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Contrasted Impact of Land Abandonment on Soil Erosion in Mediterranean Agriculture Fields

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ABSTRACT

Abandonment of agricultural land results in on- and off-site consequences for the ecosystem. In this study, 105 rainfall simulations were carried out in agriculture lands of the Mediterranean belt in Spain (vineyards in Málaga, almond orchards in Murcia, and orange and olive orchards in Valencia) and in paired abandoned lands to assess the impact of land abandonment on soil and water losses. After abandonment, soil detachment decreased drastically in the olive and orange orchards, while vineyards did not show any difference and almond orchards registered higher erosion rates after the abandonment. Terraced orchards of oranges and olives recovered a dense vegetation cover after the abandonment, while the sloping terrain of almond orchards and vineyards enhanced the development of crusts and rills and a negligible vegetation cover resulted in high erosion rates. The contrasted responses to land abandonment in Mediterranean agricultural lands suggest that land abandonment should be programmed and managed with soil erosion control strategies for some years to avoid land degradation.

Key Words: erosion rate, Mediterranean crop, rainfall simulation, terrace, vegetation cover

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INTRODUCTION

The abandonment of agricultural land results in on- and off-site consequences for soil system, but it is mostly ignored by scientific research in comparison to the investigations carried out at watershed- and slope-scale approaches (García-Ruiz and Lana-Renault, 2011). With social and economic changes in the 20th century, non-planned abandonment of agricultural land took place in developed regions due to the intensification and mechanization of agriculture. It is widely accepted that land abandonment results in a shift in the system's behavior, which can enhance land degradation processes with increasing soil erosion by water (Ries, 2010; Keesstra *et al.*, 2012a), reduce biodiversity (Cammeraat *et al.*, 2005), and cause changes in river discharges (Plieninger *et al.*, 2014) and soil quality (van Hall *et al.*, 2017). The abandonment of agricultural land is a part of the dynamic change in land uses in developed countries, and the Iberian Peninsula in the Mediterranean belt is a good laboratory to research its impact on the ecosystems (García-Ruiz *et al.*, 2010).

During the second half of the 20th century, the Mediterranean belt of Europe was affected by an intense process of land abandonment that resulted in the desertification of the rural areas due to the lack of population (Bell *et al.*, 2010). Land abandonment is a consequence of biophysical and human determinants (Novara *et al.*, 2017). Several factors can trigger land abandonment in the Mediterranean: i) low economic benefits and limited ability to compete in global markets (MacDonald *et al.*, 2000), ii) rugged terrain that reduces afforestation success (Nadal-Romero *et al.*, 2014), iii) shallow soils with highly erodible parent materials (Regüés and Nadal-Romero, 2013; Bienes *et al.*, 2016), and iv) environmental and socioeconomic constrains to introduce other activities such as livestock (Pulido-Fernández *et al.*, 2013) or organic farming due to the recurrent long periods of drought (Ruiz-Sinoga *et al.*, 2012; Nadal-Romero *et al.*, 2015).

Vegetation recovery that occurs after abandonment is characterized by changes in the biomass and floristic composition. Herbs and shrubs recover fast (< 5 years)

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after the abandonment (Lasanta *et al.*, 2015). However, vegetation recovery is by far slow in semi-arid areas as well as in the Mediterranean territories, where water is the key resource for plant recovery (Cammeraat *et al.*, 2005; Ruiz Sinoga and Martinez Murillo, 2009; Ries, 2010). In the cultivated fields, the removal of weeds by tillage or herbicides results in extremely high erosion rates (Cerdà *et al.*, 2016; Prosdocimi *et al.*, 2016a). Farmers promote bare soils to reduce the amount of water used by weeds and catch crops and this increases the soil and water losses by surface wash due to the lack of vegetation (Cerdà *et al.*, 2018). Agricultural fields are perceived as tidy and, therefore, seen by farmers as the way their orchards should look (Keesstra *et al.*, 2016; Sastre *et al.*, 2016). Recently abandoned soils show high bulk densities and low aggregate stability (Verbist *et al.*, 2007; Bienes *et al.*, 2016), and high soil and water losses (Shi *et al.*, 2010; Yazdanpanah *et al.*, 2016). Once the soil is not ploughed, bulk density increases, surface crusts develop, overland flow takes place, and soil erosion reaches high rates (Robledano-Aymerich *et al.*, 2014). However, vegetation recovery can reduce the raindrop impact, reduce the surface wash velocity, increase the infiltration rates, and as a consequence, reduce soil losses (Breton *et al.*, 2016; Keesstra *et al.*, 2016). The successful recovery of vegetation after abandonment needs a properly integrated, extensive livestock to preserve the abandoned land and to avoid forest fires (Mataix-Solera *et al.*, 2011). This is relevant to understand the carbon cycles and the ecosystem services offered by the soils (Peregrina, 2016; Szalai *et al.*, 2016; Novara *et al.*, 2017). Similar to other land use changes, the fate of the abandoned land will also determine soil erosion rates, wherein there is an interaction between the vegetation and the erosion processes.

High erosion rates in the Mediterranean are contributed to the climatic conditions and cultural development, as well as a consequence of millennia-old ploughing management that has resulted in physical, biological, and chemical soil degradation (Govers *et al.*, 1994; Gómez *et al.*, 1999; Al-Kaisi *et al.*, 2005). The most recent scientific literature shows many examples of high erosion rates. In persimmon orchards in East Spain, Cerdà *et al.* (2016) recorded lowering of soil depth by 0.5 mm during 1 h, as a consequence of raindrop impact and surface wash, in a 10-year return period storm event. Keesstra *et al.* (2016) reported that, in the soils planted with apricot trees, herbicide application resulted in 1.8 and 45.5 times more erosion than tillage and covered treatments, respectively. By conducting rill experiments in extensive plantations of almonds with bare soils from Southeast Spain on badland morphologies, Wirtz *et al.* (2013) measured sediment concentration values up to 401.5 g L^{-1}. Prosdocimi *et al.* (2016a), Rodrigo-Comino *et al.* (2016b), and Rodrigo-Comino and Cerdà (2018) demonstrated that vineyards with bare soils yielded large amounts of sediment and runoff discharges.

All the above-mentioned examples from the Mediterranean demonstrate that it is necessary to develop successful land management policies and assess soil degradation processes at the pedon scale to understand soil quality, the detachment of soil particles, and the runoff initiation (Nearing *et al.*, 1999; Khaledian *et al.*, 2017). It is also well accepted that the nature-based solutions, such as grass covers, catch crops, or geotextiles, should be involved in the new agriculture to solve the lack of sustainability (Giménez-Morera *et al.*, 2010; Palese *et al.*, 2015; Feng *et al.*, 2016). Experiments with small portable rainfall simulators are considered as a useful tool for measuring soil erosion processes and mechanisms such as splash, inter-rill erosion, and runoff generation (Iserloh *et al.*, 2013a, b). Rainfall simulators offer the possibility to quantify soil detachment and runoff initiation with high accuracy and under low-frequency high-magnitude rainfall events. This study aimed to determine the effect of the abandonment of agricultural lands (vineyard and almond, orange, and olive orchards) on soil erosion in the Mediterranean belt of Spain. This will inform policy makers to design programmed abandonment to avoid non-sustainable soil erosion.

MATERIALS AND METHODS

Study sites

Four study sites were selected in Southeast Iberian Peninsula, the Mediterranean belt of Spain (Fig. 1). At each study site the cultivated (vineyards and almond, orange, and olive orchards) and abandoned lands were selected following the paired plot sampling strategy. The main characteristics are given in Table I.

