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The stony phase as a differentiation factor in vineyard soils

La pedregosidad como factor de diferenciación en suelos de viñedo
A pedregosidade como fator de diferenciação em solos de vinha

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ABSTRACT

A study has been conducted in a viticulture area near Lezuza (Castilla-La Mancha, Spain) with the main aim of linking the effects of stoniness on vineyard productivity and quality. The studied area is unique because of the very high stoniness (6 of the 11 profiles exceeded 30% and another 3 reached 50%). A discussion is provided on the importance of the stony layer superimposed on the limestone plateau, which produces a clear contrast in the soils since these are two very different types of chemical and mineral substrates (acidic at the surface but calcareous in the subsurface). This special type of stoniness could impart unique characteristics that are highly valued in the current wine market. It was found that the importance of the stony phase is that – apart from the protective role from soil erosion – it plays a definitive role in the conservation of soil moisture, which is relevant during the growth period in the vineyard. The experience accumulated over many years by farmers, in the sense that smaller rock fragments should not be removed from the surface of the agronomic fields, should be taken into consideration, especially if the aim is to conserve soil and water.

RESUMEN

Se ha llevado a cabo un estudio en un área vitícola cercana a Lezuza (Castilla-La Mancha, España) con el objetivo principal de vincular los efectos de la pedregosidad con la productividad y la calidad del viñedo. El área estudiada es singular debido a que tiene una pedregosidad muy alta (6 de los 11 perfiles superaron el 30% y otros 3 alcanzaron el 50%). Se ha realizado una discusión sobre la importancia de la capa pedregosa superpuesta en la meseta de piedra caliza, que produce un claro contraste en los suelos ya que se trata de dos tipos muy diferentes de sustratos químicos y minerales (ácidos en la superficie pero calcáreos en el subsuelo). Este tipo especial de pedregosidad podría definir características únicas que son altamente valoradas en el mercado actual del vino. Se ha definido que la importancia de la fase pedregosa reside en que, además del papel protector sobre la erosión del suelo, desempeña una función definitiva en la conservación de la humedad del suelo que seguramente será relevante durante el período de crecimiento en el viñedo. Se debe tener en cuenta la experiencia acumulada durante muchos años por los agricultores, en el sentido de que los fragmentos de roca más pequeños no deben eliminarse de la superficie de los campos de cultivo, especialmente si el objetivo es conservar el suelo y el agua.

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RESUMO

Foi realizado um estudo em uma área de viticultura perto de Lezuza (Castilla-La Mancha, Espanha), com o objetivo principal de relacionar os efeitos da pedregosidade com a produtividade e qualidade da vinha. A área estudada é única devido à elevada pedregosidade (seis dos 11 perfis excederam 30% e outros três chegaram a 50%). É discutida a importância da camada pedregosa sobreposta à camada de calcário, o que produz um claro contraste nos solos pois estes são dois tipos muito diferentes de substratos químicos e minerais (ácidos na superfície, mas calcários na camada subsuperficial). Este tipo especial de pedregosidade poderia conferir características únicas que são altamente valorizadas no mercado atual do vinho. Verificou-se que a importância da fase pedregosa, além do papel protetor da erosão do solo, é devida ao facto de desempenhar uma função positiva na conservação da humidade do solo, o que certamente será relevante durante o período de crescimento da vinha. Deve ser levada em consideração a experiência acumulada pelos agricultores ao longo de muitos anos, no sentido em que os fragmentos de rocha de menores dimensões não devem ser removidos da superfície dos campos de cultivo, especialmente se o objetivo é conservar o solo e a água.

KEYS WORDS
Rock fragments, stony soils, terroir.

PALABRAS CLAVE
Fragmentos de rocas, suelos pedregosos, terroir.

PALAVRAS-CHAVE
Fragmentos de rochas, solos pedregosos, terroir.

