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The 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 on soil system and there is a need to evaluate the impact on soil erosion to understand the ecosystem's changes. The aim of this research is to assess the impact of abandonment in four Mediterranean crops (vineyards, almonds, citrus and olives) on soil and water losses. To achieve this goal, 105 rainfall simulation experiments were conducted in agriculture fields (vineyards in Málaga, almonds in Murcia, and citrus and olive in Valencia) and on the paired abandoned plots. After abandonment, soil detachment decreased drastically in the olive and citrus orchards, meanwhile vineyards did not show any difference and almonds registered higher erosion rates after the abandonment. Terraced orchards of citrus and olives recovered a dense vegetation cover after the abandonment, meanwhile the sloping terrain of almonds and vineyards enhanced the development of crusts and rills and a negligible plant cover that resulted in high erosion rates. The contrasted response of the abandonment is discussed.

Key Words: soil erosion, Mediterranean crops, abandonment, vegetation cover, terraces, rainfall simulation

INTRODUCTION

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

During the second half of the 20th century, the Mediterranean belt of Europe has been 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). The land abandonment is a consequence of biophysical and human determinants (Novara et al., 2017). Several factors trigger the 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 in highly erodible parent materials (Bienes et al., 2016; Regüés and Nadal-Romero, 2013); and, iv) environmental and socio-economic constrains to introduce other activities such as livestock (Pulido-Fernández et al., 2013) or organic farming due to the recurrent long periods of drought (Nadal-Romero et al., 2015; Ruiz-Sinoga et al., 2012).

Vegetation recovery is a fact after abandonment, which is characterised by changes in the biomass and also in the floristic composition. Herbs and shrub recover fast (<5 years) after the abandonment (Lasanta et al., 2015). However, vegetation recovery is by far slower in semi-arid areas as well as Mediterranean territories, where water is the key resource for plant recovery (Cammeraat et al., 2010; Ries, 2010; Ruiz-Sinoga and Martinez-Murillo, 2009). In cultivated fields, the removal of the weeds by tillage or herbicides results in extremely high erosion rates (Cerdà et al., 2010; Prosdocimi et al., 2016a). Farmers promote bare soils to reduce the amount of water used by weeds and catch crops and this increase the soil and water losses by surface wash due to the lack of vegetation (Martínez-Murillo et al., 2016). Agriculture 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). This situation enhances that recent abandoned soils show high bulk densities and low aggregate stability (Bienes et al., 2016; Verbist et al., 2007) and high soil and water losses (Shi et al., 2010; Yazdanpanah et al., 2016; Ries et al. 2014a). Once the soil is not plough, bulk density increase, surface crusts develop and overland flow take place and soil erosion reach high rates (Robledano-Aymerich et al., 2014). However, the vegetation recovery can reduce the raindrop impact, reduce the surface wash velocity, increase the infiltration rates and as a consequence reduce the soil losses (Keesstra et al., 2016; Breton et al., 2016). The successful recovery of the vegetation after abandonment needs a proper integrated extensive livestock to preserve the abandoned land and avoid forest fires (Mataix et al., 2015) as is relevant to understand the carbon cycles and the ecosystem services offered by the soils (Peregrina et al., 2016; Szalai et al., 2016; Novara et al., 2017). The fate of the abandoned land also will determine the soil erosion rates such as other land use changes do. Then, there is an interaction between the vegetation and the erosion processes.

Climate conditions and culture development in the Mediterranean contribute to high erosion rates as a consequence of millennia old ploughing management that resulted in physical, biological and chemical soil degradation (Al-Kaisi et al., 2005; Gómez et al., 1999; Govers et al., 1994). The most recent scientific literature shows many examples of high erosion rates. In Persimmon orchards in Easter Spain, Cerdà et al. (2016) recorded soil depth lowering of 0.5 mm in 1-hour during 10-year return period storm events as a consequence of raindrop impact and surface wash. Similar response was noted by Keesstra et al. (2016) in soils planted with apricot trees applying herbicide treatments arranging 1.8 and 45.5 times more erosion than tillage and covered, 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) and Rodrigo-Comino et al. (2016a) demonstrated that vineyards with bare soils enhance larger amounts of sediment yield and high runoff discharges.

All the above mentioned examples from the Mediterranean demonstrate that is necessary to develop successful land management policies and assess the soil degradation processes at the pedon scale to understand the soil quality, the detachment of soil particles and the runoff initiation (Nearing et al., 1999; Khaledian et al., 2016). It is also well accepted that should be nature-based solutions, such as grass covers, catch crops, or geotextiles 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 the soil erosion processes and the mechanism such as splash, inter-rill erosion and runoff generation (Iserloh et al., 2013a, b). Rainfall simulators offer the possibility to quantify the soil detachment and runoff initiation with high accuracy and under low frequency – high magnitude rainfall events. This research aims to determine the effect of agriculture abandonment on soil erosion in four different traditional crops in the Mediterranean belt: vineyards, almonds, citrus and olives. This will inform policy makers where should be designed a programed abandonment to avoid non-sustainable soil erosion rates.

MATERIALS AND METHODS

Study areas

Four study sites were selected in southeast Iberian Peninsula (Fig. 1). Every site was selected with cultivated (olives, vineyards, almonds or citrus) and abandoned land following the paired plot sampling strategy. Their main characteristics are given in Table I.

Fig. 1 Study areas.

TABLE I
Study area characteristics

	Vineyards	Almonds	Almonds	Oranges	Olives
Study area	A (Málaga)	S (Murcia)	CM (Murcia)	GC (Valencia)	M (Valencia)
Altitude (m.s.n.m.)	300-400	300-310	258	130	340
Soil tillage	Hand-made tillage and herbicides	Machinery and herbicides	Tillage	Herbicide	Tillage
n (years of abandonment)	C: 14 Ab (20): 9	C: 4 Ab (40): 6	C: 6 Ab (>15): 6	C: 10 Ab (3): 10 Ab (10): 10	C: 10 Ab (5): 10 Ab (20): 10
T° ($\bar{x}$)	17.2	11.6	17.8	16	14
mm (total)	520	414	258.8	590	450
Geology	Metamorphized schits and quartzites	Conglomerates with a clayey to loamy matrix	Marls and limestones	Limestones, although the terraces are developed on fluvial materials	Cretaceous limestones and Tertiary marly deposits
Clays (%)	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
TOC (%)	C: 3.1 Ab: 3.5	C: 0.5 Ab: -	C: 3.3 Ab (>15): 2.8	C: 1.2 Ab (3): 2.3 Ab (10): 5.4	C: 1 Ab (5): 2.1 Ab (20): 3.2
pH	7.6	8.3	8.4	7.75	7.2

n: number of experiments; A: Almáchar; S: Salada; CM: Campo de Murcia; GC: La Granja de la Costera; M: Moixent. T° ($\bar{x}$): Mean yearly temperature; mm (total): mean yearly rainfall amount; TOC (%): total organic carbon; C: cultivated plots; Ab: abandoned plots.