The vineyard plots were selected in Almáchar, Málaga. The altitude ranges from 300 to 400 m above sea level (a.s.l). The vineyard was situated on the steep slopes of $> 30°$ with the grape variety muscat of Alexandria. Conventional ploughing has been conducted over millennia. Clear signals of soil erosion in the form of rills were surveyed (Rodrigo-Comino *et al.*, 2017c). Mean annual rainfall is 520 mm and mean annual temperature is 17.2 °C. Total organic carbon ranged from 31 to 35 g kg^{-1} in silty soils (72.2%). The soil parent material is Paleozoic dark schist. The soils

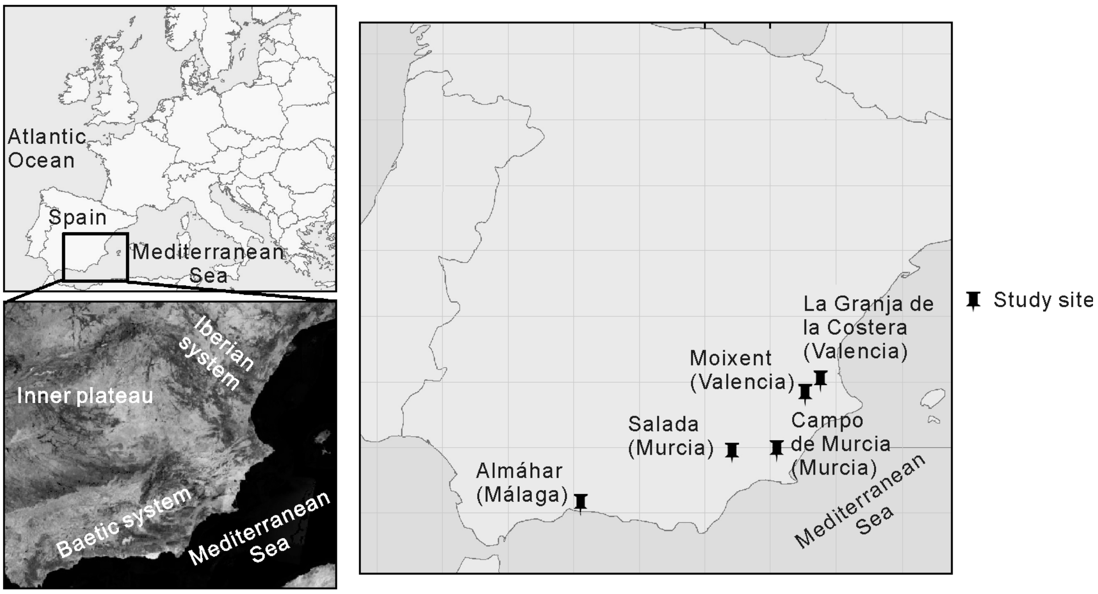

Fig. 1 Location of the study sites in the Mediterranean belt in Spain.

TABLE I

Main characteristics of the cultivated (vineyards and almond, orange, and olive orchards) and abandoned lands in the Mediterranean belt of Spain

Characteristic	Vineyards	Almond orchards	Almond orchards	Orange orchards	Olive orchards
Study site	Almáchar, Málaga	Salada, Murcia	Campo de Murcia, Murcia	La Granja de la Costera, Valencia	Moixent, Valencia
Altitude (m a.s.l.[a])	300–400	300–310	258	130	340
Soil tillage	Hand-made tillage and herbicides	Machinery and herbicides	Tillage	Herbicide	Tillage
No. of plots	Cultivated: 14 Abandoned (20)[b]: 9	Cultivated: 4 Abandoned (40): 6	Cultivated: 6 Abandoned (> 15): 6	Cultivated: 10 Abandoned (3): 10 Abandoned (10): 10	Cultivated: 10 Abandoned (5): 10 Abandoned (20): 10
Mean annual temperature (°)	17.2	11.6	17.8	16	14
Mean annual rainfall (mm)	520	414	258.8	590	450
Soil property					
Geology	Metamorphized schits and quartzites	Conglomerates with a clayey to loamy matrix	Marls and limestones	Limestones, although developed on fluvial materials	Cretaceous limestones and Tertiary marly deposits
Clay (%)	5.6	27.3	9.9	32.3	28.6
Silt (%)	72.2	42.1	79.4	42.1	42.1
Sand (%)	22.2	60.6	16.7	20.6	30.3
Total organic carbon (g kg^{-1})	Cultivated: 31 Abandoned (20): 35	Cultivated: 5 Abandoned (40): –	Cultivated: 33 Abandoned (> 15): 28	Cultivated: 12 Abandoned (3): 23 Abandoned (10): 54	Cultivated: 10 Abandoned (5): 21 Abandoned (20): 32
pH	7.6	8.3	8.4	7.8	7.2

[a] Above sea level.
[b] Data in parentheses represent years of abandonment.

can be described as Eutric Leptosol (IUSS Working Group WRB, 2015) and are characterized by high stone content and shallowness less than 30 cm (Rodrigo-Comino *et al.*, 2017b).

The almond orchards were located in Salada and Campo de Murcia municipalities, Murcia Province. Both study sites received the same traditional soil tillage and were cultivated with almonds. The soils in Salada are developed in marls and show low organic matter content (5 g kg^{-1}). The grain sizes include 27.3% clay, 42.1% silt, and 60.6% sand. In Salada, mean annual temperature is 11.6 °C and mean annual rainfall is 414 mm. The soils in Campo de Murcia are characterized by marls and limestones with high silt contents (79.4%), but low clay particles (9.9%). Total organic carbon content was low (28 and 33 g kg^{-1} in the abandoned and cultivated orchards, respectively). In Campo de Murcia mean annual temperature is 17.8 °C and mean annual rainfall is 258.8 mm.

The olive orchards were located in Moixent, Southwest Valencia Province at 350 m a.s.l. on agriculture terraces without inclination. Manzanilla was the olive variety used, and tillage has been used over millennia in this traditional rain-fed agriculture region. Two abandoned fields of 5 and 20 years were selected to compare with the active one. The traditional management consisted of four ploughs per year in the active field. Soil grain sizes were 30.3% sand, 42.1% silt, and 28.6% clay. Total organic carbon ranged from 10 (cultivated) to 32 g kg^{-1} (abandoned for 20 years), with values around 21 g kg^{-1} in the 5-year abandoned orchard (Rodrigo-Comino *et al.*, 2017a). The parent materials are marls. Rills can be found after thunderstorms in the ploughed active soils, but can not in the abandoned ones where the vegetation recovery was very fast. Mean annual rainfall reaches up to 450 mm, with minimum and maximum in August and October, respectively.

The orange orchards were selected in La Granja de la Costera Municipality, located in the south of Valencia Province. The orchards were flood irrigated and herbicides were used to avoid weeds and keep the soil bare. Mean annual rainfall is 590 mm and the parent materials are limestones. The soils are characterized by the lack of rock fragments and the widespread presence of surface crust when under agricultural use due to the extensive use of herbicides in the orange plantations. Total organic carbon content varied between 12 (cultivated) and 54 g kg^{-1} (abandoned for 10 years), with 23 g kg^{-1} in the orchards abandoned for 5 years. The grain size of the soil is 20.6%, 42.1%, 32.3% for clay, silt, and sand, respectively.

Rainfall simulation in laboratory

The rainfall simulator is a nozzle type, which was described by Cerdà (1997) and Iserloh *et al.* (2012), and is widely used in Europe (Iserloh *et al.*, 2013a). A calibrated and reproducible rainfall of 40 mm h^{-1} was sprayed from a height of 2 m by a Lechler 460 608 nozzle on a 0.28 m^2 circular test plot. The simulator was covered by a rubber tarpaulin to avoid external influences such as wind. Duration of the rainfall simulation experiments was 30 min, divided into six intervals of 5 min each to collect the runoff discharge and take samples to determine the sediment concentration. The collected runoff water in each bottle was filtered separately with fine-meshed filter paper. The filtrates were dried to constant weight at 105 °C and weighed for getting soil loss for each 5-min interval. Roughness was measured by the chain method (Saleh, 1993).