1. Introduction

There are numerous studies on the influence of the presence of rock fragments in soils (Abrahams and Parsons 1991; Bunte and Poesen 1993; Danalatos et al. 1995; Moustakas et al. 1995; Nyssen et al. 2001; Poesen and Lavee 1994; Poesen and Bunte 1996; Poesen et al. 1998; Van Wesemael et al. 1996). Indeed, in many areas of the world and in particular in the Mediterranean area, it has been observed that an appreciable proportion of soils contain rock fragments both in the soil surface and within the soil profile (Poesen and Lavee 1994). These soils that contain abundant rock fragments (particles > 2 mm or > 5 mm in diameter according to Miller and Guthrie (1984) are usually denoted as stony soils.

In recent decades, interest in studying the effect of this stoniness on the ground has increased, particularly given the abundance of this type of soil. For example, Poesen and Lavee (1994) indicated that in the Mediterranean region stony soils occupy more than 60% of the land. Furthermore, in Africa, the Sahara, Sahel, and most of the soils in the west of the African continent are gravel (Jones et al. 2013) and areas with stoniness of 15-80% are predominant in Central America and many other areas of Chile, Peru, Venezuela and Brazil, according to Gardi et al. (2014).

Regarding the effects produced by the presence of stones, Poesen et al. (1994) carried out a study in which they reviewed the main processes that involve stoniness. They pointed out the beneficial role of stoniness, since the presence of stones reduces soil erosion by protecting the soil surface against the impact of raindrops and consequent runoff, thus reducing the possibility that the ground is sealed on the surface. Other authors (Kosmas et al. 1993; Abrahams and Parsons 1994; Brakensiek and Rawls 1994; Poesen and Lavee 1994; Poesen et al. 1994; Valentín 1994; van Wesemael et al. 1995; van Wesemael et al. 1996) reported that in arid or semi-arid environments stoniness increases soil productivity, since it affects hydrological processes and soil degradation, such as surface sealing, infiltration, evaporation, generation of runoff, runoff energy dissipation and water erosion.

Many soils in the Castilla-La Mancha region have been formed from limestones, marls, sandstones or carbonated sediments. There are also soils that have been formed above quartzites, slates and shales. These soils all frequently have a layer of stones, which come from fragmentation of the rocks or from the surface setting of fragments of petrocalcic horizons broken by anthropic action. The stones that cover the soils of vineyard surfaces in Castilla-La Mancha (one of the most extensive regions of vineyards in the world) comprise fragments of petrocalcic horizons or rocks, or both, and their spatial variation is largely controlled by anthropic action and slope gradient. Indeed, a proportion of this fraction is linked to plough mechanization, which raises fragments from deep horizons (usually petrocalcic) to the surface. Similarly, there are vineyard soils with stony coverings from erosion and/or drag linked fundamentally to geological processes. Both cases involve an edaphic skeleton that helps to protect the soil structure or leads to greater macro-porosity and saturated hydraulic conductivity (Saini and Grant 1980; Magier and Ravina 1984; Ravina and Magier 1984; Childs and Flint 1990; Chow et al. 1992). However, Mehuys et al. (1975) reported that the saturated hydraulic conductivity in desert soils decreased as the percentage of rock fragments increased.

Stoniness does not necessarily imply an improvement in soil fertility, although sometimes stones provide a greater production of biomass (for example in wheat), as demonstrated by Kosmas et al. (1993). With respect to erosion, Poesen et al. (1994) analysed the effect of rock fragments at different scales (as mentioned before), while Rodrigo Comino et al. (2018) analysed the most important factors that influence erosion and soil runoff from ecological vineyards and concluded that, in addition to the vegetation cover, the layer of rock fragments, soil moisture and slope are factors that influence soil erosion.