The vineyards plots were selected in Almáchar, Málaga. Altitude ranges from 300 to 400 m.a.s.l. Vines were cultivated following the steep slope angles (> 30º) with the grape variety *Muscat of Alexandria*. Conventional ploughing was conducted for millennia. Clear signals of soil erosion in form of rills were surveyed (Rodrigo-Comino et al., 2016b). Mean annual rainfall is 520 mm and mean annual temperature 17.2 ºC. Total organic carbon ranged from 3.1 to 3.5% on silty soils (72.2%). The parent material is Palaeozoic dark schist and soils can be described as *Eutric Leptosol* (IUSS Working Group WRB, 2014). Soils are characterized by high stone content and shallowness less than 30 cm (Rodrigo-Comino et al., 2017).

The almond orchards are located in Salada and Campo de Murcia municipalities, province of Murcia. 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 (< 0.5%). The grain sizes are clay (27.3%), silt (42.1%) and sand (30.6%). Mean annual temperature is 11.6 °C and the mean annual rainfall 414 mm. The Campo de Murcia study sites is characterized by marls and limestones and soils with high silt contents (79.4%), but lower clay particles (9.9%). Total organic carbon content is low (2.8% and 3.3%). Mean temperature is 17.8 °C, and mean annual rainfall 258.8 mm.

The olive plantation of Moixent is located in the southwest Valencia province at 350 m.a.s.l. on agriculture terraces without inclination. *Manzanilla* is the olive's variety, and tillage is used for millennia in this traditional rainfed 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 size is 30.3% sand, 42.1% silt and 20.6% clay. The total organic carbon ranged between 1% (cultivated) and 3.2% (abandoned 20 years ago), with values around 1.5% in the 5-years abandoned orchards. The parent materials are marls. Rills can be found after thunderstorms in the ploughed active soils, but not in the abandoned ones where the vegetation recovery is very fast. Total annual rainfall reaches up to 390 mm, with minimum and maximum in August and October, respectively.

Citrus farms were selected at La Granja de la Costera municipality, located in the south of Valencia province. The orchards are flood irrigated and herbicides are use to avoid weeds and keep the soil bare. The mean annual rainfall is 590 mm and the parent material is limestones. The soils are characterized by the lack of rock fragments and the widespread presence of surface crust when under agriculture use due to the widespread use of herbicides in the citrus plantations. Organic carbon content varies between 1.2% (cultivated) and 5.4% (abandoned 10-years), with 2.1 % in the abandoned after 5-years. Soils grain size is 20.6%, 42.1%, 32.3% for clay silt and sand, respectively.

Small portable rainfall simulator characteristics and procedures in laboratory

The rainfall simulator is a nozzle type, which was described by Cerdà (1999) and Iserloh et al. (2012) and is widely used in Europe (*e.g.*, Iserloh et al., 2013a). A calibrated and reproducible rainfall of 40 mm h^{-1} is sprayed from a height of 2 m by a Lechler 460 608 nozzle on a 0.28 m² circular test plot. The simulator is covered by a rubber tarpaulin to avoid external influences such as wind. Duration of the experiments was 30 minutes, divided into six intervals of five minutes to collect the runoff discharge and take samples to determine the sediment concentration (SC). The collected runoff water in each bottle was filtered separately with fine-meshed filter paper. The filters were dried to constant weight at 105 °C and weighed for getting soil loss for each 5-minute intervals. Roughness was measured by chain method (Saleh, 1993).

Statistical analysis

Rainfall simulation results are plotted per study area in graphics with the total average per intervals (every 5 minutes). For comparison, data of sediment load (g m^{-2}), runoff (L m^{-2}) and sediment concentration (g L^{-1}) were presented as box plot showing the medians, averages, percentiles (5% and 95%) and outliers. Finally, to compare them which each other and to assess which environmental factor determined the soil erosion processes, a Spearman rank coefficient using SPSS 23 software (IBM, USA) and a *t*-test with SigmaPlot 13 (Systat Software, Inc.) were conducted after performing a Saphiro-Wilk test.

RESULTS

Plot characteristics

Plot characteristics showed differences between study sites as they represent different cropping systems (Table II). The lowest slope values were registered in the olive and citrus crops with 0° and the highest in the vineyards between 31.3º (cultivated) and 33.6° (abandoned). The contrasted slope angles are due to the different farmers' strategies. In Valencia (Moixent and Granja de la Costera study sites), the slopes were terraced, but in Málaga (Almáchar) and Murcia (Salada and Campo de Murcia) the slopes were plough without any conservation strategy. Average vegetation cover (VC) in cultivated areas showed minimum values close to 1.5%--13% in vineyards and almonds, and 0% in olives and oranges due to the tillage and herbicides. The highest values (95%) were reached in abandoned olives (20 years) and oranges (10 years) due to the successful natural re-vegetation. Vegetation cover ranged between 1.7% (almonds in Campo de Murcia) and 54.7% (olives abandoned 20-years in Moixent). Regarding the rock fragment cover, high values were observed, reaching the highest (87.7%) in the vineyards. The highest roughness values were observed in the olives and oranges with values of 116. Regarding time to runoff (Tr), vineyard, almond and orange crops showed the highest values, which were 644, 660 and 955 s, respectively. Abandoned areas with vineyards and almonds registered quicker runoff than the soils under cultivation, meanwhile the soils abandoned in oranges and olives orchards shown a delayed runoff initiation due to the successful vegetation recovery and also as a consequence of the litter layer developed by the herbs and shrubs.

