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ABSTRACT: New trends related to market incomes, cultural human development, non-sustainable soil management practices, and climate change are affecting land abandonment in Mediterranean sloping vineyards. It is generally accepted that hydrological processes and, subsequently, soil erosion rates are usually different between cultivated and abandoned soils. However, these alterations are still poorly studied in relation to the general weather conditions in vineyards and abandoned vineyards. Thus, the main goals of this research are to (1) estimate the differences in soil properties, (2) quantify water and soil losses due to rainfall and specific soil management practices, and (3) analyze which kind of weather type and rainfall event is able to generate specific surface flows and soil loss rates. To achieve these goals, we focused on the specific case of the sloping vineyards of the Montes de Málaga (South Spain). We used 4 paired-erosion plots with Gerlach troughs to quantify soil loss and surface flow and conducted an analysis of the weather conditions during each rainfall event. The weather types that generated the highest amount of rainfall in the studied area came from the western (32.6%) and southeast (28.2%) types. The low rainfall events came from the south type (5.9%) and at the 500 hPa level, whereas the rainiest ones came from the southwest (47.7%) and south (34.1%). It is confirmed that there is a bimodality in the rainfall patterns. The results of soil erosion showed that there is a mixed mechanism depending on the state of the soil (vegetation cover, compaction, and initial soil moisture), soil management (tillage, trampling effect, and the use of herbicides). It is observed that the intensity of surface flow is highly correlated to the total rainfall amount and intensity. In the poorly managed abandoned plot, it is important to remark that the effect of tillage in the past, the elimination of the vegetation cover to preserve the soil in bare condition, and its use as a grazing area by cultivating barley highly affects the generation of the highest erosive events. Therefore, it is confirmed that these soil management options are not the most sustainable way to conserve the soil after the abandonment of cultivation.

KEYWORDS: Weather type, abandonment, soil erosion, agricultural management systems, vineyard, land conservation

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Introduction

New trends related to market incomes, cultural human development, and environmental degradation processes are causing increased land abandonment,[1,2] including agricultural areas such as vineyards.[3,4] Enterprises, farmers, and consumers are playing a changing role in agricultural land degradation and abandonment. However, the causes and human perception vary significantly among regions.[5–7] On the global scale, Lasanta et al[8] estimated that almost 1.5 million km^2 of agricultural lands have been abandoned. Several studies stated that the impacts of poorly planned land abandonment can also modify future production and quality of goods and services,[9] which directly affects the local population, and also society as a whole.[10,11]

García-Ruiz and Lana-Renault[12] stated that land abandonment consequences are especially critical for semi-arid, arid, and mountain territories. Hydrological processes are usually modified by cultivated and abandoned soils.[13,14] Lesschen et al[15] and Seeger and Ries[16] affirmed that the main causes are the absence of tillage practices and slow vegetation recovery due to the formation of soil crusts, which, in turn, decrease water retention capacity and hydraulic conductivity. The main manifestations of these environmental issues are the generation of rills and gullies, sediment and water losses and the loss of soil depth, and, consequently, soil fertility.[17,18]

A recent review[19] regarding the Mediterranean vineyards confirmed that this crop registers non-sustainable soil erosion rates.[20] Several representative studies have confirmed similar critical situations in several Mediterranean countries with active vineyard plantations. Notable examples are in Spain,[21,22] Italy,[23–25] France,[26,27] Slovenia,[28] and Cyprus.[29] However, in abandoned vineyard soils, the impacts of land abandonment on soil erosion are still poorly understood.

Normally, studies about abandoned vineyards focus on vegetation recovery, soil quality changes, and biodiversity.[4,30,31] To date, little is known about soil erosion and hydrological dynamics. Using rainfall simulations, Rodrigo-Comino et al[32] compared the initial soil erosion processes in a vineyard and on abandoned land, and