Statistical analysis

Rainfall simulation results were plotted for each study site with the means per 5-min interval. For comparison, data of sediment load (SL, g m^{-2}), runoff (L m^{-2}), and sediment concentration (SC, g L^{-1}) were presented as box plots showing the medians, means, 5% and 95% percentiles, and outliers. Finally, to compare the data with each other and to assess the environmental factors determining soil erosion processes, a Spearman rank coefficient using SPSS 23 software (SPSS, USA) and a *t*-test with SigmaPlot 13 (Systat Software, Inc., USA) were conducted after performing a Shapiro-Wilk test.

RESULTS

Plot characteristics

The study plots showed different characteristics among the study sites as they represented different cropping systems (Table II). The lowest slope values (0°) were registered in the olive and orange orchards and the highest in the vineyards between 31.3° (cultivated) and 33.6° (abandoned). The contrasting slope angles are due to different strategies employed by the farmers. In Valencia (Moixent and Granja de la Costera study sites), the slopes were terraced, but in Málaga (Almáchar study site) and Murcia (Salada and Campo de Murcia study sites), the slopes were ploughed without any conservation strategy. Vegetation cover (VC) in cultivated plots showed minimum values close to 1.5%–13% in the vineyards and almond orchards, and 0% in the olive and orange orchards due to tillage and herbicides. The highest VC values (95%) were observed in the abandoned olive (20 years) and orange orchards (10 years) due to the successful natural revegetation. Average VC ranged between 1.7% (almond orchards in Campo de Murcia) and 54.7% (olive orchards abandoned for 20 years in Moixent). High values of rock cover were observed, with the highest (87.7%) in the vineyards. The highest roughness values (116%) were observed in the olive and orange orchards. Regarding time to runoff generation, vineyards and almond and orange orchards showed the highest values of 644, 660, and 955 s, respectively. The abandoned plots of vineyards and almond orchards registered quicker runoff than those under cultivation, while the plots of the abandoned orange and olive orchards showed a delayed runoff initiation due to the successful vegetation

TABLE II

Environmental characteristics and time to runoff generation (t_r) of the study plots

Plot[a)]	Result[b)]	Slope	Vegetation cover	Rock cover	Roughness	t_r
		°	%			s
V-c	Mean	31.1 ± 8.5	3.4 ± 2.6	87.7 ± 9.4	104.2 ± 1.9	644 ± 461
	Max./Min.	42/15	10/0	95/60	108.0/102	1 378/125
V-ab	Mean	33.6 ± 7.4	28.9 ± 15.6	56.1 ± 13.2	117.1 ± 14.9	611 ± 311
	Max./Min.	45/18	60/10	70/35	147.4/105	970/194
A1-c	Mean	4.6 ± 1.6	1.9 ± 2.4	4.4 ± 1.3	103.4 ± 0.7	225 ± 119
	Max./Min.	7/3.5	5/0	5/2.5	104.0/102	330/74
A1-ab	Mean	7.6 ± 2.3	7.3 ± 4.0	44.2 ± 38.7	104.6 ± 2.3	301 ± 218
	Max./Min.	11/4.5	15/5	90/5	108.6/101.6	702/135
A2-c	Mean	4.3 ± 5.5	2.5 ± 4.5	64.2 ± 40.0	103.8 ± 3.2	660 ± 509
	Max./Min.	15/0	10/0	100/10	110.0/101.7	1 380/300
A2-ab	Mean	5 ± 6.3	1.7 ± 6.3	77.5 ± 24.8	104.2 ± 2.4	360 ± 73.5
	Max./Min.	15/0	10/0	100/40	107.5/101.7	480/300
O-c	Mean	0	0	33.7 ± 11.4	116.2 ± 2.5	955 ± 31
	Max./Min.	0/0	0/0	46/5.9	121.4/112.5	1 001/912
O-ab3	Mean	0	54.7 ± 8.3	4.9 ± 1.7	107.2 ± 1.9	386 ± 32
	Max./Min.	0/0	67/45	8/3	110.2/103.9	441/340
O-ab10	Mean	0	95.6 ± 3.7	10.7 ± 7.2	100.5 ± 35.3	972 ± 43
	Max./Min.	0/0	100/89	22.2/5	115.3/0.3	1 032/902
Ol-c	Mean	0	0	50 ± 16.5	116.8 ± 3.5	352 ± 25
	Max./Min.	0/0	0/0	65/6.5	123.2/110.3	387/312
Ol-ab5	Mean	0	35.8 ± 5.8	50 ± 16.5	110.3 ± 2.16	683.3 ± 79
	Max./Min.	0/0	43/25	65/6.5	114.5/106.6	713/435
Ol-ab20	Mean	0	78.7 ± 17.0	66.8 ± 26.4	113.5 ± 5.3	1 113 ± 324
	Max./Min.	0/0	99/38	97/8.7	124.3/107.6	1 398/627

[a)] V = vineyards in Almáchar, Málaga; c = cultivated; ab = abandoned; A1 = almond orchards in Salada, Murcia; A2 = almond orchards in Campo de Murcia, Murcia; O = orange orchards in La Granja de la Costera, Valencia; Ol = olive orchards in Moixent, Valencia; Years of abandonment is indicated by the number following ab.
[b)] Max. = maximum; Min. = minimum.

recovery and also as a consequence of litter layer developed by the herbs and shrubs.

Vineyards

Fourteen rainfall simulations were carried out on the cultivated vineyards and nine on abandoned ones (Fig. 2). The cultivated plots showed an average total SL (a sum of the results within 30-min duration, the same below) of about 9.4 g m^{-2} with a maximum value of 33.3 g m^{-2} (Fig. 2c). Mean runoff was 1.6 L m^{-2} with a maximum value of 4.52 L m^{-2}. In the abandoned plots, average SL was 7.2 g m^{-2} with a maximum value of 23.9 g m^{-2} (Fig. 2d). Average runoff in the abandoned plots reached a higher value (2.2 L m^{-2}) than that in the cultivated ones (Fig. 2a, b); however, SC showed a lower mean value (2.7 g L^{-1}) (Fig. 2d). Low runoff coefficients (10.4%) were measured on the vineyards (Fig. 2a, b).

Almond orchards

In Salada, 10 rainfall simulations were conducted on the almond orchards (Fig. 3). The cultivated plots showed an average SL of 37.4 g m^{-2} with a maximum value of 56.7 g m^{-2} (Fig. 3c); runoff reached an average value of 10 L m^{-2} with a high value of 13.9 L m^{-2} (Fig. 3a). In Campo de Murcia, a total of 12 rainfall simulations were conducted in the abandoned and cultivated plots (Fig. 4). Average SL in the cultivated plots was 1.5 g m^{-2} with a maximum value of 2.92 g m^{-2}; mean SC was 9.6 g L^{-1} and runoff coefficient was low (3.4%) (Fig. 4a, c). In the abandoned plots, higher average SL (2.1 g m^{-2}) was measured than that in the cultivated ones (Fig. 4d).

Orange orchards

Thirty rainfall simulations carried out in the orange orchards are summarized in Fig. 5. In the cultivated plots, the mean SL reached 119.6 g m^{-2} (Fig. 5d); in the 3- and 10-year abandoned plots, the value decreased to 20.2 (Fig. 5e) and 6.0 g m^{-2} (Fig. 5f), respectively. The runoff on the cultivated lands was on an average of 15.4 L m^{-2} (Fig. 5a). In the abandoned plots, the runoff value was between 2.7 (10-year abandoned) and 5.0 L m^{-2} (3-year abandoned) (Fig. 5b, c). This resulted in an average SC of about 7.8 g L^{-1} in the cultivated plots, and 2.4 and 2.4 g L^{-1} in the 10- and 3-year abandoned plots, respectively (Fig. 5d, e, f).