TABLE II

Environmental plot characteristics and time to runoff generation

Plots	Results	Slope (°)	Vegetation cover (%)	Stone cover (%)	Roughness (%)	Tr (s)
V	$\bar{x}$	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	108/102	1378/125
V-ab	$\bar{x}$	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
A	$\bar{x}$	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	104/102	330/74
A-ab	$\bar{x}$	7.6±2.3	7.3±4	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	$\bar{x}$	4.3±5.5	2.5±4.5	64.2±40	103.8±3.2	660±509
	Max/Min	15/0	10/0	100/10	110/101.7	1380/300
A2-ab	$\bar{x}$	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	$\bar{x}$	0	0	33.7±11.4	116.2±2.5	955±31
	Max/Min	0	0	46/5.9	121.4/112.5	1001/912
O-ab (3 years)	$\bar{x}$	0	54.7±8.3	4.9±1.7	107.2±1.9	386±32
	Max/Min	0	67/45	8/3	110.2/103.9	441/340
O-ab (10 years)	$\bar{x}$	0	95.6±3.7	10.7±7.2	100.5±35.3	972±43
	Max/Min	0	100/89	22.2/5	115.3/0.3	1032/902
Ol	$\bar{x}$	0	0	50±16.5	116.8±3.5	352±25
	Max/Min	0	0	65/6.5	123.2/110.3	387/312
Ol-ab (5 years)	$\bar{x}$	0	35.8±5.8	50±16.5	110.3±2.16	683.3±79
	Max/Min	0	43/25	65/6.5	114.5/106.6	713/435
Ol-ab (20 years)	$\bar{x}$	0	78.7±17	66.8±26.4	113.5±5.3	1113±324
	Max/Min	0	99/38	97/8.7	124.3/107.6	1398/627

c: cultivated; ab: abandoned; (): years of abandonment; Tr: time to runoff generation; V: vineyards (Almáchar-Málaga); A: almonds (Salada-Murcia); A2: almonds (Campo de Murcia); O: oranges (La Granja de la Costera-Valencia); Ol: Olives (Moixent-Valencia).

Vineyards

Fourteen rainfall simulations on cultivated and nine on abandoned vineyards were carried out (Fig. 2). The vineyards (Fig. 2a) showed a total average SL about 9.4 g m^{-2} with a maximum value of 33.3 g m^{-2}. Mean runoff was 1.6 L m^{-2} with maximum values of 4.52 L m^{-2}. On the abandoned vineyards (Fig. 2b), average SL was 7.2 g m^{-2} with maximal values of 23.9 g m^{-2}. Average runoff reached higher values (2.2 L m^{-2}) than on the cultivated one. However, SC showed lower mean values (2.7 g L^{-1}). We measured low runoff discharge (10.4%).

Fig. 2 Rainfall simulations in cultivated and abandoned vineyards (Almáchar, Málaga). a: cultivated plot; b: abandoned plot.

Almonds

In Salada, ten rainfall simulations were conducted (Fig. 3). The performed rainfall simulations in almonds crops (Fig. 3a) showed an average sediment load of 37.4 g m^{-2} with maximum values of 56.7 g m^{-2}. Runoff reached an average value of 10 L m^{-2} with high values of 13.9 L m^{-2}. In Campo de Murcia research site, a total of 12 rainfall simulations (Fig. 4) were conducted in plots with abandoned and active almond fields. Average SL on almonds (Fig. 4a) was 1.5 g m^{-2} with maximum values of 2.92 g m^{-2}. Mean SC for was 9.6 g L^{-1}. Runoff was low (3.4%). In the abandoned crop fields (Fig. 4b), higher average SL (2.1 g m^{-2}) was measured.

Fig. 3 Rainfall simulations in cultivated and abandoned almonds (Salada, Murcia). a: cultivated plot; b: abandoned plot.

Fig. 4 Rainfall simulations in cultivated and abandoned almonds (Campo de Murcia, Murcia). a: cultivated plot; b: abandoned plot.

Oranges

Thirty experiments carried out in citrus orchards are summarised in Fig. 5. In the cultivated area (Fig. 5a), the mean SL reached 119.6 g m^{-2}. On 3- and 10-year old abandoned land, the values decreased to 20.2 g m^{-2} (Fig. 5b) and 6 g m^{-2} (Fig. 5c). The runoff on the cultivated land was in average 15.4 L m^{-2}. On abandoned lands, results were between 2.7 L m^{-2} (10-years abandonment) and 5 L m^{-2} (3-years abandonment). This results in a SC of about 7.8 g L^{-1} in average, on active orchards, and 2.4 g L^{-1} (10-years abandonment) and 2.4 g L^{-1} (3-years abandonment) on abandoned land.

Fig. 5 Rainfall simulations in cultivated and abandoned oranges (Granja de la Costera, Valencia). a: cultivated plot; b: abandoned plot.

Olives

The results of the 30 rainfall simulations are given in Fig. 6. On the conventional olive orchards, a total average SL of 33.75 g m^{-2} and maximum values of about 61.3 g m^{-2} were measured, while the mean runoff reached 15.1 L m^{-2}. The maximum observed runoff was 16.64 L m^{-2}. The mean SC was 4.1 g L^{-1} with a runoff coefficient of 78.1%. Mean total SL values reached 31.5 g m^{-2}. Mean runoff value was 7.9 L m^{-2} and mean sediment concentration was 4.2 g L^{-1}. On the 30-years abandoned olive plot, runoff was measured after 20 minutes (Fig. 6c). The total SC was 3.9 g L^{-1}, with a total runoff coefficient of 12.3%. During the experiment, the mean total maximum SL and runoff amounts were 11.07 g m^{-2} and 3.14 L m^{-2}, respectively.

Fig. 6 Rainfall simulations in cultivated and abandoned olives (Moixent, Valencia). a: cultivated plot; b: abandoned plot.

Comparison between cultivated and abandoned areas

The results of 105 rainfall simulations are shown in Fig. 7 for comparison of cultivated and abandoned lands. In cultivated areas, the total average of sediment load (SL) reached 47.71 g m^{-2}, the mean runoff 8.03 L m^{-2} and the mean sediment concentration about 7.21 g L^{-1}. In the abandoned areas, total mean values decreased drastically. The mean soil loss was 15.57 g m^{-2}, the mean runoff 4.39 L m^{-2} and the mean sediment concentration 3.88 g L^{-1}. Maximum values were also higher in the cultivated areas, reaching on the citrus orchard a total soil loss of 163.7 g m^{-2} and a runoff rate of 19.57 L m^{-2}, and in the almonds up to 70 g L^{-1}. There is then a clear impact of the process of abandonment of agriculture land: a reduction in the soil losses. The main reason of the soil erosion control is due to 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 the soil erosion, the vegetation recovery act as a sink of sediments and water and this will result in the lost of connectivity (López-Vicente et al., 2013) and as a consequence lower erosion rates and runoff discharge. However, some authors found a decrease in the soil quality and then an increase in the soil erosion rates 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 the soil erosion and the lost of water. This active erosion process is a relevant factor in the low vegetation cover in Málaga and Murcia study sites. We also found that the abandonment in the southern locations is not more a land use change into the low intensity grazing, although this results in an increase in trampling and vegetation cover reduction and plant species change (and as a consequence higher erosion rates is enhanced (Romero-Díaz et al., 2017).