In regions such as Castilla-La Mancha a proportion of the vegetation cover has been preserved. However, some of the vegetation has disappeared due to agricultural land use. As a result of the semi-arid nature of this area, water availability for crops is scarce and the spatial pattern of soil surface properties therefore affects both water availability and nutrient flows. This role should be recognized in order to establish appropriate management measures while addressing possible degradation processes. This is the case in Lezuza (Albacete, Spain), a flat or almost flat area with abundant carbonated materials that are overlaid in stony environments with heavy stony deposits that are quartzite in nature.

In this context it can be deduced that the stony phase that appears on the surface of the soils can modify certain soil properties, an issue that is scarcely understood in vineyard soils. Heavily stony soils are abundant in an area of the Castilla-La Mancha region located around Lezuza (Albacete, Spain). In the work reported here the role of stoniness was analysed to link the effects of stoniness on vineyard productivity and quality. For this purpose, the relationships between stoniness and bulk density, texture (sand, silt, clay), organic matter and some parameters related with water availability – namely gravimetric moisture at field capacity (FC), gravimetric moisture at the Permanent Wilting Point (PWP) and Available Water Capacity (AWC) – were evaluated. The research was carried out as part of a more extensive study in which the properties, cartography and agronomic capacity of these soils were analysed.

2. Material and Methods

2.1. The site

The study area is located to the north of the boundary with the External Prebetic Zone (**Figure 1**), with an altitude between 980 and 1100 m. More specifically, the area is in the province of Albacete (near Lezuza), at the intersection of roads that connect the reliefs at the centre of the peninsula and the plateau with the Eastern Andalusia.

Since the delimitation of the physiographic units is influenced by the presence of large karstified flat surfaces, a preliminary photointerpretation was made, interspersed with field work. To this recognition, judgment sampling techniques were added for the selection of representative soil profiles.

The climate of the area is characterised by an average annual temperature of 13 °C and average annual precipitation of 400 mm, with an average duration of the dry period of 4-5 months (Ministerio de Medio Ambiente 2004). According to the Köppen-Geiger classification, the climate is Csa type (AEMET 2011).

Figure 1. Location of the study area (1:6.000.000)

From a geological point of view, the Mesozoic and Cenozoic geological ages are represented. The Mesozoic is constituted by limestones, dolomites and marls (García and Pendas 1971), which appear in sub-horizontal forms. Above these deposits, conglomerates of very rounded and heterometric quartzites appear, in some cases with a red clay matrix and in others as completely clean materials that could correspond to 'rañas' formed during the Cenozoic age.

The geomorphology of the area corresponds to the characteristic modelling derived from the nature of the geological materials, within the Mediterranean-type regime that affects the area, where the glacis of accumulation of raña-type materials and glacis of quaternary accumulation stand out. Glacis are gentle slopes that bring the upper structural surface into contact with another, softer, derived surface. Raña-type material accumulation in the majority of the hills is formed by deposits of raña, inclined surfaces of erosion, in which more or less rounded quartzite mixed with sand or clay appear.

The grape varieties that are grown in the zone are Tempranillo, Cabernet Sauvignon and Merlot.

2.2. Soil identification and sampling

Eleven soil profiles were selected in relation to soil fragment rock percentage (**Table 1**). Their description and soil sampling were carried out according to FAO (FAO 2006). Based on the morphological and analytical data, soils were classified by Soil Taxonomy (Soil Survey Staff 2014) and by WRB (IUSS Working Group WRB 2006).

2.3. Analytical methods

The usual soil physico-chemical characteristics of the samples were analysed. In profiles 1, 4, 6, 8, 10 and 11, values of gravimetric moisture were determined in triplicate for surface horizons according to the matric potentials of Richards' method (1948): gravimetric moisture at –33 kPa for Field Capacity (FC) and gravimetric moisture at –1500 kPa for the Permanent Wilting Point (PWP). Available Water Capacity was calculated by subtraction (AWC = FC – PWP).