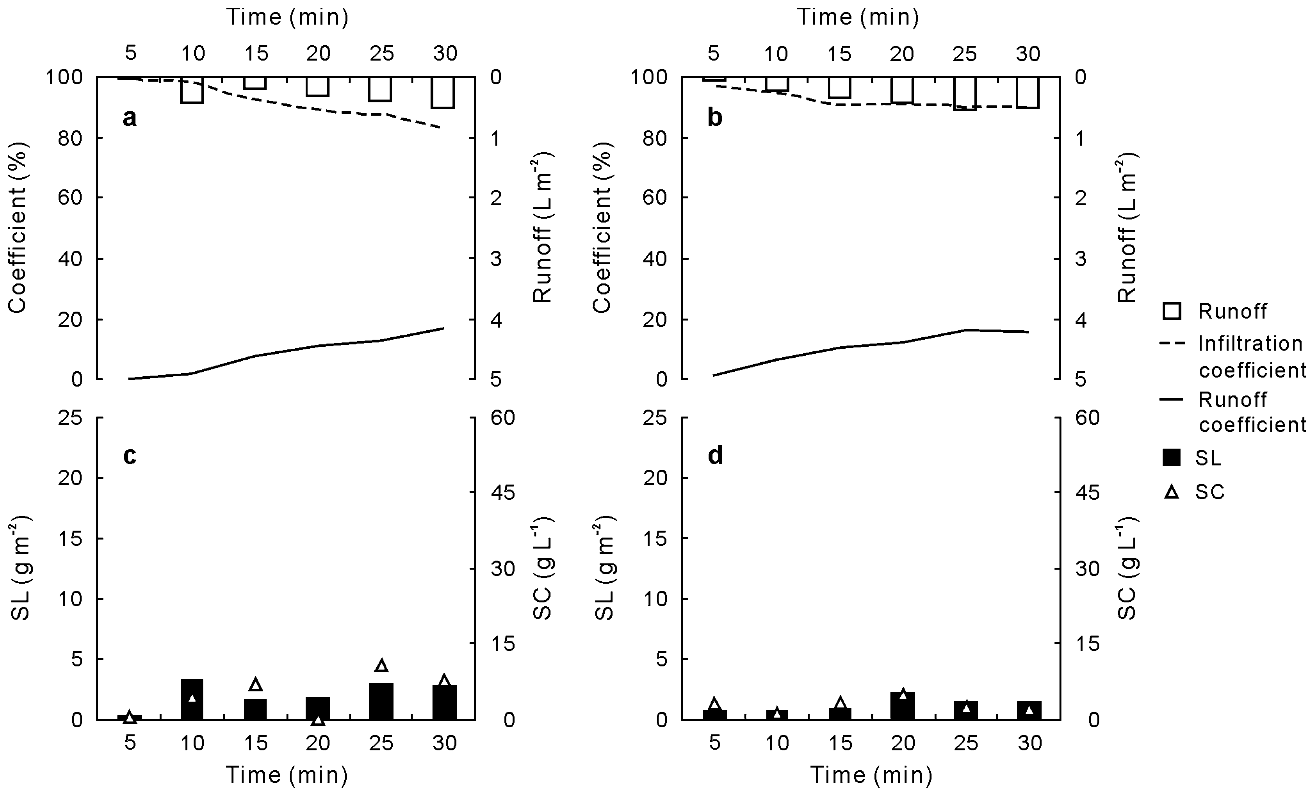

Fig. 2 Rainfall simulations in cultivated (a and c) and abandoned vineyards (b and d) in Almáchar, Málaga of Spain. SL = sediment load; SC = sediment concentration.

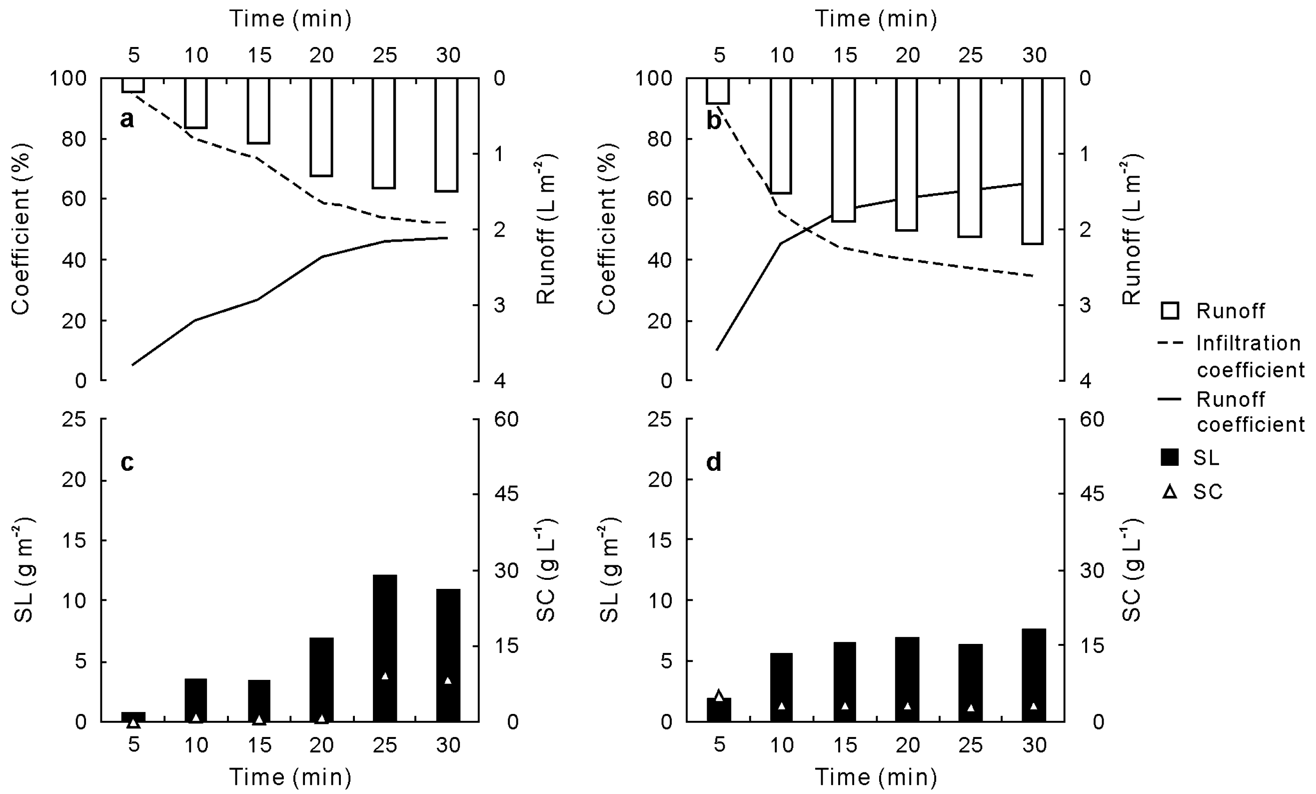

Fig. 3 Rainfall simulations in cultivated (a and c) and abandoned almond orchards (b and d) in Salada, Murcia of Spain. SL = sediment load; SC = sediment concentration.