Fig. 7 Comparison of the sediment load, runoff and sediment concentration experiments in all studied areas. c: cultivated; ab: abandoned; (): years of abandonment; Tr: time to runoff generation; V: vineyards (Almáchar-Málaga); A: almonds (Salada-Murcia); A2: almonds (Campo de Murcia); O: oranges (La Granja de la Costera-Valencia); Ol: Olives (Moixent-Valencia).

With the box plots shown in Fig. 7, we demonstrate high differences by regarding the total amounts, the maximum values and the variability of the results between the study sites. Thus, to compare the total averages of rainfall simulation results with environmental plot characteristics on every observed land uses, a T-test was applied (Table III). Total mean values of runoff, time to runoff generation and roughness did not show any statistically significant difference between cultivated and abandoned areas. However, SL, SC, angle slopes, vegetation and stone covers showed high statistically differences, confirming that one or more environmental plot characteristics could potentially operate as key factor. By applying a Spearman rank coefficient between the plot characteristics and soil and runoff losses, we have observed which factor could enhance soil erosion processes. In the Table IV, cultivated areas showed high statistical significance ($P < 0.001$) between the increase of the runoff and the decrease of slope gradient, vegetation and stone covers, and with an increase of the roughness. An increase of the SL showed also a high correlation with the decrease of the slope, vegetation and stone covers, being much higher if roughness also increases. For the abandoned areas (Table V), a delay in the time to runoff generation showed a high statistical significance with increasing vegetation cover and roughness. This is due to the impact of vegetation on soil erosion and runoff generation.

TABLE III

Comparison between crops and their respective abandoned areas using T-test

Rainfall simulation results	T-test (*P*)	Statistically significant difference	Environmental plot characteristics	T-test (*P*)	Statistically significant difference
R	0.059	No	S	0.032	Yes
SL	0.006	Yes	Vc	0.001	Yes
SC	0.024	Yes	Rc	0.001	Yes

Tr	0.89	No	Rg	0.753	No

R: runoff; SL: suspended sediment load; SC: sediment concentration; Tr: time to runoff generation; S: slope; Vc: vegetation cover; Rc: rock cover; Rg: roughness.

TABLE IV

Spearman rank coefficient between environmental plot characteristics and rainfall simulation results in cultivated areas.

	R	SL	SC	S	Vc	Rc	Rg	Tr
R		0.868	0.231	-0.726	-0.692	-0.548	0.699	0.033
SL			0.505	-0.718	-0.627	-0.627	0.647	0.222
SC				-0.278	-0.048	-0.252	0.305	0.274
S					0.664	0.572	-0.703	-0.277
Vc						0.390	-0.562	-0.023
Rc							-0.114	0.025
Rg								0.189
Tr								

R: runoff; SL: suspended sediment load; SC: sediment concentration; S: slope; Vc: vegetation cover; Rc: rock cover; Rg: roughness; Tr: time to runoff generation. *Cells with grey colors mean *P* > 0.001.

TABLE V

Spearman rank coefficient between environmental plot characteristics and rainfall simulation results in abandoned areas.

	R	SL	SC	S	Vc	Rc	Rg	Tr
R		0.838	0.209	-0.183	-0.120	-0.198	-0.092	-0.429
SL			0.539	-0.243	-0.064	-0.231	-0.063	-0.397
SC				-0.022	-0.193	0.022	-0.288	-0.292
S					-0.579	0.458	-0.147	-0.339
Vc						-0.638	0.432	0.726
Rc							0.000	-0.135
Rg								0.571
Tr								

R: runoff; SL: suspended sediment load; SC: sediment concentration; S: slope; Vc: vegetation cover; Rc: rock cover; Rg: roughness; Tr: time to runoff generation. *Cells with grey colors mean *P* > 0.001

DISCUSSION

The impact of abandonment

The process of abandonment can be considered as a world-wide change associated to a progressive abandonment of traditional agricultural practices, which is enhancing land degradation processes by increasing sediment and water yield (García-Ruiz and Lana-Renault, 2011;Ruiz-Sinoga and Martinez-Murillo, 2009; Ries 2010). However, we found that not always the abandonment results in higher soil erosion rates. The increase in soil erosion was true for the sloping terrain affected by grazing in abandoned almond orchards in Murcia and vineyards in Málaga. However, in general abandoned lands generated much lower volume of sediment and runoff as we found in olive and citrus in Spain as before found other researchers in La Rioja (Arnáez et al., 2011). Regarding several researches focused on this topic, pedological factors (such as roughness or texture) and parent materials were the most highly related factors to explain the soil erosion by water (Cerdà, 1997). Slope inclination is also a key issue to understand the fate of the soil losses in agriculture land (Koulouri and Giourga, 2007).

Fig. 8 show several differences related to SL and runoff between the different types of crops with vegetation cover. Regarding this, we noted that there was a delayed time to runoff generation in abandoned areas, being specifically higher the time to runoff generation in the abandoned olive and orange crops due to the higher vegetation cover. Similar results were also obtained in Greece (Kairis et al., 2013) and other study areas from Spain (Espejo et al., 2013; Gómez et al., 2009; Sastre et al., 2016) in olive orchard plantations.

Fig. 8 Scatter plots with sediment load (SL), runoff, runoff coefficient, sediment concentration (SC) and vegetation cover. a: sediment load (SL) and vegetation cover; b: runoff and vegetation cover; c: runoff and suspended sediment load (SL); d: runoff coefficient and sediment concentration (SC). Legend: c: cultivated; ab: abandoned; (): years of abandonment; Tr: time to runoff generation; V: vineyards (Almáchar-Málaga); A: almonds (Salada-Murcia); A2: almonds (Campo de Murcia); O: oranges (La Granja de la Costera-Valencia); Ol: Olives (Moixent-Valencia).

During our experiments, at pedon scale, we observed micro-ponds that acted as sinks in the agriculture land due to the high roughness such as was found in other research (Cerdà, 2001; Rodrigo-Comino et al., 2016a). Then, we highly encourage researching the impact of abandonment in the micro-topography 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 also obtained showing connectivity mechanisms (Zhang et al., 2013), therefore, we claim the need of researching to shed light into the scale and connectivity via mapping techniques or connectivity index (López-Vicente et al., 2013; Masselink et al., 2016). Moreover, we need further experimental approaches 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.