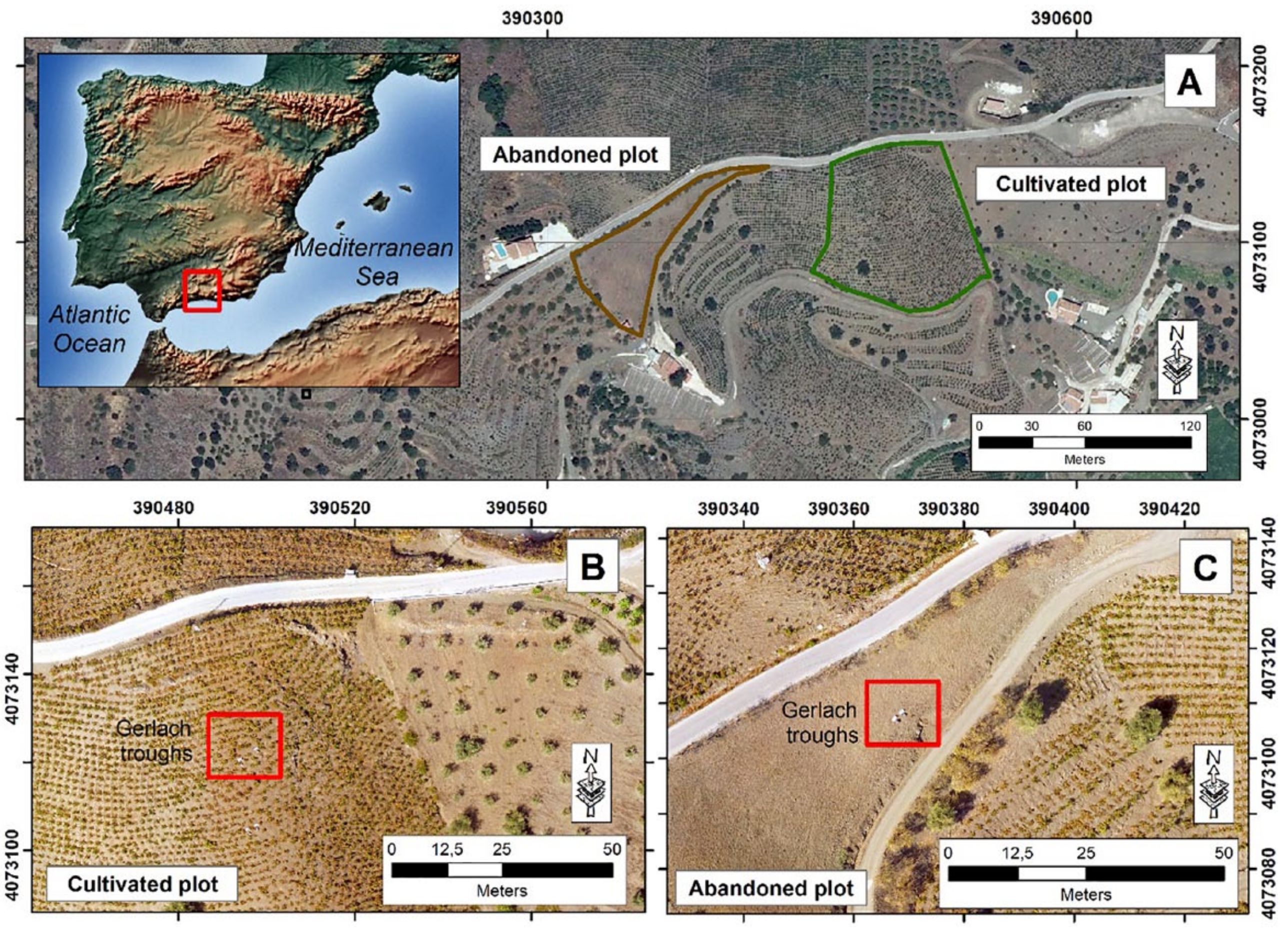

Figure 1. Localization of the study area: (A) general view of the study area (the brown line represents the abandoned vineyard and the green one the cultivated area); (B) vineyard's plot; and (C) abandoned plot.
UAV, unmanned aerial vehicle.
Source: UAV air photo by I Marzolff, Institute of Physical Geography, Goethe University Frankfurt am Main, Germany.

also other land uses such as olive, almond, and citrus orchards. The results showed that the lack of conservation of the vegetation cover by the farmers enhanced runoff generation under medium to high rainfall intensities of about 40 mm h^{-1}. In another study in German sloping abandoned vineyards, also using a small portable rainfall simulator, Rodrigo-Comino et al[33] demonstrated that, possibly due to the absence of tillage practices, a clear difference in the activation of runoff generation among the seasons (harvest and pre- or post-harvest) could not be observed. Both studies confirm that the initial hydrological and erosional dynamics are affected, but little is known about the annual evolution under different weather conditions and types, which was demonstrated to be vital for the design of future soil conservation or erosion control measures.[34–36]

Therefore, the obvious knowledge gap regarding the response of vineyard soils against abandonment processes motivated this research. Our goals are to (1) estimate the differences in soil properties, (2) quantify water and soil losses due to rainfall and specific agricultural practices, and (3) analyze which weather type and rainfall event generate specific surface flow and soil loss rates. The study area for this work is situated in the viticultural region of the Montes de Málaga in the Axarquía region, southern Spain. A total of 4 paired-Gerlach troughs were installed on the vineyard and poorly managed abandoned plots to monitor 1-year (October 2015 to October 2016) soil loss and surface flow, considering rainfall, tillage practices, and weather types as the contributing factors.

Materials and Methods

The study area

Two experimental plots located in the viticultural region of the Montes de Málaga, in the municipality of Almáchar within the Axarquía region, southern Spain, were selected (Figure 1A). Both plots (Figure 1B and C) are situated in the shoulder of 2 hillslopes with an inclination higher than 30°. The parent material is characterized by Palaeozoic dark schists, mica-schists with well-developed schistosity, small garnets (1–2 mm), and intercalations of lenticular levels of white quartz and quartz-mica schists without garnets, which have less developed schistosity, showing higher resistance than the first facies.[37] The soils are classified as *Eutric Leptosols*[38] because they are characterized by high stoniness, low organic matter content, silty loam soil textures, and near-neutral pH.