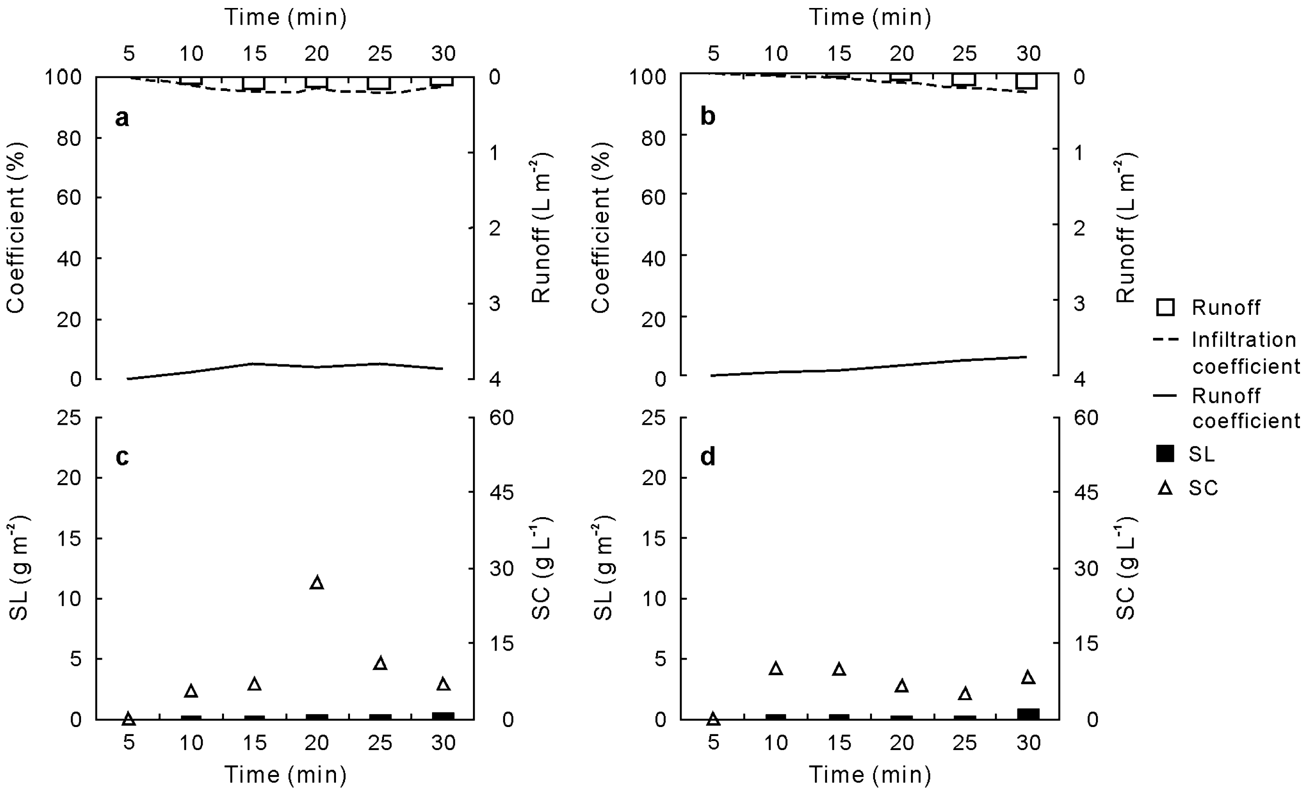

Fig. 4 Rainfall simulations in cultivated (a and c) and abandoned almond orchards (b and d) in Campo de Murcia, Murcia of Spain. SL = sediment load; SC = sediment concentration.

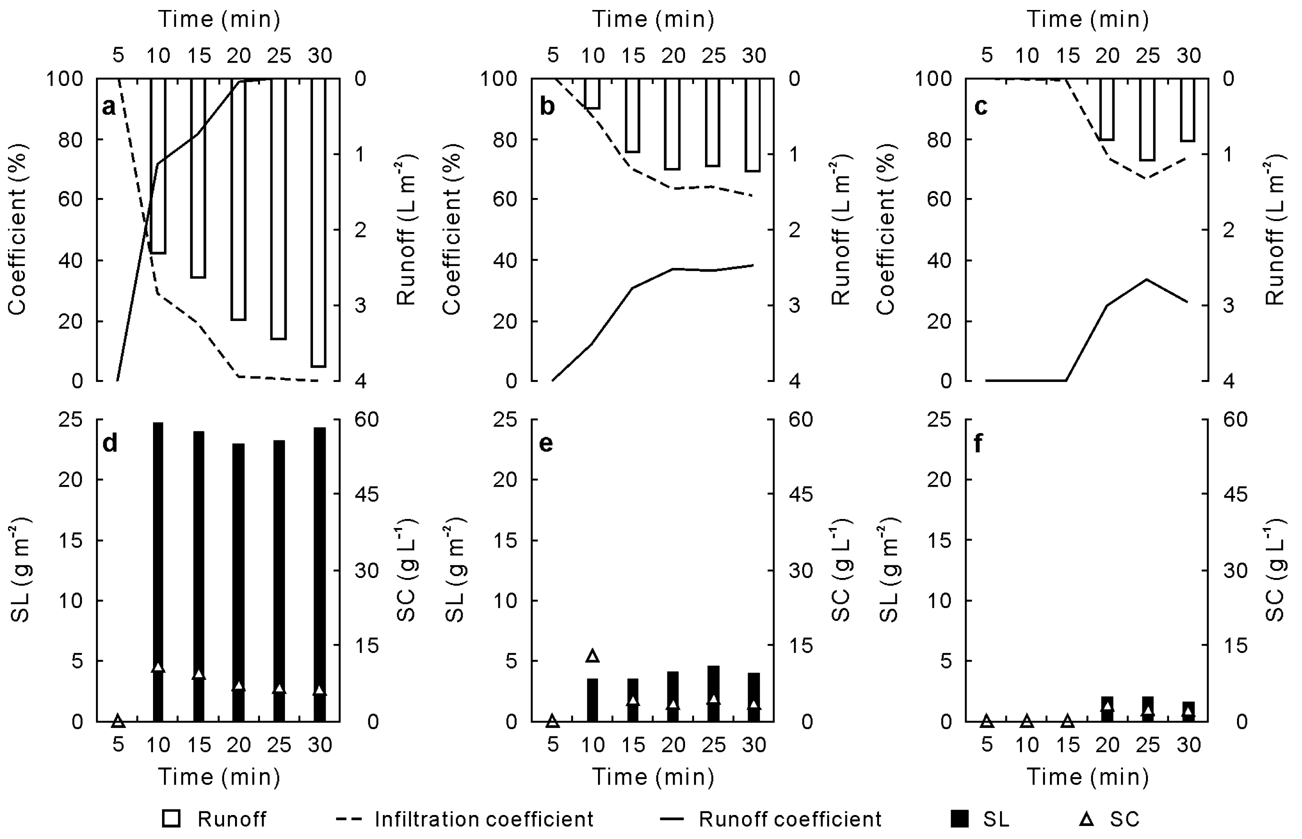

Fig. 5 Rainfall simulations in cultivated (a and d), 3-year abandoned (b and e), and 10-year abandoned orange orchards (c and f) in Granja de la Costera, Valencia of Spain. SL = sediment load; SC = sediment concentration.

Olive orchards

The results of the 30 rainfall simulations in the olive orchards are given in Fig. 6. In the cultivated olive plots, an average SL of 33.75 g m^{-2} and a maximum value of about 61.3 g m^{-2} were measured (Fig. 6d), while the mean runoff reached 15.1 L m^{-2} with a maximum value of 16.64 L m^{-2} (Fig. 6a). The mean SC was 4.1 g L^{-1} with a runoff coefficient of 78.1% (Fig. 6a, d). In the 5-year abandoned olive plots, the mean SL value reached 31.5 g m^{-2}, the mean runoff value was 7.9 L m^{-2}, and the mean SC was 4.2 g L^{-1} (Fig. 6b, e). In the 20-year abandoned olive plots, the runoff was detectable only after 20 min and the mean SC was 3.9 g L^{-1} with a runoff coefficient of 12.3% (Fig. 6c, f). During the experiment, the maximum SL and runoff amounts were 11.07 g m^{-2} and 3.14 L m^{-2}, respectively.

Comparison between cultivated and abandoned plots

The SL, runoff, and SC results of 105 rainfall simulations are shown in Fig. 7 for comparison of the cultivated and abandoned plots. In cultivated plots, the average SL reached 47.71 g m^{-2}, the mean runoff 8.03 L m^{-2}, and the mean SC about 7.21 g L^{-1}. In the abandoned plots, the mean values decreased drastically. The mean SL was 15.57 g m^{-2}, the mean runoff 4.39 L m^{-2}, and the mean SC 3.88 g L^{-1}. The maximum values were also higher in the cultivated plots, reaching 163.7 g m^{-2} and 19.57 L m^{-2} for SL and runoff, respectively, in the orange orchards, and up to 70 g L^{-1} for SC in the almond orchards. There is hence a clear impact of the process of abandonment of agriculture land: a reduction in soil losses.