In this way, with the high statistical significance between runoff and SL (in abandoned and cultivated areas), we have demonstrated that the cultivated areas generate Hortonian overland flow under high magnitude – low frequency rainfall events (Figs. 8 and 9). The citrus and olives terraced orchards planted recover faster the vegetation after the abandonment, and this resulted in an increase in the infiltration rates and a decrease in the surface runoff and soil losses as a consequence of the soil quality improvements. Meanwhile, the sloping terrain of almonds and vineyards enhance the development of crusts and rills and a negligible vegetation cover resulted in high erosion rates as 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 establish 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 more active (Lesschen et al., 2008).

Fig. 9

Our research confirmed that the vegetation cover is the key factor to determine the fate of the abandonment and the erosion rates. The vegetation recovery in the orange and olive terraced orchards is the key factor to determine the high infiltration rates and negligible soil erosion. Vegetation can function as natural filter enhancing infiltration, and avoid soil crusting development and enhance aggregate formation (Keesstra et al., 2012; Bienes et al., 2016; Ruiz-Sinoga and Martinez-Murillo, 2009). Governmental policies must promote plant recovery after abandonment. For the regions that the recovery is poor such as the ones we have seen in Murcia and Málaga with almonds and vineyards crops, we recommend to actively use strategies to reduce the soil erosion after the abandonment, and we suggest to avoid grazing during the first years after the 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 (Fernández-Calviño et al., 2016; Giménez-Morera et al., 2010; Yazdanpanah et al., 2016)) can reduce soil losses and improve the soil quality, which is the first step to avoid non-sustainable soil erosion rates.

CONCLUSIONS

Sloping fields of almond orchards and vineyards showed the highest soil loss and runoff rates which are due to the bare soils and the lack of vegetation cover. In terraced orange and olive plantations, after the abandonment, and due to the natural plant recovery, soil erosion decreased drastically in both plots and soil erosion was low after 3- and 10-years in the citrus and 5- and 20-years after the abandonment in olive. As older the age of abandonment as lower the soil losses. In almond orchards and vineyards, after the abandonment, the vegetation recovery was low and resulted in an increase of soil erosion rates after land abandonment. High slope inclinations in the almond and vineyard plantations contribute to increase the soil losses after the abandonment such as the rill and crust formations show in the spare vegetated soils, meanwhile in the flat terraces of the olive and orange orchards, the dense vegetation cover resulted in an improvement in the soil properties and as a consequence in the soil erosion rates reduction. This contrasted response to the abandonment in Mediterranean crops suggest that the abandonment should be programed and managed with soil erosion control strategies for some years to avoid the degradation of the land.

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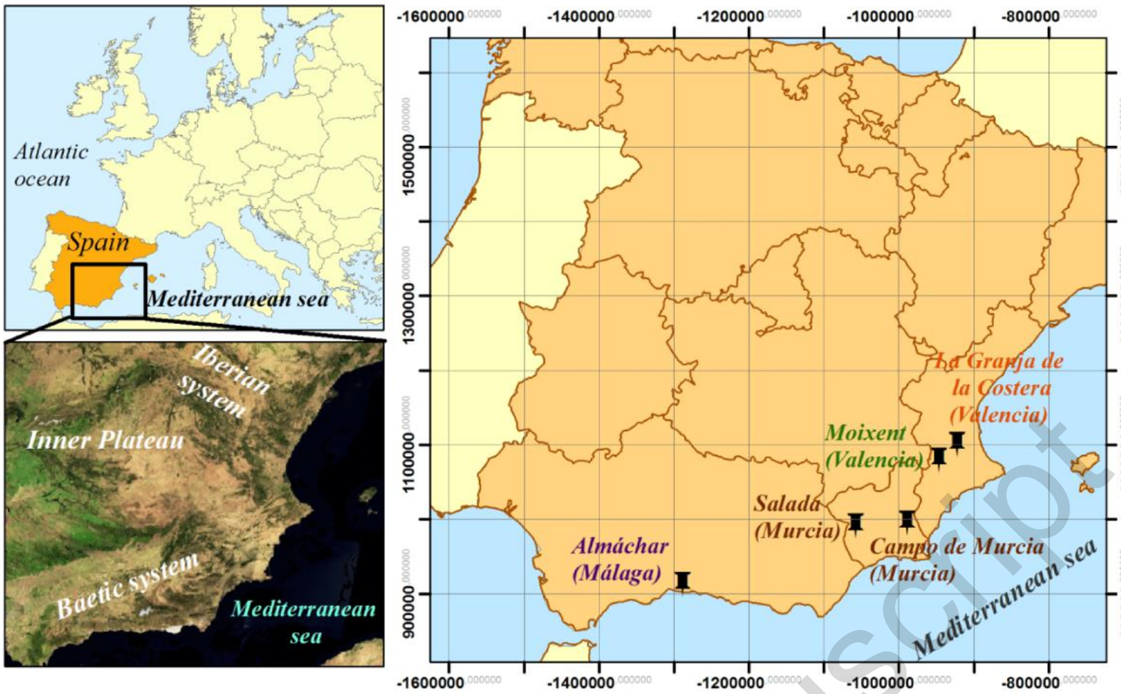
Atlantic ocean
Spain
Mediterranean sea
Iberian system
Inner Plateau
Baetic system
Mediterranean sea
La Granja de la Costera (Valencia)
Moixent (Valencia)
Salada (Murcia)
Campo de Murcia (Murcia)
Almáchar (Málaga)
Mediterranean sea
-1600000
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-800000
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1300000
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900000