The total annual rainfall amount is 520 mm, the wettest period being from October to January. June to September is

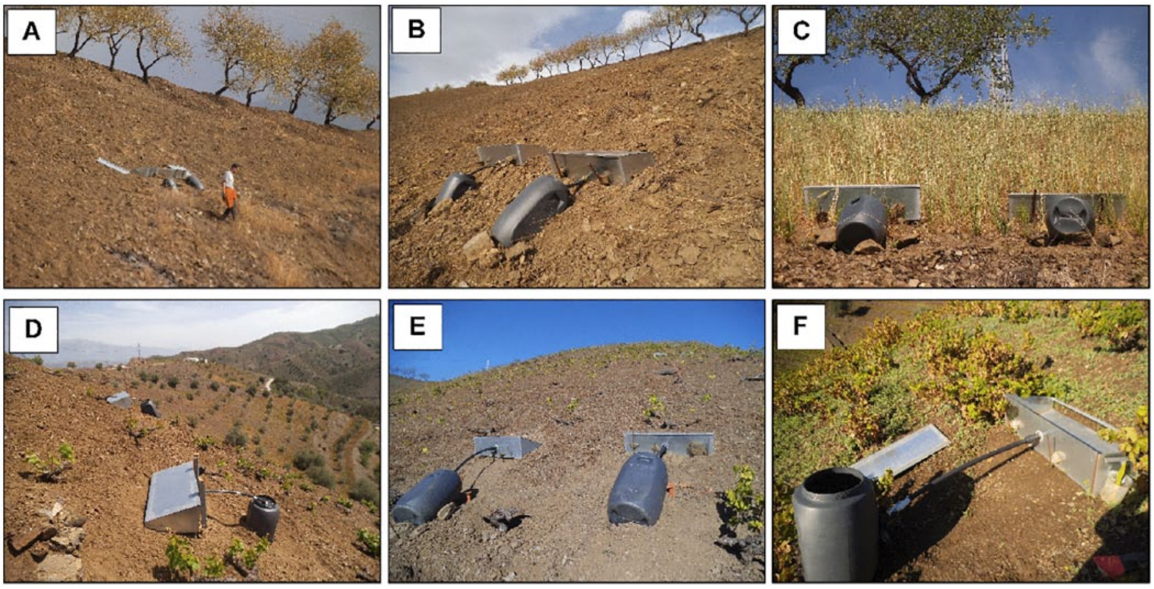

Figure 2. General views of the erosion plots: (A) installation of the Gerlach troughs in the abandoned plot; (B) bare soils in the abandoned plot after using herbicides; (C) growing of the barley for the animals; (D) installation of the Gerlach troughs in the cultivated plot; (E) general view of the cultivated plot; and (F) collecting soil erosion results from the cultivated areas after 1 rainfall event.

generally the dry season[39] with high inter-annual variability.[40,41] The temperature registers annual averages of 17.2°C, with maximums in July and August (24.5°C-24.9°C) and minimums in December through February (11.3°C-11.5°C). Also, it is important to highlight the significant thermal variability in this region.[42]

The cultivated plot follows a conventional and traditional grape production of the variety Muscat of Alexandria. It is registered by the Spanish DO (Designation of Origin) with the name of "Málaga, Sierras de Málaga, and Pasas de Málaga." Recently, the raisins have been classified as the first Globally Important Agricultural Heritage System in Europe. The last harvests (from 2014 to 2018) were made at the beginning of July using draft animals such as mules or donkeys. The soil management follows non-mechanical tillage twice a year from April to May and from October to December. In November and December, herbicides are usually used to eliminate the weeds to avoid water competition. Also, it is important to remark that natural and organic soil fertilizers from domestic cows and goats are usually added to the soil during February and March.

The farmer eliminated 20 years ago the vines from the second studied plot (Figure 2A). Once per year (usually in May), the farmer eliminates the weeds (Figure 2B) to keep the soil bare. To obtain another income from this abandoned plot, barley is sown in some parts once per year (usually in September; Figure 2C) and grazed by animals walking on the slope prior to the start of the rainy period.

Soil properties

The soil samples were collected in 2014 at 2 different depths (0-5 cm and 5-15 cm) in the row and inter-row areas and with 3 replicates. In total, 12 samples of about 3 to 4 kg each were collected. The samples were immediately air-dried and sieved through a 2-mm mesh to determine the selected physical and chemical parameters. Grain particle size distribution (percentage by volume) from 0.004 to 2 mm was determined using a Coulter LS230 and by combining different diffraction patterns of a light beam. Bulk density (BD) was measured using steel cylinders of volume 100 cm^3. The total organic carbon content was measured by the loss of weight differences after 24 hours in a muffle furnace at 430°C.[43,44] Electrical conductivity (EC) was analyzed by a digital conductivity meter and carbonates with a Bernard calcimeter. pH values were estimated in distilled water and KCl with a digital pH meter with a dilution factor of 1:5. Differences larger than 1 between the values of pH with H_2O and KCl solutions show a soil acidification trend.[45] Finally, soil water-holding capacity (SWC) was measured with a pressure plate extractor, estimating the field capacity and the permanent wilting point in percentage by mass (weight).