With the box-plots shown in Fig. 7, high differences were demonstrated in the mean values, the maximum values, and the variability of the results among the study plots. Thus, to compare the averages of rainfall simulation across environmental characteristics between the cultivated and abandoned agricultural lands, the t-test was applied (Table III). Mean values of runoff, time to runoff generation, and roughness did not show any statistically significant differences between the cultivated and abandoned areas. However, SL, SC, slope angle, vegetation cover, and rock cover showed statistically significant differences, confirming that one or more environmental characteristics could potentially operate as key factor(s). By applying a Spearman rank coefficient between environmental characteristics and soil and runoff losses, the factors affecting soil ero-

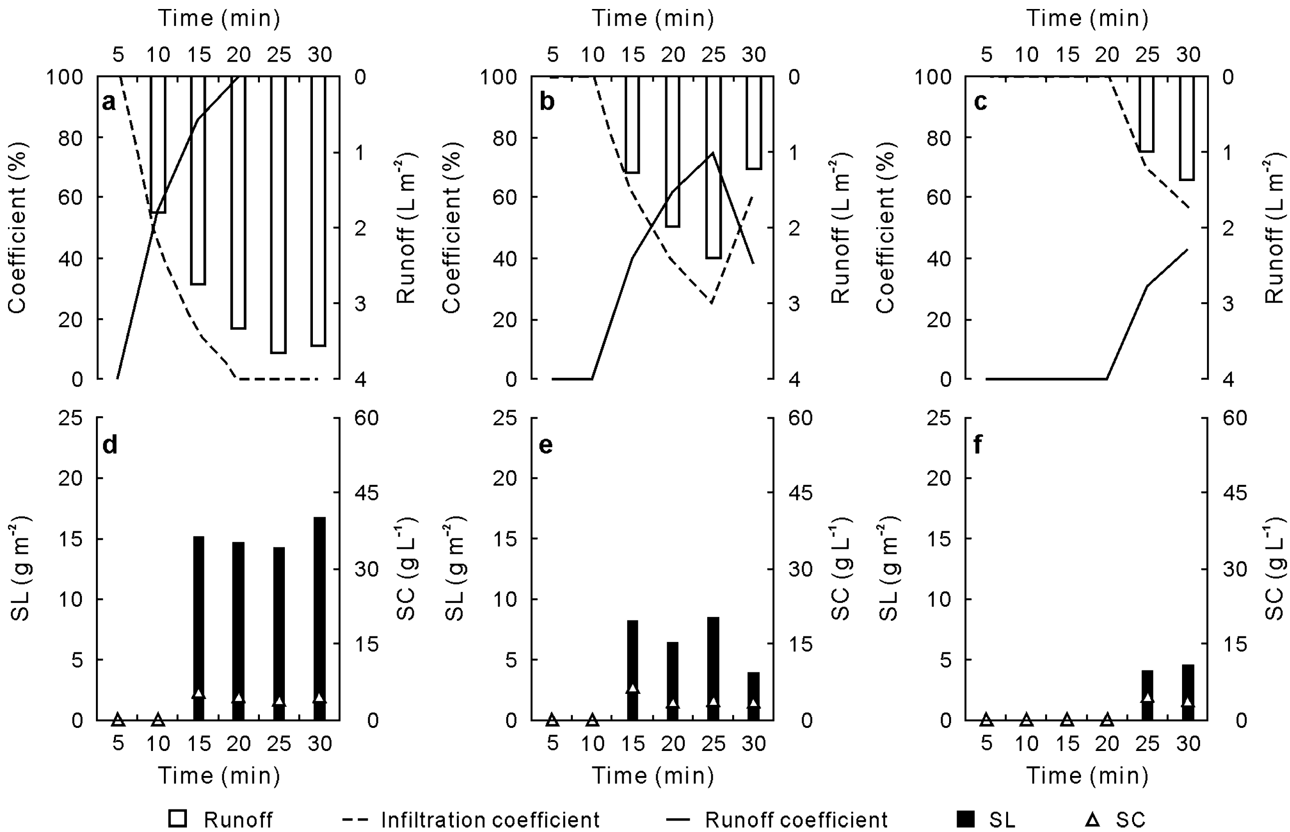

Fig. 6 Rainfall simulations in cultivated (a and d), 5-year abandoned (b and e), and 20-year abandoned olive orchards (c and f) in Moixent, Valencia of Spain. SL = sediment load; SC = sediment concentration.