Fig. 1

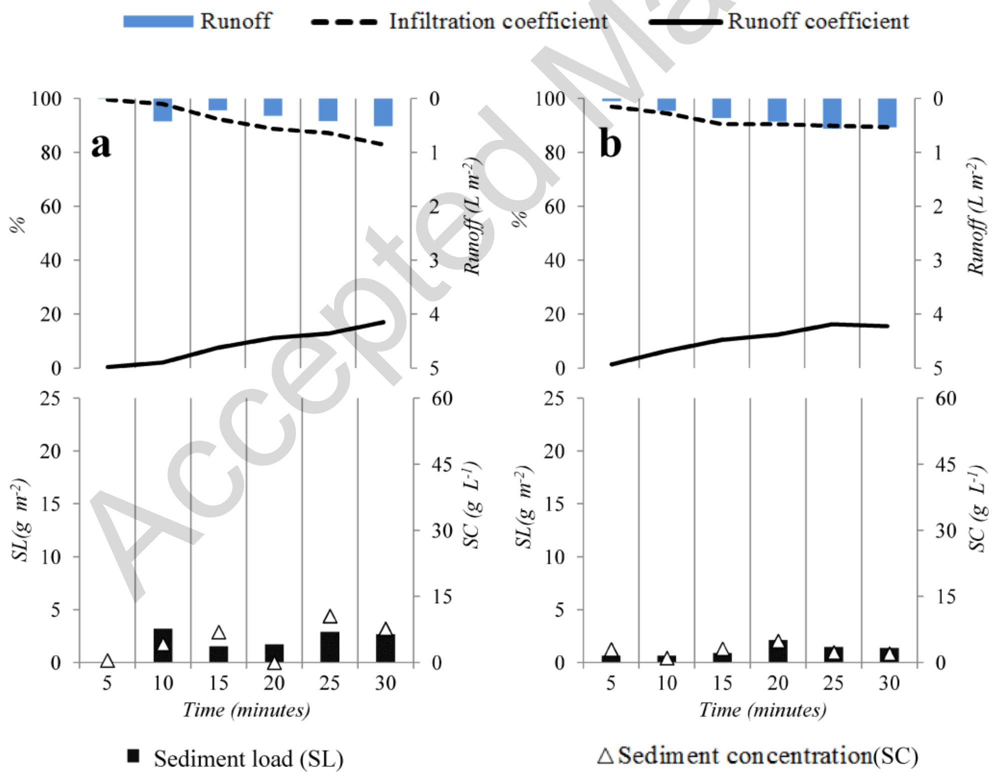
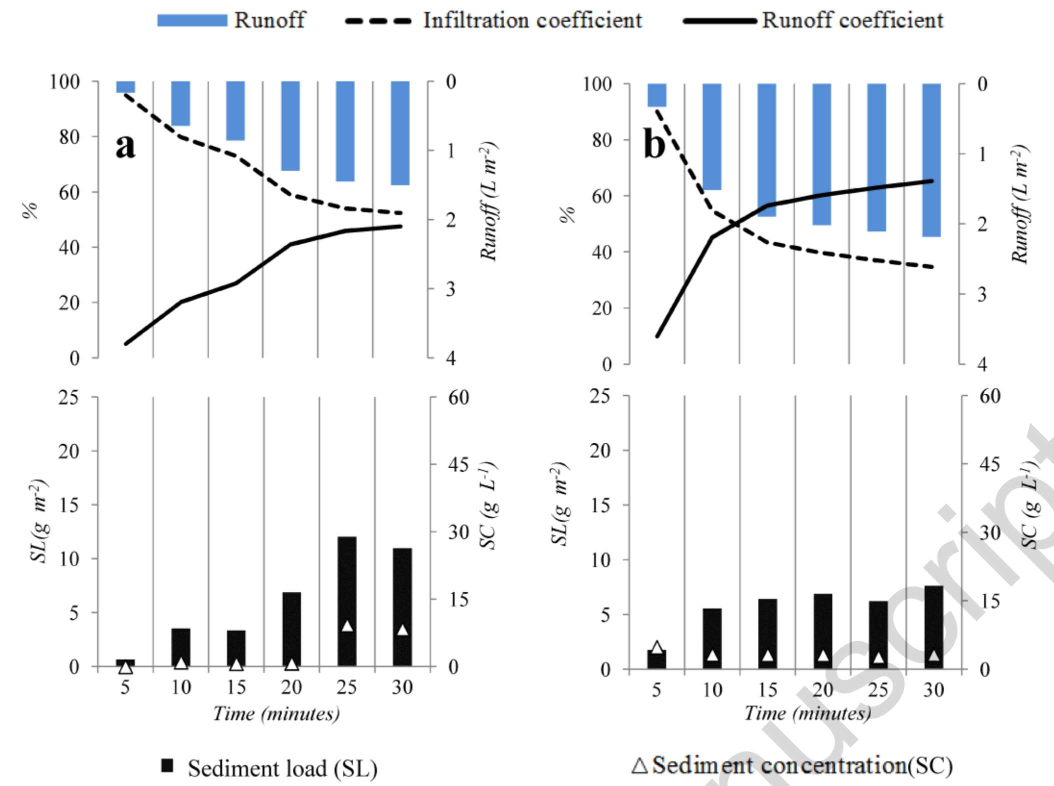
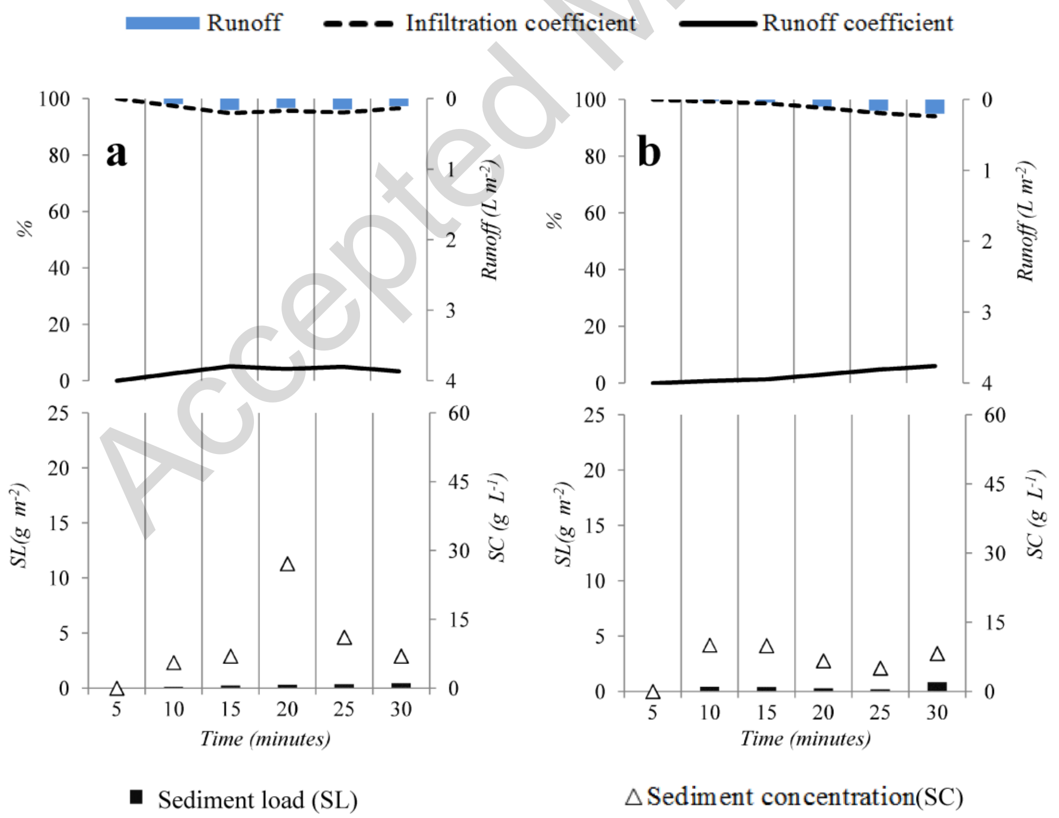