Surface flow and soil loss monitoring

A total of 4 paired-Gerlach troughs or sediment collectors[46] were installed, 2 each in the cultivated and abandoned plots in a similar aspect. In the vineyard, there were also 4 more paired-sediment collectors from previous research published by Rodrigo-Comino et al.[37]

The Gerlach troughs, with 1 m length and 50 L capacity, are metal collectors installed on the soil surface. In the case of the cultivated plot, they were installed in the inter-rows of the vineyard since the vines are irregularly distributed along the hillslope (Figure 2D and E). All the sediment collectors were linked to external plastic tanks (60 L) to prevent loss of data generated by heavy rains (Figure 2F). They were also provided with a slanted front edge to prevent scouring or undercutting of the sediment collector. It is important to highlight the main limitation of this erosion plot design, being that the open contributing area gives information about the surface flow and soil losses, but the exact contributing area is uncertain. Therefore, the results are summarized as proposed by Gerlach[46] in units of $g\,m^{-1}$ and $L\,m^{-1}$ for soil loss and surface flow, respectively. After each rainfall event, mobilized soil and water were collected from the Gerlach troughs. To measure the total rainfall data after each event, a Hellmann rain gauge was installed between the plots. In this research, rainfall events are separated by a minimum of 24 hours of the continuous dry period and having a minimum total rainfall amount of 0.1 mm. After each rainfall event, soil and water samples were transported to the laboratory for drying, weighing, and estimation of soil loss (g), surface flow (L), and sediment concentration ($g\,L^{-1}$).

Weather type analysis

The classification of the different weather types follows the method applied to the Iberian Peninsula by Cuadrat and Pita[47] and Gil Olcina and Olcina Cantos.[48] Rainfall events are classified into weather types depending on 4 characteristics[49]: (1) superficial synoptic maps showing pressure and rainy fronts; (2) synoptic maps at the 500 hPa level (height level and barometric pressure situations); (3) generalized superficial direction of the winds throughout Málaga province; and (4) wind direction at the 500 hPa level above Málaga province. Hourly rainfall event data from Automatic Hydrological Information System (SAIH; http://www.redhidrosurmedioambiente.es/saih/resumen/precipitacion) as well as the data collected by the rain gauge between the plots were analyzed. Rainfall event statistics of interest were (1) total amount, (2) total rainy hours, (3) total rainy days, (4) 24-hourly rainfall amounts, (5) mean intensity, (6) maximum hourly intensity, and (7) annual average rainfall amount of each weather type.

To determine the rainfall intensity values which were lacking in the study site, we applied a linear correlation between the elevation in meters and rain. Then, we applied the Thiessen polygons, measuring distance and differences in rainfall between each peripheral station and the central point, that is, our study area,[50] and considering the elevation as a key factor explaining rainfall variations.[51] The elevation and coordinates of the gauging stations used are Colmenar-Torrijos (718 m; 36.828N, –4.357W), Contadoras (758 m; 36.811N, –4.382W), Olías (421 m; 36.776N, –4.323W), Rincón de la Victoria (7 m; 36.722N, –4.279W), Moclinejo (433 m; 36.772N; –4.251W), Comares (731 m; 36.851N, –4.247W), Benamargosa (96 m; 36.837N, –4.191W), Benamocarra (126 m; 36.792N, –4.159W), and Vélez-Málaga (60 m; 36.78N, –4.099).

Statistical analysis

The statistics of the rainfall events were summarized in an Excel database (Microsoft, USA). For each Gerlach trough, the mean, the standard deviation, the total, and the maximum of soil loss and overland flow were calculated. The values were represented in bar graphs and box plots using the SigmaPlot v.13 software (Systat Software Inc, USA). To evaluate the statistically significant differences between plots and sediment collectors, we used a one-way analysis of variance (ANOVA) test. Since the normality test failed (Shapiro-Wilk), a Tukey test was performed, and when the homogeneity variance also failed, the Levene test was used. This post hoc test was applied because it is based on a studentized range distribution and allows detecting which specific groups' means (comparing the vineyard and abandoned plots) were statistically significantly different, comparing all the possible paired means. Finally, a Spearman rank correlation coefficient calculation was conducted to assess the relationships between soil loss and surface flow and weather conditions, as soil erosion and weather type results are usually characterized by non-linear trends.[52] The results were estimated at .05 and .01 levels of significance using the SPSS v.23 software (IBM, USA).

Results

Soil properties

Table 1 presents the results obtained from the laboratory analysis. In general, there are no significant differences between the soil properties in the cultivated (CT) and abandoned (AB) vineyards. Both plots show the same elevated gravel content (54%) but small differences in sand and silt contents: 22.2% and 72.2% in the CT, and 31.8% and 62.3% in the AB, respectively. The abandoned plot shows a slightly higher value of the loss on ignition (LOI) which can be attributed to the slow plant recolonization controlled at a lesser frequency than the cultivated one. The soil water content results show higher field capacity (SWC-FC) and wilting point (SWC-WP) values in the cultivated plot than in the abandoned one.

Weather types during the monitoring period

Table 2 shows the distribution of total rainfall over the different weather types at the surface and at the 500 hPa level, and the types of atmospheric situations are depicted in Figure 3. During the monitoring period, a total of 13 rainfall events were identified, which have a cumulative rainfall of 340.2 mm. The weather types at the surface that generated the highest amount of rainfall in the studied area are the W (32.6%) and SE (28.2%). The least rainy weather type at the surface is the S type (5.9%). For the 500 hPa level, the rainiest weather types are the SW (47.7%) and S (34.1%). Finally, it is important to remark that the atmospheric situation that generated the highest occurrence of rainfall in the study area is the dynamic low-pressure system (63.4%).

Surface flow and soil loss

The results of runoff and soil loss from the plots are represented in bar graphs with the rainfall amount for each erosion

Table 1. Soil properties of the cultivated and abandoned plots.