3. Results and Discussion

The general and pedological characteristics of the investigated soils are provided in **Table 1**. The parent material was usually limestone and the stoniness is C2 class (very stony) in profiles 1, 2 and 3, C3 class (extremely stony) in profiles 8 and 9 and C4 class (stony or very stony lands) in profile 10, while there were no stones or very few stones (C1 class) in the rest of the soils. A partial view of soil profile details, photographs of some soil profile surface stoniness, fragments of petrocalcic horizon and fragments of quartzite are shown in **Figure 2**.

The lithology of the study area is very contrasted because carbonated (mainly limestone) and other non-carbonated materials (sediments of quarzitic nature) coexist and these control the distribution of the stone pavement size and the percentage of coverage (**Table 1**). This spatial variation of the cover is conditioned by the parent material nature: the rock fragments reflect the spatial variation in the previous erosion and deposition rates, but it is the anthropic action that substantiates the space distribution of the layers formed by fragments of petrocalcic horizons.

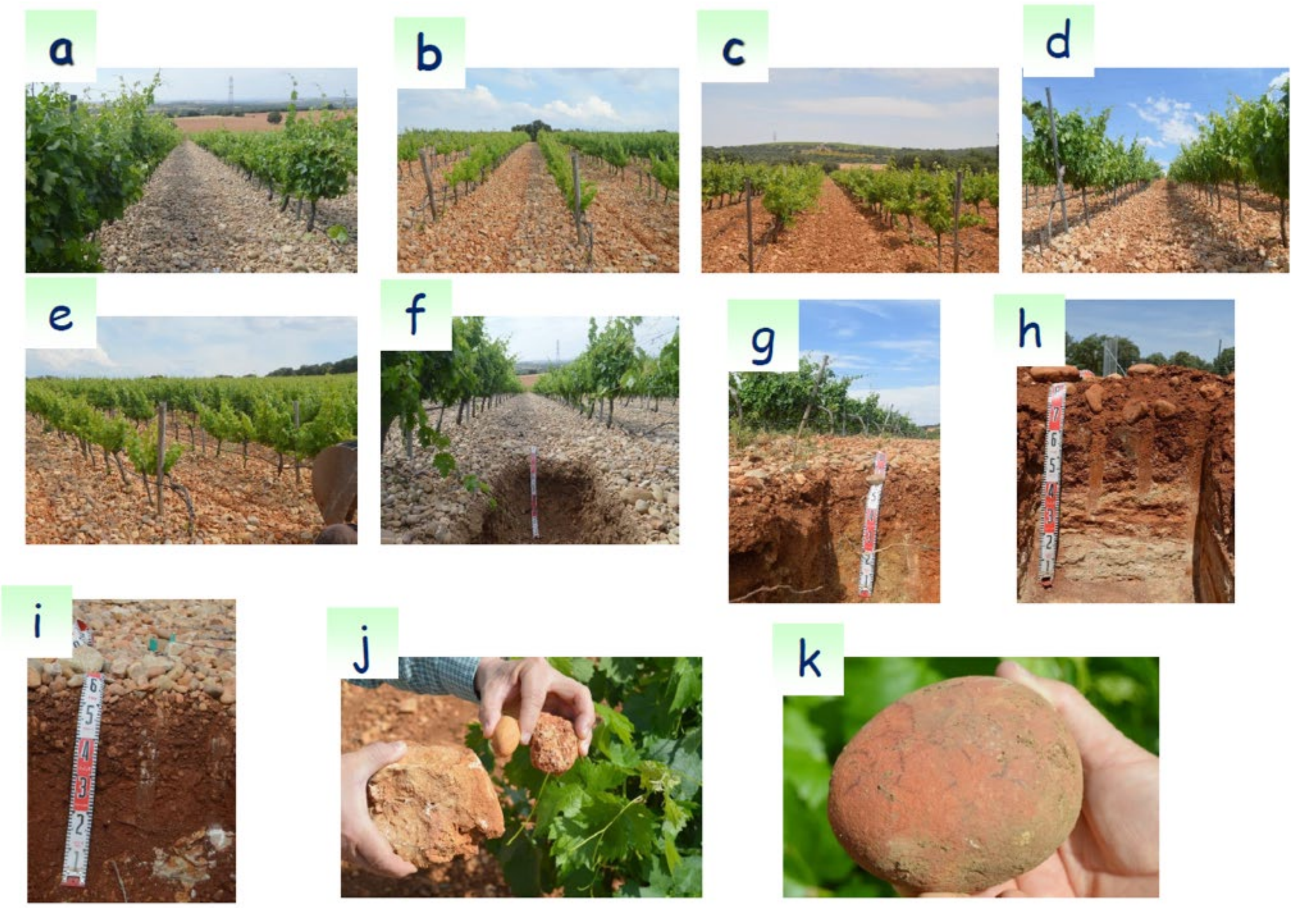

Figure 2. Photographs of partial views of some soil profile details (taken in July 2018). Photographs a, b, c, d, e, detail of some soil profile surface stoniness. Photographs f, g, h, i, details of some soil profiles. Photograph j, fragments of petrocalcic horizon and quartzite. Photograph k, fragment of quartzite. Note the thickness of the rock fragments.

Table 1. General and pedological characteristics of the investigated soils. Drainage class according to FAO (1977). Soil Type according to IUSS Working Group WRB (2006) and Soil Survey Staff (2014)

PROFILE	1	2	3	4	5	6	7	8	9	10	11
Location (Coordinates)	38º 59´ 50.4“ N - 02º 26´17.7” W (30s) 0548645 x - 4316628 y	38º 59´ 48.8“ N - 02º 26´14.1” W (30s) 0548732 x - 4316583 y	38º 59´ 52.1“ N - 02º 26´11.1” W (30s) 0548803 x - 4316682 y	38º 58´ 46.8“ N - 02º 25´10.9” W (30s) 0550258 x - 4314673 y	38º 59´ 57.9“ N - 02º 26´38.3” W (30s) 0548147 x - 4316858 y	38º 59´ 57.8“ N - 02º 26´30.3” W (30s) 0548340 x - 4316847 y	39º 00´ 46.5“ N - 02º 26´21.5” W (30s) 0548552 x - 4318361 y	39º 00´ 29.2“ N - 02º 26´07.5” W (30s) 0548883 x - 4317830 y	39º 00´ 22.4“ N - 02º 26´01.0” W (30s) 0549041 x - 4317618 y	39º 00´ 20.4“ N - 02º 25´36.2” W (30s) 0549638 x - 4317560 y	39º 00´ 25.8“ N - 02º 25´33.5” W (30s) 0549699 x - 4317729 y