Runoff
Infiltration coefficient
Runoff coefficient
a
b
%
Runoff (L m-2)
SL(g m-2)
SC (g L-1)
Time (minutes)
Sediment load (SL)
Sediment concentration(SC)

Fig. 2



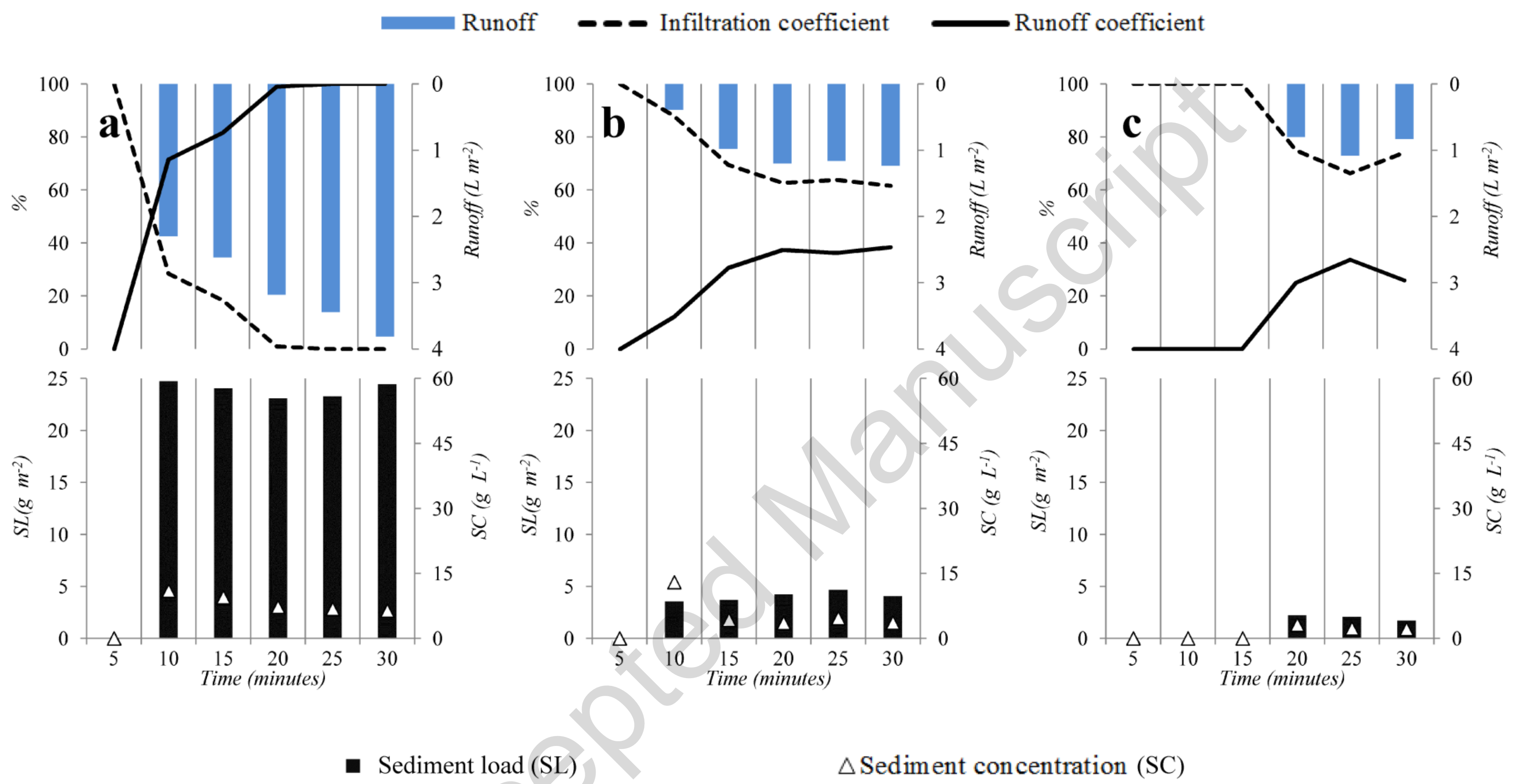
Runoff
Infiltration coefficient
Runoff coefficient
a
b
%
Runoff (L m-2)
SL(g m-2)
SC (g L-1)
Time (minutes)
Sediment load (SL)
△Sediment concentration(SC)

Fig. 3



Runoff
Infiltration coefficient
Runoff coefficient
a
b
%
Runoff (L m-2)
SL(g m-2)
SC (g L-1)
Time (minutes)
Sediment load (SL)
△Sediment concentration(SC)

Fig. 4



Runoff
Infiltration coefficient
Runoff coefficient
a
b
c
%
Runoff (L m-2)
SL (g m-2)
SC (g L-1)
Time (minutes)
Sediment load (SL)
Sediment concentration (SC)