PARAMETER	GRAVEL (>2 MM) (%)	SOIL PARTICLE DISTRIBUTION (%)			LOI (%)	BD (G CM^{-3})	PH (H_2O)	PH (KCL)	CARBONATES (%)	EC (S M^{-1})	SWC-FC (%)	SWC-WP (%)
		SAND	SILT	CLAY								
CT	54.4 ± 4.7	22.2 ± 6.5	72.2 ± 6.3	5.6 ± 0.5	3.1 ± 0.5	1.5 ± 0.04	7.1 ± 0.2	5.3 ± 0.2	0.9 ± 0.1	0.10 ± 0.04	24.2 ± 1.6	7.7 ± 0.6
AB	54.3 ± 4.4	31.8 ± 5.6	62.3 ± 4.9	5.9 ± 0.8	3.5 ± 0.4	1.4 ± 0.05	7.3 ± 0.2	5.4 ± 0.6	1.4 ± 0.1	0.06 ± 0.03	19.3 ± 1.3	6.9 ± 0.3

AB, abandoned plot; BD, bulk density; CT, cultivated plot; EC, electrical conductivity; LOI, loss on ignition; SWC-FC, soil water content at field capacity; SWC-WP, soil water content at wilting point.
Values are given as mean ± standard deviation.

event shown in Figure 4. Box plots in Figure 5 show the mean (black dotted line), median (continuous line), and variability (5th and 95th percentiles) of the surface flow and soil loss of the plots. In the cultivated plot, the Gerlach troughs CT1 and CT2 registered a total of 24.5 L m^{-1} (average of 1.9 L m^{-1}) and 44 L m^{-1} (average of 3.4 L m^{-1}), respectively, reaching the highest maximum values in 4 different events in November, October, May, and January. The Tukey test showed that there are statistical differences between both plots (P = .029). In the abandoned plot, the total surface flow amount in the Gerlach trough AB1 was 25.7 L m^{-1} and in the AB2 it was 27.0 L m^{-1}. The mean values are close to 2 L m^{-1}. The Tukey test shows that there are no statistical differences between the troughs (P = .914) within the group. However, it is important to remark that the highest surface flow rates were not generated exclusively by the rainiest events.

In general, the soil loss in the cultivated plot was higher than that in the abandoned plot. CT1 registered a total soil loss of 3828.6 g m^{-1} with an average value of 294.5 g m^{-1}. Similar results, as confirmed by the Tukey test (P = .705), were obtained for CT2, with a total of 4467.8 g m^{-1} and an average value of 343.7 g m^{-1}. The highest soil loss events were found in January, March, and summer (June-September) with less rain due to harvest and tillage. On the contrary, in the abandoned plot, soil losses were much lower at 913.2 g m^{-1} (average of 70.2 g m^{-1}) and 1846 g m^{-1} (average of 142.0 g m^{-1}) in the AB1 and AB2 plots, respectively, and not showing statistically significant differences as judged by the Tukey test (P = .39). The highest soil losses were registered in May, from June to September, and October.

With respect to the surface flow, the Tukey test (P = .535) did not show any statistical differences between the AB and CT plots. However, there were statistical differences for soil losses (P = .031) between the AB and CT plots.

Relationship between weather conditions and soil erosion processes

The characterization of each rainfall event (total amount, intensity, maximum intensity, number of hours and days), surface flow, and soil erosion recorded in the cultivated and abandoned plots is summarized in Table 3. In November (November 6, 2015), weather types of SE at the surface and S at the 500 hPa level generated a rainfall amount of 67.6 mm with the second highest mean rainfall intensity (3.1 mm h^{-1}). The second highest rainfall event was developed by the W and SW weather types (56.8 mm) in October (October 20, 2016) during the second longest rainfall event (25 wet hours) which lasted 4 days. Also, this event registered the maximum peak rainfall intensity of 16 mm h^{-1}. The SE-S and W-SW weather types registered 2 events: (1) one in October (October 20, 2015) with a heavy storm over 17 hours and one in May (May 18, 2016) which was the longest duration event (67 hours) and the third biggest

Table 2. Weather type classification.

WEATHER TYPE	SURFACE WIND		WIND AT 500 HPA	
	TOTAL RAIN (MM)	PERCENTAGE	TOTAL RAIN (MM)	PERCENTAGE
E	41	12.1	0.0	0.0
SE	96	28.2	0.0	0.0
S	20	5.9	116.0	34.1
SW	35.2	10.4	162.1	47.7
W	111	32.6	58.6	17.2
NW	37	10.9	3.5	1.0
Total	340.2	100.0	340.2	100.0

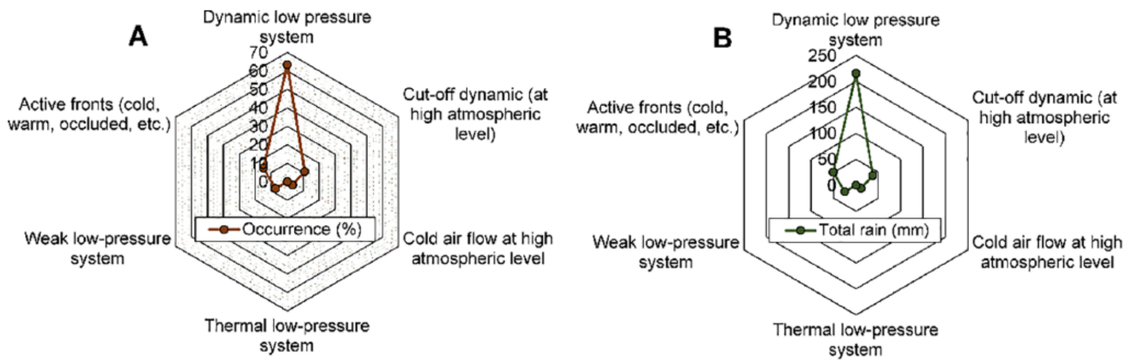

Figure 3. (A) Occurrence (%) and (B) total rainfall amount (mm) of the different atmospheric situations in the study plot area.