Parent Material	Limestone	Limestone	Fluvial carbonated sediments	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone	Quarcitic sediments (raña)	Limestone
Topography	Karstic flat structural surface	Karstic flat structural surface	Alluvial surface	Karstic flat structural surface	Karstic flat structural surface	Karstic flat structural surface	Karstic structural surface	Karstic structural surface	Karstic structural surface	Hilly slope	Karstic flat structural surface
Slope	Flat or almost flat	Flat or almost flat	Flat or almost flat	Flat or almost flat	Flat or almost flat	Flat or almost flat	Gently inclined	Gently inclined	Flat or almost flat	Gently inclined	Flat or almost flat
Drainage	Well drained	Well drained	Imperfectly drained	Moderately well drained	Moderately well drained	Well drained	Moderately well drained	Well drained	Well drained	Well drained	Moderately well drained
Stoniness	Very stony	Very stony)	Very 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	Extremely stony	Extremely stony	Stony or very stony lands	No stones or very few stones
Morphology	Ap-Bt-R	Ap-Bt-R	Ap-AC-C	Ap-Bt-Ckm	Ap-Bw-Cg-R	Ap-Bw-R	Ap-Cg-R	Ap-C-R	Ap-Bw-C/R-R	Ap-C-2R	Ap-Bw-Cg-R
Soil Type	Leptic Luvisol (Skeletic, Rhodic)/ Inceptic Rhodoxeralf.	Leptic Luvisol (Skeletic, Chromic)/ Inceptic Rhodoxeralf.	Haplic Regosol (Calcaric, Siltic)/ Typic Xerorthent.	Calcic Luvisol (Rhodic, Novic)/ Calcic Rhodoxeralf	Endogleyc Cambisol (Calcaric, Chromic)/ Aquic Haploxerept	Leptic Cambisol (Calcaric, Rhodic) /Typic Haploxerept	Endogleyic Regosol (Calcaric, Skeletic)/ Aquic Xerorthent	Haplic Leptosol (Calcaric, Skeletic)/ Lithic Xerorthent	Haplic Cambisol (Calcaric, Skeletic)/ Typic Haploxerept	Colluvial Regosol (Eutric, Calcaric)/ Typic xerothent	Leptic Luvisol (Skeletic, Rhodic)/ Typic Xerorthent
Grape Variety	Tempranillo	Tempranillo	Tempranillo	No vineyard	Merlot	Cabernet Sauvignon	No vineyard	Tempranillo	Tempranillo	Tempranillo	Cabernet Sauvignon