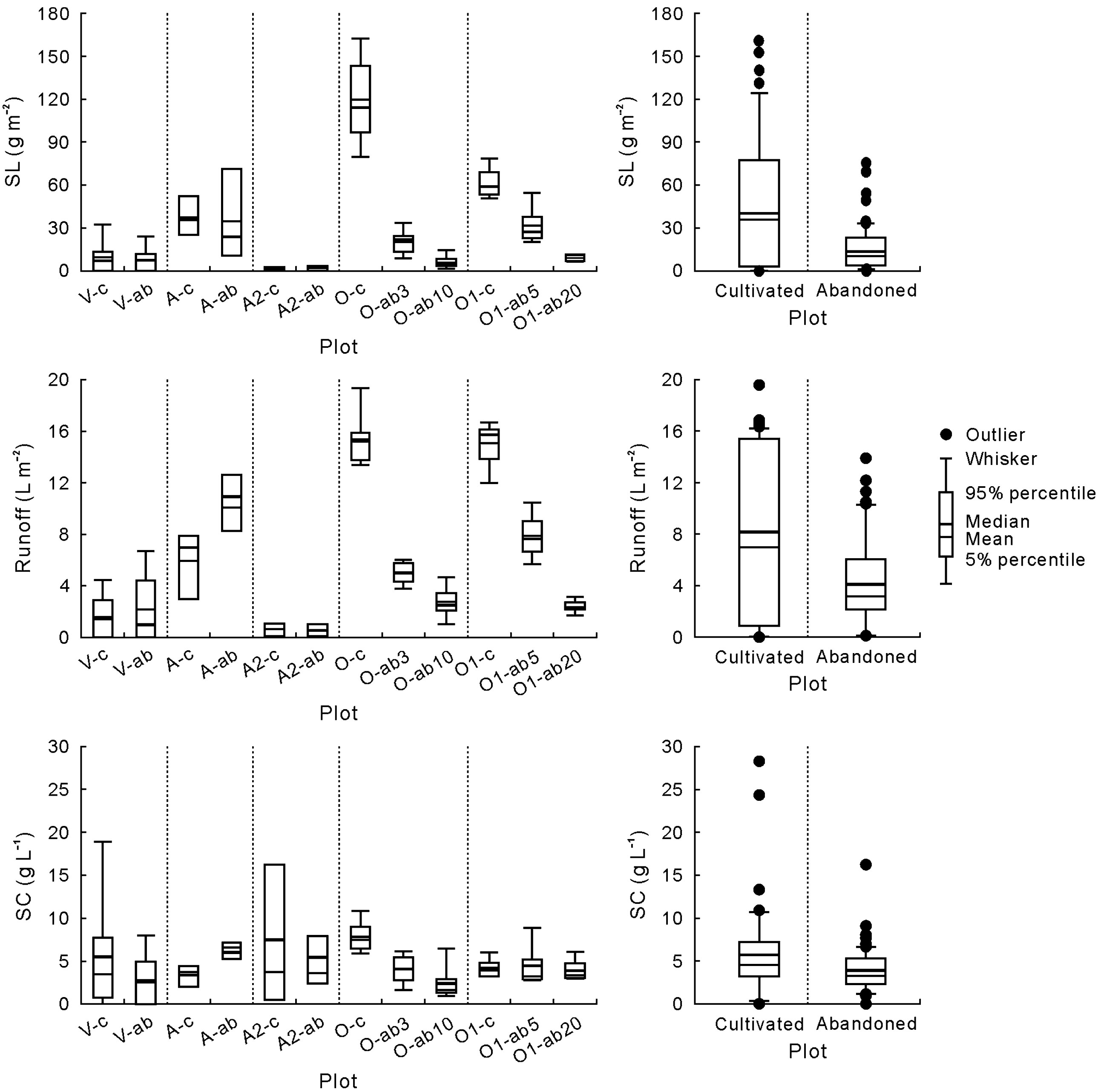

Fig. 7 Comparisons of sediment load (SL), runoff, and sediment concentration (SC) in all study plots. V = vineyards in Almáchar, Málaga; c = cultivated; ab = abandoned; A1 = almond orchards in Salada, Murcia; A2 = almond orchards in Campo de Murcia, Murcia; O = orange orchards in La Granja de la Costera, Valencia; Ol = olive orchards in Moixent, Valencia. Years of abandonment is indicated by the number following ab.

sion processes could be noted. In the cultivated lands, statistically significant correlations ($P < 0.001$) were observed between the increase of runoff, the decreases of slope angle, vegetation, and rock covers, and the increase of roughness (Table IV). An increase of SL also showed a high correlation with the decreases of slope, vegetation cover, and rock cover, which was much higher if roughness increased. For the abandoned lands (Table V), a delay in the time to runoff generation showed a statistically significant correlation with increasing vegetation cover and roughness. This is due to the impact of vegetation on soil erosion and runoff generation.

DISCUSSION

Impact of land abandonment on soil erosion

The process of abandonment can be seen worldwide and is associated with the progressive abandonment of traditional agricultural practices, which is en-

TABLE III

Comparisons of rainfall simulation results and environmental characteristics between the cultivated agricultural lands and their respective abandoned lands using *t*-test

Rainfall simulation result	P value	Environmental characteristics	P value
Runoff	0.059	Slope angle	0.032*
Sediment load	0.006**	Vegetation cover	0.001***
Sediment concentration	0.024*	Rock cover	0.001***
Time to runoff generation	0.890	Roughness	0.753

*, **, ***Significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

TABLE IV

Spearman rank coefficients between rainfall simulation results and environmental characteristics in the cultivated agricultural lands

Parameter[a)]	Runoff	SL	SC	SA	VC	RC	Roughness	t_r
Runoff	1.000	0.868	0.231	−0.726	−0.692	−0.548	0.699	0.033
SL		1.000	0.505	−0.718	−0.627	−0.627	0.647	0.222
SC			1.000	−0.278	−0.048	−0.252	0.305	0.274
SA				1.000	0.664	0.572	−0.703	−0.277
VC					1.000	0.390	−0.562	−0.023
RC						1.000	−0.114	0.025
Roughness							1.000	0.189
t_r								1.000

[a)]SL = sediment load; SC = sediment concentration; SA = slope angle; VC = vegetation cover; RC = rock cover; t_r = time to runoff generation.

TABLE V

Spearman rank coefficients between rainfall simulation results and environmental characteristics in the abandoned agricultural lands

Parameter[a)]	Runoff	SL	SC	SA	VC	RC	Roughness	t_r
Runoff	1.000	0.838	0.209	−0.183	−0.120	−0.198	−0.092	−0.429
SL		1.000	0.539	−0.243	−0.064	−0.231	−0.063	−0.397
SC			1.000	−0.022	−0.193	0.022	−0.288	−0.292
SA				1.000	−0.579	0.458	−0.147	−0.339
VC					1.000	−0.638	0.432	0.726
RC						1.000	0.000	−0.135
Roughness							1.000	0.571
t_r								1.000

[a)]SL = sediment load; SC = sediment concentration; SA = slope angle; VC = vegetation cover; RC = rock cover; t_r = time to runoff generation.

hancing land degradation processes by increasing sediment and water yields (Ruiz Sinoga and Martinez Murillo, 2009; Ries, 2010; García-Ruiz and Lana-Renault, 2011). However, it was found that land abandonment did not always result in high soil erosion rate. The increase in soil erosion was true for sloping terrains in the abandoned almond orchards in Murcia and vineyards in Málaga, which was affected by grazing. However, abandoned lands generally generated much lower volume of sediment and runoff as found in the olive and orange orchards in Spain, similar to the results from other studies in La Rioja, Spain (Arnáez *et al.*, 2011). Several researches focused on this topic showed that pedological factors (such as roughness or texture) and parent materials were the most highly related factors to explain soil erosion by water (Cerdà, 1997). Slope angle is also a key issue to understand the fate of soil losses in agriculture land (Koulouri and Giourga, 2007).

The main reason for the soil erosion control is the increase in the infiltration rates that results also in an ecological shift in the abandoned land (Lasanta *et al.*, 2006; Romero Díaz *et al.*, 2007). From the point of view of soil erosion, the vegetation recovery acts as a sink for sediments and water and this will result in the loss of connectivity (López-Vicente *et al.*, 2013) and as a consequence lower erosion rates and runoff discharge. However, some authors found a decrease in soil quality and then an increase in soil erosion rate after abandonment (Cerdà, 1997). This is due to the arid climatic conditions that slow the vegetation recovery, but also the steep slope angles that activate soil erosion and the loss of water. The active erosion process is a relevant factor resulting in low vegetation cover in Málaga and Murcia study plots. We also found that the impact of abandonment in the southern study sites is not more than that of a land use change to low intensity grazing, although the latter resulted in an increase in trampling, vegetation cover reduction, plant species change, and as a consequence higher erosion rates (Romero-Díaz *et al.*, 2017).

Fig. 8 shows several differences in the correlations between SL, runoff, and vegetation cover among the study plots. It was noted that there was a delayed time to runoff generation in the abandoned plots, which was specifically higher in the abandoned olive and orange orchards due to the higher vegetation cover. Similar results were also obtained in olive plantations from Greece (Kairis *et al.*, 2013) and Spain (Gómez *et al.*, 2009; Espejo *et al.*, 2013; Sastre *et al.*, 2016).

During our experiment, at the pedon scale, microponds were observed that acted as sinks in the agricultural lands due to the high roughness, which was similar to the observations in other studies (Cerdà, 2001; Rodrigo-Comino *et al.*, 2016a). Hence, the research on the impact of land abandonment on micro-topography was highly recommended and the advances in the use of photogrammetric techniques such as Structure from Motion will be of help (Hänsel *et al.*, 2016). At larger scales, similar results were obtained showing connectivity mechanisms (Zhang *et al.*, 2013), suggesting the need to conduct research on the scale and connectivity using mapping techniques or a connectivity index (López-Vicente *et al.*, 2013; Masselink *et al.*, 2016). Moreover, further experimental approaches are needed to investigate challenging processes like wind-driven rain erosion (Marzen *et al.*, 2015, 2016) or animal trampling (Pulido-Fernández *et al.*, 2013; Schnabel *et al.*, 2013) and their relation to land degradation.