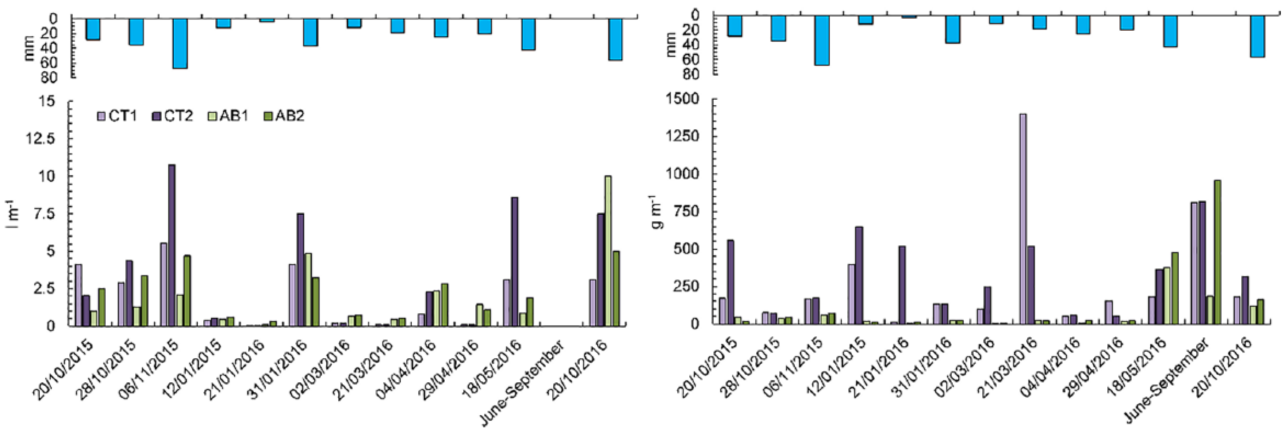

Figure 4. Results of surface flow (left) and soil loss (right) in the cultivated and abandoned plots in each rainfall event. Numbers 1 and 2 represent the number of Gerlach trough. Rainfall recorded for each event is shown at the top of the figures.
AB, abandoned plot; CT, cultivated plot.

event regarding the total rainfall amount. Conversely, events of light rainfall, low intensities, and shortest duration were generated by the E and NW weather types at the surface and the W and NW types at the 500 hPa level.

Finally, a Spearman rank correlation coefficient calculation was conducted to assess the relationships between weather conditions and the average total soil loss and surface flows of the pair of the abandoned and cultivated plots (Table 4). The highest correlation was found between the results of surface flow (SL) in the paired plots (CT and AB), and the total rainfall amount (0.938 and 0.885) and rainfall intensity (0.663 and 0.852). Also, in the cultivated plot, the rainfall intensity negatively correlates with the soil loss (–0.588). With lower correlations, the maximum rainfall intensity and the number of hours can affect the generation of surface flow but do not significantly influence the amount of soil loss. The duration of a

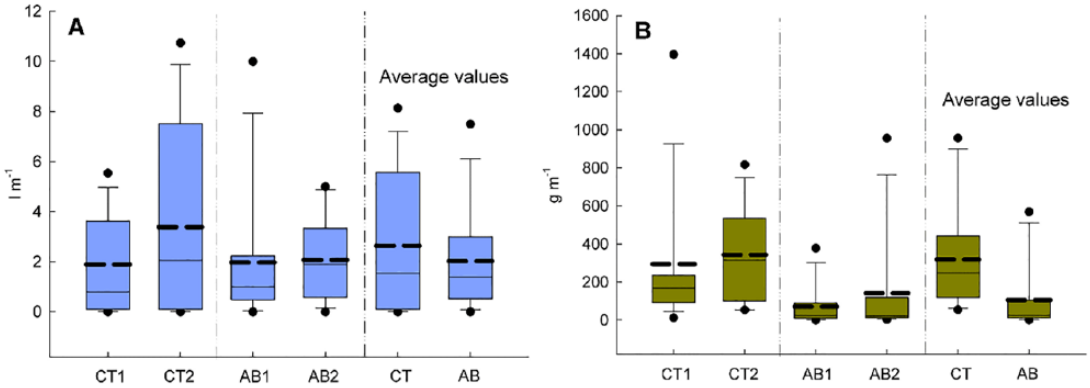

Figure 5. Box plots of (A) surface flow and (B) soil loss in the cultivated and abandoned plots. Numbers 1 and 2 represent the number of the Gerlach trough. Black circles represent the 5th and 95th percentiles.
AB, abandoned plot; CT, cultivated plot.

Table 3. Characterization of rainfall events.