Although stony ground cover is relatively common in many vineyard soils in Castilla-La Mancha, the truth is that it has hardly been studied, both from the point of view of productivity and the quality of the grapes. In fact, stoniness has been seen as positive, negative or ambivalent in general agricultural terms. According to Abrahams et al. (1994) and Schlesinger et al. (1996) surface stoniness can promote runoff and nutrient loss from the soil, with Schlesinger et al. (1990) pointing out that these losses mark steps towards desertification. With these criteria it would seem reasonable to withdraw the stony phase in soils such as those in the study area.

The soils in the study area, like others in the Mediterranean region, contain appreciable amounts of rock fragments on the surface. The percentages found vary between 50 and 30% and only in one soil was a level 15% observed (**Table 2**). The distribution of stones with depth can be seen in **Figure 3**. The presence of stones is associated with the nature of the parent rock and the gently inclined topography, where natural erosion has occurred such that rock fragments of the highest levels have accumulated at the base of the slopes (colluviums) and in the floodplains and drainage routes (floods). The stones produced by accelerated cultural actions (elimination and relocation of the stoniness by the farmers) has been added to this type of accumulation.

The organic matter contents (**Table 2**) are relatively high compared to those in other areas of Castilla-La Mancha (Amorós et al. 2015), a fact that can be related to the presence of the stone layers. Vallejo (1983), Van Wesemael and Veer (1992) and Fons and Vallejo (1999) pointed out that these fragment contents are associated with unusually high amounts of organic matter in the soil, although their studies were focused on forest soils. Our interpretation is that stony fragments affect soil temperature and humidity, as reported by De Vries (1963), Mehuys et al. (1975), Jury and Bellantuoni (1976), Childs and Flint (1990) and Ingelmo et al. (1994), while Kadmon et al. (1989), Kosmas et al. (1994), Poesen and Lavee (1994) and Van Wesemael et al. (1995) pointed out that stoniness decreases ecological aridity. The interpretation offered by Fons and Vallejo (1999) is that the layer of stones can lead to a physical and biological disconnection between the organic and mineral layers.

Table 2. Analytical results of different parameters of the studied soils

Profile (A horizon)	Stoniness (%)	Textural class	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm^3)	Organic matter (%)	*AWC (%)	*FC (%)	*PWP (%)
1	40	Loam	41.7	34.0	24.3	0.95	1.8	8.81	21.63	12.82
2	40	Loam	45.7	40.0	14.3	1.14	2.5			
3	30	Loam	35.0	40.0	25.0	1.09	2.4			
4	20	Loam	44.2	38.7	17.0	1.22	1.2	5.79	25.52	19.73
5	30	Loam	35.0	40.0	25.0	1.12	2.5			
6	40	Loam	43.0	44.0	13.0	0.86	2.2	7.25	21.76	14.51
7	15	Clay loam	42.8	30.0	27.2	1.05	1.1			
8	40	Clay loam	39.0	34.0	27.0	1.21	1.2	6.26	21.85	15.59
9	50	Clay loam	35.7	37.3	27.0	0.93	1.4			
10	50	Clay loam	61.7	28.4	9.9	1.02	1.0	8.15	13.50	5.35
11	50	Clay loam	42.2	23.4	34.4	1.06	2.9	5.84	19.36	13.52

