Tejedor et al., 2003; van Wesemael et al., 1995). Thus, because run-off decreases and soil erosion effectively decreases, improvements in infiltration rates, depth water penetration, and even soil water storage and availability are cited as benefits. The presence of a mantle of rock fragments led to reduces evaporation rates in areas like those previously studied (Kemper et al., 1994; van Wesemael et al., 1996). This is especially relevant in areas like that studied herein, where high evaporation lasts 3–4 months.

5 | CONCLUSIONS

The present study investigated the existing viticultural agrosystem, in a site associated with *raña* and *rañizo* landforms in Castilla-La-Mancha, central-western Spain, with an emphasis on soil characteristics and classification. The

zoning approach of the present study was based on identifying environmental factors to control vineyard quality by merging both geomorphologies and soil scientist knowledge. The results offered in this study serve as a decision-making support tool during the site selection process for a potential new Protected Denomination of Origin. Fieldwork was conducted to identify landforms and associated soils, and placed emphasis on macromorphological soil properties. The results showed that the soils of these formations (*raña* and *rañizo*) have unique properties, which are far removed from many others in the Castilla-La-Mancha region. A well-differentiated macromorphological profile, the appearance of light hydromorphic processes, intensely altered parent material, low pH and EC and high CEC all reveal a singular potential for future terroirs or terrons for meeting suitability criteria. Soil development in the Rosalejo is the result of intense weathering. In addition, as these landforms and materials are characterised by having abundant and extensive rock fragments, the role of rocky mantles was investigated. It was found that the presence of a mantle of rock fragments led to a series of beneficial properties, such as increased water penetration depth, soil water storage and availability, and decreased run-off, and effectively reduced soil erosion.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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