	WT SURFACE	WT 500 HPA	TOTAL RAINFALL EVENT (MM)	RAINFALL INTENSITY (MM H^{-1})	INT. MAX. (MM H^{-1})	NO. HOURS	NO. DAYS	SL-CT (G M^{-1})	SF-CT (L M^{-1})	SL-AB (G M^{-1})	SF-AB (L M^{-1})
October 20, 2015	SE	S	28.4	1.7	10.4	17	4	362.8	3.1	31.0	1.8
October 28, 2015	W-SW	W	35.2	1.9	16.3	19	3	73.3	3.6	41.2	2.3
November 6, 2015	SE	S	67.6	3.1	4.1	22	3	169.8	8.1	67.5	3.4
January 12, 2016	NW	W	12	1.5	5.9	8	3	522.6	0.5	12.6	0.6
January 21, 2016	E	NW	3.5	0.4	1.3	8	1	264.4	0.04	6.7	0.2
January 31, 2016	E	SW	37.5	2.3	3.3	16	2	132.6	5.8	24.9	4.1
March 2, 2016	W	W	11.4	1.4	5.7	8	9	173.9	0.2	1.3	0.7
March 21, 2016	NW-W	NW-SW	18.8	0.9	2.7	21	5	956.5	0.1	22.8	0.5
April 4, 2016	NW	SW	25	12.5	2.3	2	2	54.4	1.5	13.8	2.6
April 29, 2016	S	S	20	0.7	6.8	31	4	103.4	0.1	20.2	1.3
May 18, 2016	W	SW	42.8	0.6	8.1	67	9	272.2	5.9	427	1.4
September 7, 2016	S	W	0	0.0	0.0	0	0	813.8	0.0	569.9	0.0
October 20, 2016	W	SW	56.8	2.3	16.6	25	4	248.5	5.3	141.1	7.5

AB, abandoned plot; CT, cultivated plot; Int. max., hourly intensity maximum; No. days, number of days raining per event; No. hours, number of hours raining per event; SF, average total surface flow between the paired-Gerlach troughs; SL, average total soil loss between the paired-Gerlach troughs; WT surface, weather type at surface level; WT 500 hPa, weather type at 500 hPa.

rainfall event does not show any correlation with either the surface flow or soil loss.

Discussion

Soil erosion activation and differences among cultivated and abandoned vineyards

In the past, several authors have indicated that a low content of organic matter and a high fraction of stones embedded in or on the surface can determine the runoff activation by enhancing or inhibiting the infiltration processes.[53,54] As observed in Figure 2, the rocks are embedded and lying on the soil surface as well, and it may, therefore, be possible that a mixed mechanism of Hortonian and Hewlettian runoff developed along the hillslope, generating a high variability of runoff and soil mobilization.[17,55] Arnau-Rosalén et al[56] and Ruiz-Sinoga and Martínez-Murillo[57] stated that the soil surface components (SSCs) play a vital role in the hydrological mixed patterns, which, with the low content of sand and the high content of silt, would cause particle detachment after heavy storms or tillage practices.[58,59]

Table 4. Spearman rank correlation coefficient between weather conditions and soil erosion processes.

PLOT	TOTAL RAINFALL EVENT (MM)	RAINFALL INTENSITY $\bar{x}$ (MM H^{-1})	INT. MAX. (MM H^{-1})	NO. HOURS	NO. DAYS
CT SL	−0.390	−0.588*	−0.176	−0.088	0.150
CT SF	0.938**	0.663*	0.531	0.517	0.243
AB SL	0.505	−0.016	0.253	0.381	−0.028
AB SF	0.885**	0.852**	0.505	0.392	0.084

AB, abandoned plot; CT, cultivated plot; Int. max., hourly intensity maximum; No. days, number of raining days per event; No. hours, number of raining hours per event; SF, total surface flow; SL, soil loss.
*Significant correlation at .05; **significant correlation at .01.

Our results confirmed that the total amount of rainfall and the average intensity show a high correlation with the surface flow, but not with the soil loss in the cultivated plot which follows an irregular mechanism of redistribution along the hillslope as was documented by the pioneering investigation of Lasanta,[60] and the more recent work performed in France by Follain et al[61] and Quiquerez et al.[62] Therefore, it is important to highlight that 1 or more factors could be playing a vital role in soil erosion activation related to surface processes such as roughness,[63] rill formation,[64] or shallow flow transport.[65] Something that could happen is high variability of the capacity of flow to transport the sediments, which could significantly change because of the tillage practices[23] and the variation of the soil moisture content that enhances the saturation processes.[66,67]

As suggested by several researchers monitoring or applying techniques for long periods of soil erosion,[23,68,69] human factors could be a determinant for the activation of erosion due to tillage or clearing the vegetation cover. In the cultivated plot, the highest soil erosion events occurred after the harvest (summer) with the influence of the trampling effect[70] and hand-made tillage,[37] and during the strongest storm when the soil remained bare because of the use of herbicides and the shedding of the vine leaves. This dynamic was highly recognized in pioneering studies by Kosmas et al[71] and Ramos and Porta.[72]