*AWC: Available Water Capacity; FC: Field Capacity; PWP: Permanent Wilting Point.

The clay and organic material contents (**Table 2**) lead to better moisture retention properties (Saxton and Rawls 2006; Igwe et al. 2013; Pérez-

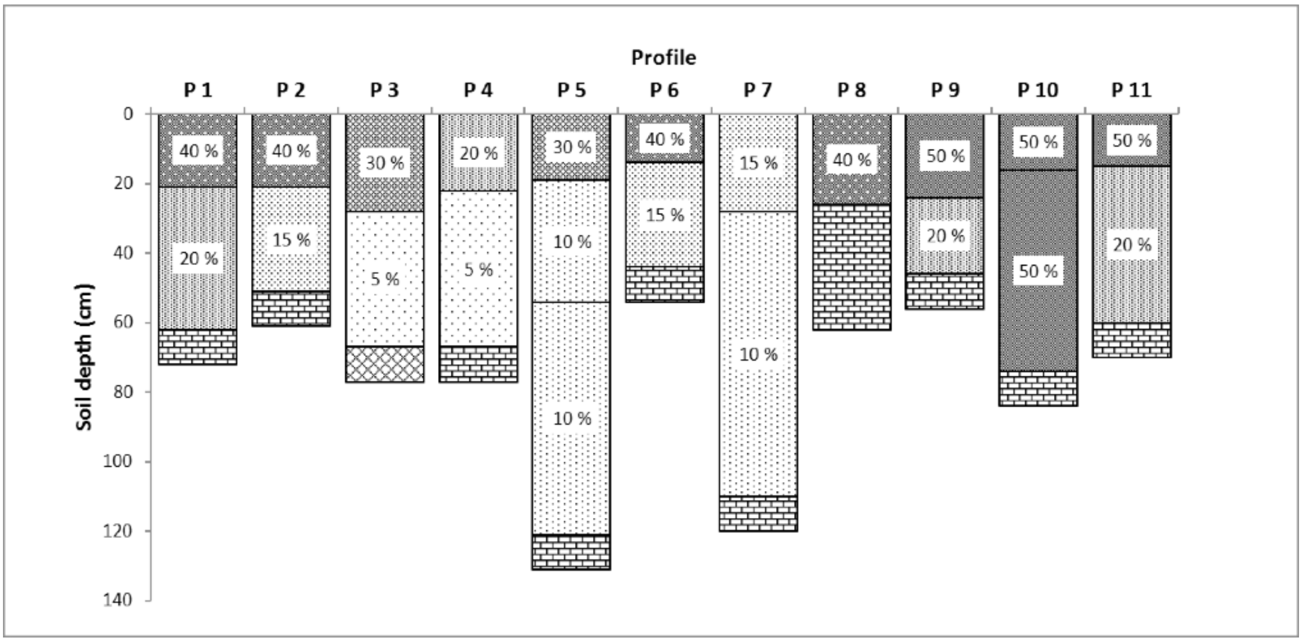

Figure 3. Rock fragment content (%) versus soil depth (cm) in the studied profiles.

de-los-Reyes et al. 2015). In general, lower bulk density should have a marked influence on AWC, which is the case here, in accordance with the results reported by Pérez-de-los-Reyes et al. (2011) and Igwe et al. (2013).