With the statistically significant correlation between runoff and SL in the abandoned and cultivated lands, it was demonstrated that the cultivated lands generated Hortonian overland flow under low-frequency high-magnitude rainfall events (Figs. 8 and 9). Vegetation recovery was faster in the terraced orange and olive orchards after land abandonment, which resulted in an increase in the infiltration rate and a decrease in the surface runoff and soil loss as a consequence of soil quality improvement. Meanwhile, the sloping terrain of almond orchards and vineyards enhanced the development of crusts and rills and a negligible vegetation cover resulted in high erosion rate as

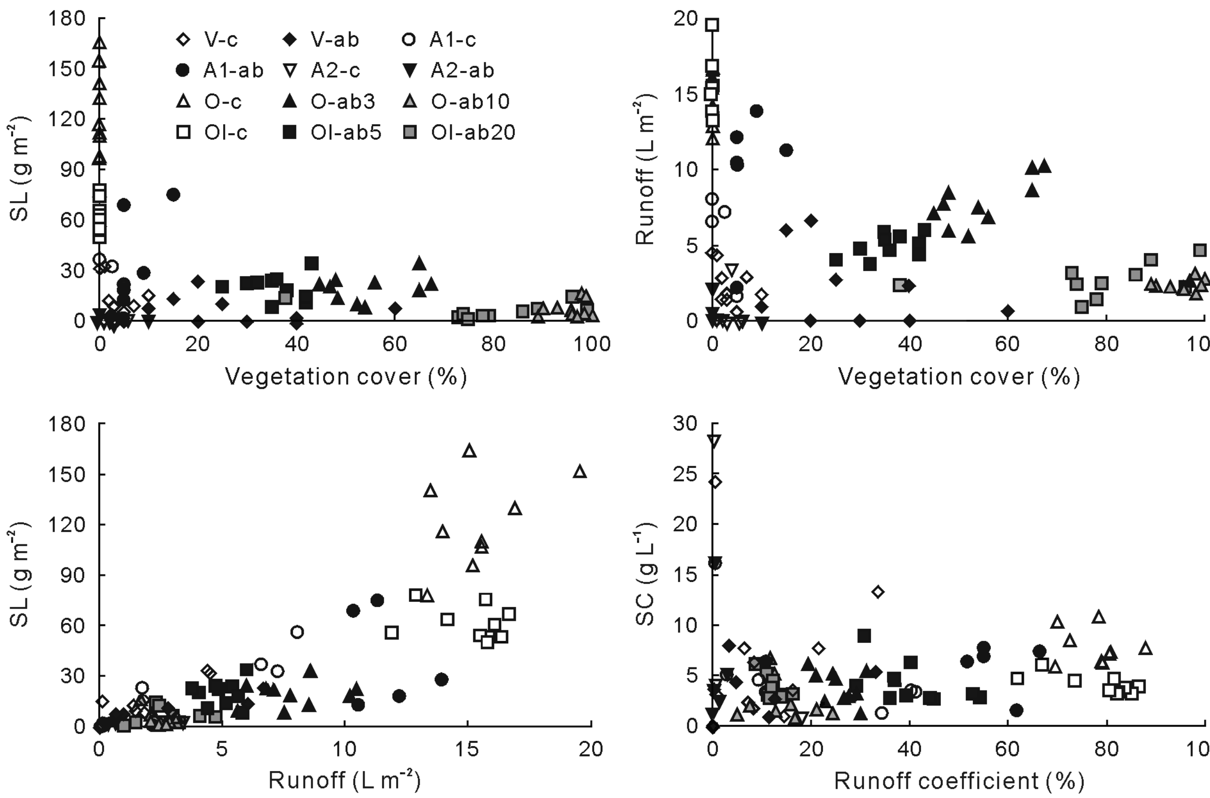

Fig. 8 Scatter plots of the relationships between sediment load (SL), runoff, runoff coefficient, sediment concentration (SC), and vegetation cover among all study plots. V = vineyards in Almáchar, Málaga; c = cultivated; ab = abandoned; A1 = almond orchards in Salada, Murcia; A2 = almond orchards in Campo de Murcia, Murcia; O = orange orchards in La Granja de la Costera, Valencia; Ol = olive orchards in Moixent, Valencia. Years of abandonment is indicated by the number following ab.

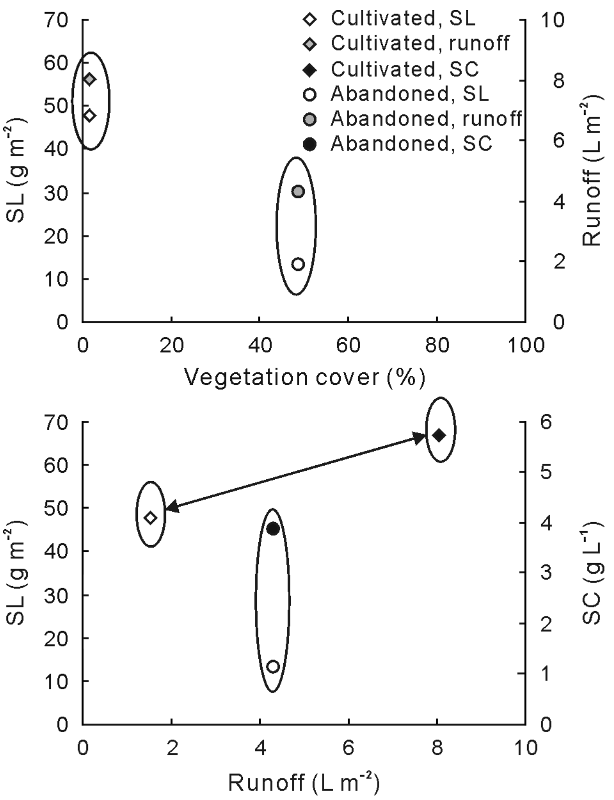

Fig. 9 Scatter plots with sediment load (SL), runoff, sediment concentration (SC), and vegetation cover in the abandoned and cultivated lands.

a consequence of Hortonian runoff generated during the simulated rains. When surface wash is active, there is the risk that the failure of the terraces will increase the connectivity, but due to the successful natural vegetation recovery the disconnection established by the terraces is maintained after the abandonment. In the sloping almond orchards and vineyards, the connectivity is enhanced by the rill and crust formation, and surface wash is more active (Lesschen *et al.*, 2008).

Our research confirmed that vegetation cover was the key factor to determine the fate of land abandonment and the erosion rate. Vegetation recovery in the terraced orange and olive orchards was the key factor influencing high infiltration rate and negligible soil erosion. Vegetation can function as a natural filter, which can enhance infiltration and help to avoid soil crusting development and enhance aggregate formation (Ruiz Sinoga and Martinez Murillo, 2009; Keesstra *et al.*, 2012b; Bienes *et al.*, 2016). Governmental policies must be made to promote vegetation recovery after land abandonment. For the regions where vegetation recovery is poor, such as the almond orchards and vineyards in Murcia and Málaga, it was recommended to actively take measures to reduce soil erosion after abandonment, and grazing is suggested to avoid during the first year after abandonment. Straw covers or the use of organic materials such as compost (Cerdà *et al.*, 2016; Prosdocimi *et al.*, 2016b), strip grass cover (Novara *et al.*, 2011; Sastre *et al.*, 2016), or geotextiles and organic amendments (Giménez-Morera *et al.*, 2010; Yazdanpanah *et al.*, 2016; Fernández-Calviño *et al.*, 2017) can reduce soil losses and improve soil quality, which is the first step to avoid non-sustainable soil erosion.

CONCLUSIONS

Sloping fields of almond orchards and vineyards showed the highest soil loss and runoff, due to the bare soils and the lack of vegetation cover. In the terraced orange and olive orchards, due to natural vegetation recovery, soil erosion decreased drastically after land abandonment. Soil erosion was low after 3- and 10-year abandonment in the orange orchards and 5- and 20-year abandonment in the olive orchards. The older the age of abandonment, the lower the soil losses. Vegetation recovery was low in the almond orchards and vineyards after land abandonment, resulting in an increase in soil erosion. Steep slopes in the almond orchards and vineyards contributed to the increasing soil losses after abandonment, due to the development of rills and crusts in the sparsely vegetated soils. On the contrary, in the flat terraces of the olive and orange orchards, the dense vegetation cover resulted in an improvement in soil properties and as a consequence in the reduction of soil erosion. These contrasted responses to the abandonment in Mediterranean agricultural lands suggest that land abandonment should be programmed and managed with soil erosion control strategies for some years to avoid land degradation.

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