In vineyards, the role of SSC, tillage, and trampling is still poorly studied, but there is none in poorly managed abandoned vineyards.[33] It is important to remark that the results related to SWC at field capacity and wilting point contradict the soil textural interpretations because it is well known that higher contents of sand and clays increase the stability of the aggregates.[73,74] However, we hypothesize that the effect of tillage in the past, and the lower content of carbonates, could have modified the aggregate stability, making the aggregate more stable, which is also reflected in a higher BD.[75,76]

In the abandoned plot, there is no vegetation cover because of a very generalized perception by the farmers in the Mediterranean vineyards to make their properties tidy by removing the vegetation cover.[77] Again, we observed that the highest erosive events were recorded in 2 specific periods: first, when the soil was cleared of plant cover (autumn and winter) by the farmers with herbicides; second, to obtain some cash flow from the abandoned soils in this area, the farmers plant barley for animals in July-August. When the barley grows, the animals graze on the plots, thus generating a high impact due to the trampling effect and the elimination of the vegetation cover. Therefore, we could confirm that this soil management is probably not the most sustainable way to conserve the soil after abandonment. These issues should be considered to adjust the soil management systems according to the Sustainable Development Goals for people and the planet and Land Degradation Neutrality.[78,79]

Understanding soil erosion responses using the description of weather types

This article could show the first application of a weather type classification and asesesment of soil erosion processes proposed by Nadal-Romero et al[35] in vineyards. The weather types at the surface that generated the highest amount of rainfall in the studied area came from the west (32.6%) and southeast (28.2). The weather type that registers the least rainy events at the surface came from the south type (5.9%) and at the 500 hPa level, whereas the weather type with most of the rains came from the southwest (47.7%) and south (34.1%). This observation is in agreement with other climate research that confirmed the highest rain events occurred with these origins because of the warm air winds and the influence of the Strait of Gibraltar.[80,81]

It was observed that there is a bimodality in rainfall patterns on the surface and for the circulation at 500 hPa. For the 500 hPa situation, we could hypothesize that it could be also less dependent on the relief disposition and morphology because the distances between sectors are smaller, being very contiguous (W-SW-S). However, soil erosion activation could also start up with raindrop impact geometry, and recently many more papers on that have started to appear.[82,83] It is rare that the flow at 500 hPa comes from the east in the studied region except in the situations of a Rex Block as defined at Basic Wave Patterns; see https://www.weather.gov/jetstream/basic.[84]

On the other hand, it is relevant to pay attention to the maximum intensities. They are also consistent with the summary values in that the most intense events occurred with the

W, SW, and SE (on the surface) types and similar positions in height. The duration of the event, both in hours and days, does not seem to be ascribed to any type of weather. In fact, there are slow and fast barometric fronts and dynamic low-pressure systems, and they follow one another without any apparent order. These results also agree with some Mediterranean cultivated areas.[35,36] The slow-moving systems could be responsible for the long-duration events, and the fast-moving ones for the events of short duration (Figure 3). Also, in the cultivated plot, the rainfall intensity negatively correlates with the soil loss (–0.588). It would be interesting to further study this negative correlation, which could be explained because of the higher runoff depth that limited the soil detachment (splash) during heavy storms.

Future research directions

In the future, it is clear that an elevated number of rainfall events should be used to confirm or reject the weather type pattern outcomes obtained in this research. The results obtained in this research should be contrasted with the investigations published by other authors that also worked with modeling.[85] However, we agree that it is very difficult to compare our results based on 13 rainfall events with other studies that were conducted with several years of monitored data.[18,86] Therefore, in the future, we expect to collect more data to reach a stronger trend to confirm this first approach.

Moreover, further research should be conducted comparing this poorly managed abandoned vineyard with others where the vegetation is managed during the year as indicated by authors in other Mediterranean areas.[12,15] This could help develop the most useful strategies for designing soil conservation measures, which also affect other soil physical and chemical properties.[3,4,30]

Moreover, over a sloping soil surface having more than 30° of inclination, rainfall distribution would vary with wind direction and velocity as well as hillslope aspect and degrees (trigonometric model, eg, Sharon[87] and Sharon and Arazi[88]). When the effect of rainfall on soil loss and surface runoff is at stake, the variation of rainfall distribution with rainfall incidence could become a serious issue to deal with the final results, for example, as represented in Figure 3. In erosion processes, especially on highly sloping surfaces where wind also acts during rainfall, recognizing the inclined raindrop impact, a correction factor should be considered to estimate actual rainfall flux on the surface.[89,90]

Conclusions

In this research, we have presented an initial approach for relating weather types and soil loss in a cultivated and abandoned sloping vineyard. Regarding the results of soil loss in the cultivated area, we can confirm that there is a mixed mechanism that will depend on the state of the soil (vegetation cover, tillage, compaction) influenced by the soil management (tillage, trampling effect, and the use of herbicides) and the intensity of the surface flow, which is highly correlated with the total rainfall amount per event and rainfall intensity. In the poorly managed abandoned plot, it is important to remark that the effect of tillage in the past, the elimination of the vegetation cover to render the soil bare, and its use as a grazing area by cultivating barley highly affects the generation of the highest erosive events. Therefore, we could confirm that this soil management is probably not the most sustainable way to preserve the soil after abandonment in this area.

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Author Contributions

JR-C: Data collection; data analysis; ms writing; ms final proof.
JMS: Data collection; data analysis; ms wirting.
JAS-M: Data collection; ms writing.
YGA: ms writing; final proof.
JDR-S: ms writing, ms final proof.
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