In systematic direct field observations, it has been determined that the stony fragments on the soil surface dissipate the kinetic energy of the raindrops, which is a beneficial effect with respect to possible erosion. Comparison of the contents of rock fragments in the different soils shows that, although the porosity is low, the macro-porosity increases in soils that have a greater stoniness, which implies an improvement in the penetration of the rain into the soil.

Water restrictions is one of some environmental stress factors that affect phenolic metabolism as well as grape development and chemical composition in vines (Downey et al. 2006; Teixeira et al. 2013). It is known that to produce high quality wines, the growth of sprouts and berries must take place without drought since polyphenols (anthocyanins, tannins) and aromatic compounds could be affected (Downey et al. 2006). That is why the presence of a layer of stones could be significant due to its protective function against moisture loss. In fact, stony soils force vines to search for water and nutrients in deep horizons (Jackson 2014).

On the other hand, the authors observed that the strong stoniness of the soils under investigation have a positive effect on the soil structure, since the stones impart a certain protective tapestry, which is particularly notable for the small rock fragments (approximately between 1-3 cm) since they provide high macro porosity in the topsoil. For this reason, the removal of rock fragments in vineyards should be discouraged. However, the elimination of the stoniness of soils has been an almost constant task for several generations of farmers and this has been carried out with the aim of facilitating tillage and reducing damage to certain crops (Saini and Grant 1980; Witney 1984). Until very recently (2-3 decades) in Castilla-La Mancha, farmers have removed stones even if stoniness was related to the lifting of fragments of petrocalcic horizons. Although many local farmers consider the presence of rock fragments to be beneficial, if they perceive that the coverage of stones negatively affects the productivity of their soils, they would remove a proportion of them. However, the trend observed is that Castilla-La Mancha farmers never remove all rock fragments from their fields, but rather leave sufficient gravel (small in size) in the knowledge that the stones probably help to improve infiltration, protect against erosion, retain more moisture and protect the roots. The most widely observed trend is to eliminate the gravel of larger size (> 25 cm in diameter), with those that are of intermediate sizes, i.e., between 5 and 25 cm in diameter, being partially removed. Only the smallest fragments are left in the field.

From a soil productivity and conservation point of view, most of the vineyard soils in the studied area are irrigated and it is observed that the irrigation is more effective under the stony layer, a finding that is consistent with the conclusion reached by Miller and Bunger (1963) and Unger (1971), who reported that those soils that have a layer of gravel retain more water than those that do not when water is applied. Similarly, Van Wesemael et al. (1995) considered that a high content of rock fragments facilitates the penetration of water in the soil profile, while causing (according to Poesen and Lavee 1994) a reduction in evaporation losses as a result of their low unsaturated hydraulic conductivity.

In summary, it can be deduced that the vineyard soils in the studied area are unique because of their stoniness, which is very high (6 of the 11 profiles exceed 30% and another 3 reach 50%). In addition, these stones are quartzite in nature, rounded or sub-rounded and of different sizes (cobbles, stones and boulders). It is also worth noting that these stony mantles are acidic and this contrasts with the subsurface part of the soils, which is calcareous and therefore basic in nature. The soils are unique and distinctive when compared to other vineyard soils in the Castilla-La Mancha region.

4. Conclusions

The results obtained suggest that, apart from the protective role of rock fragments on the soil surface, the presence of stones plays a definitive role in the conservation of soil moisture, which is relevant during the vineyard's growth period.

The studied area contains large areas of soils covered by a strong mantle of stony fragments. These mantles, which control the spatial variability of erosion and hydrological conditions, have a positive influence on the development of the vineyard and, given their geological characteristics (carbonated materials overlaid in stony environments with stony deposits of a quartzite nature), they could provide unique characteristics that are highly valued in the current wine market.

The experience accumulated over many years by farmers – in the sense that smaller rock fragments should not be removed from the surface of the edaphic fields – should be taken into consideration, especially if the aim is to conserve soil and water.

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