Fig. 5

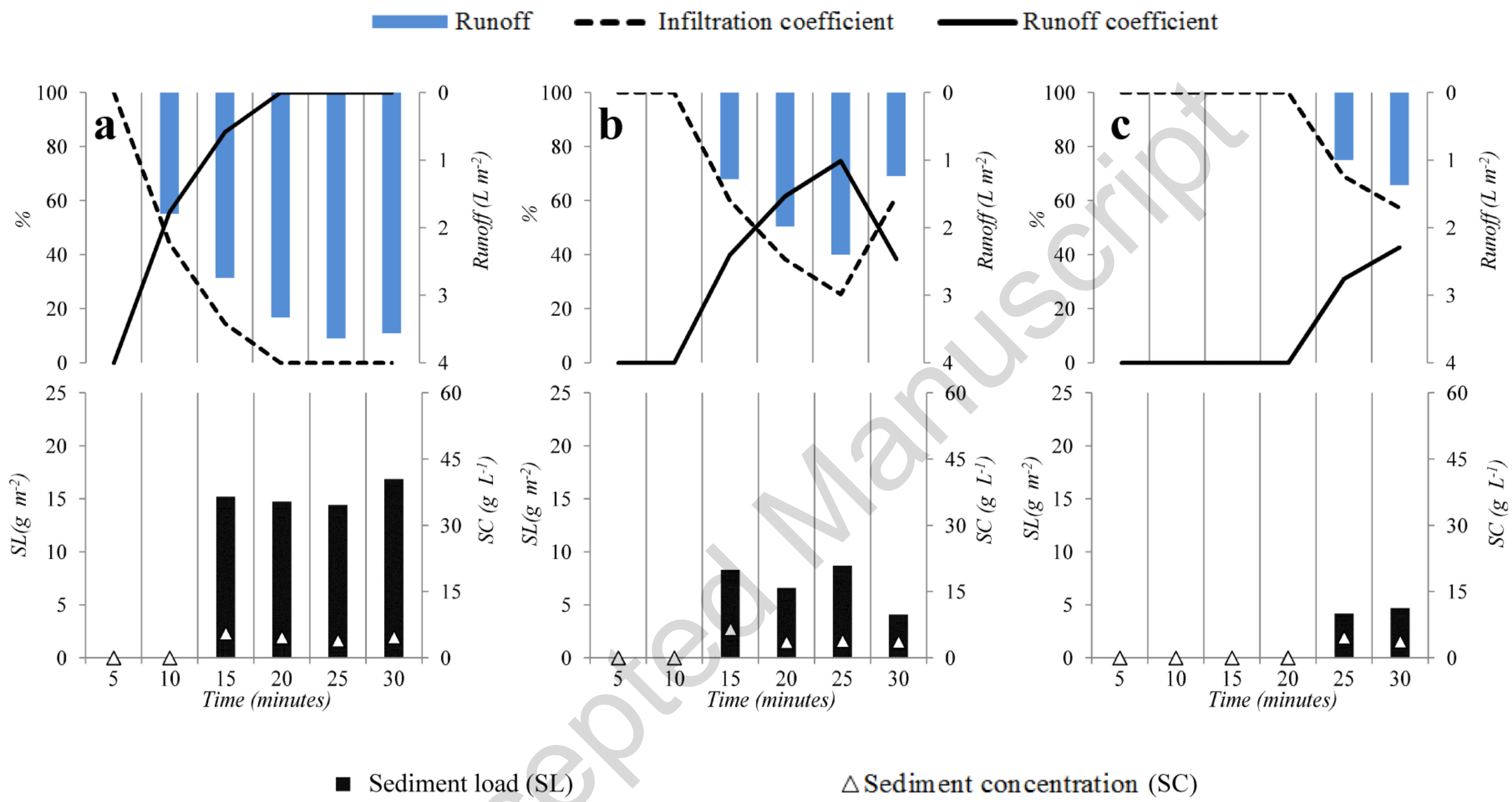
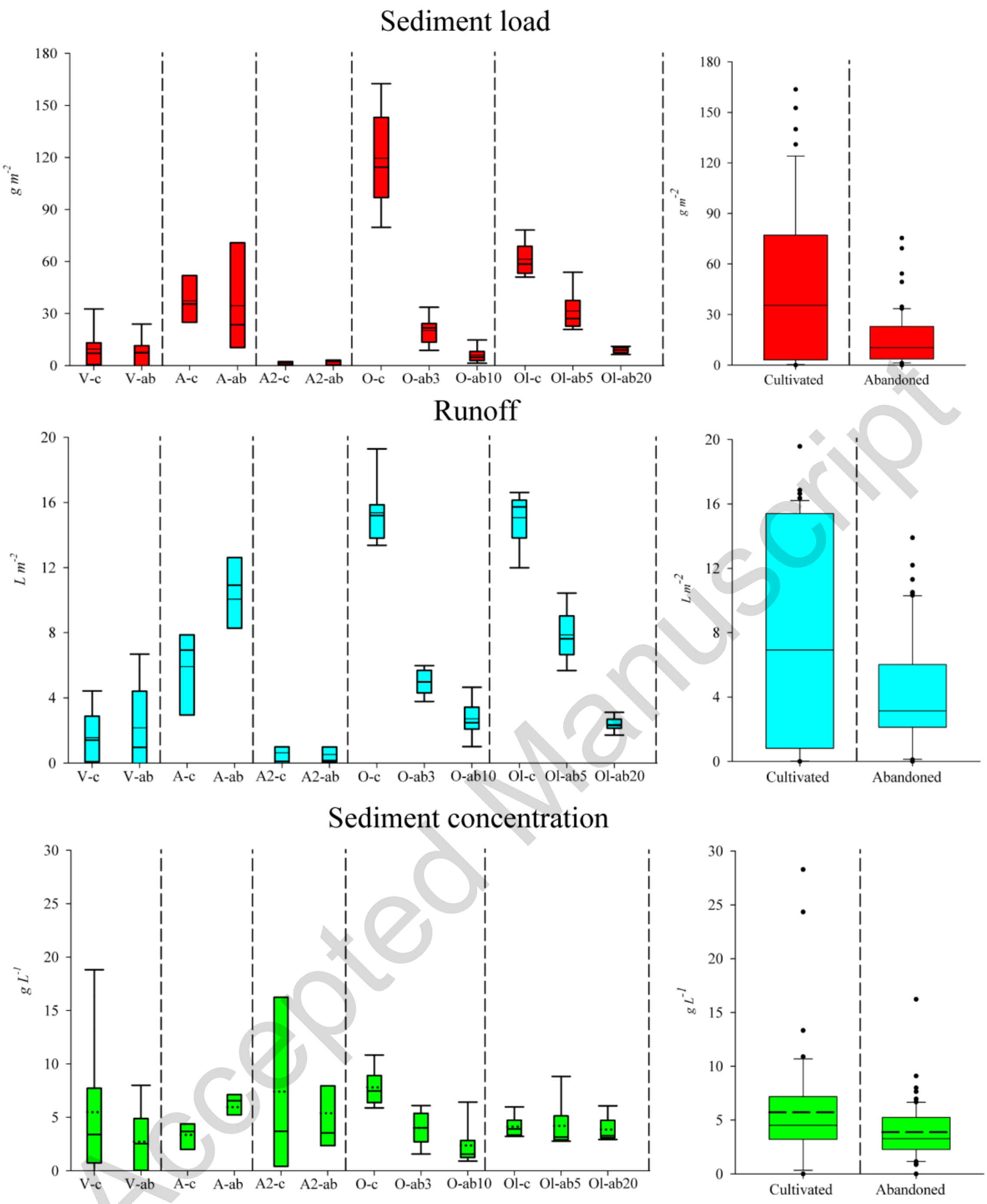
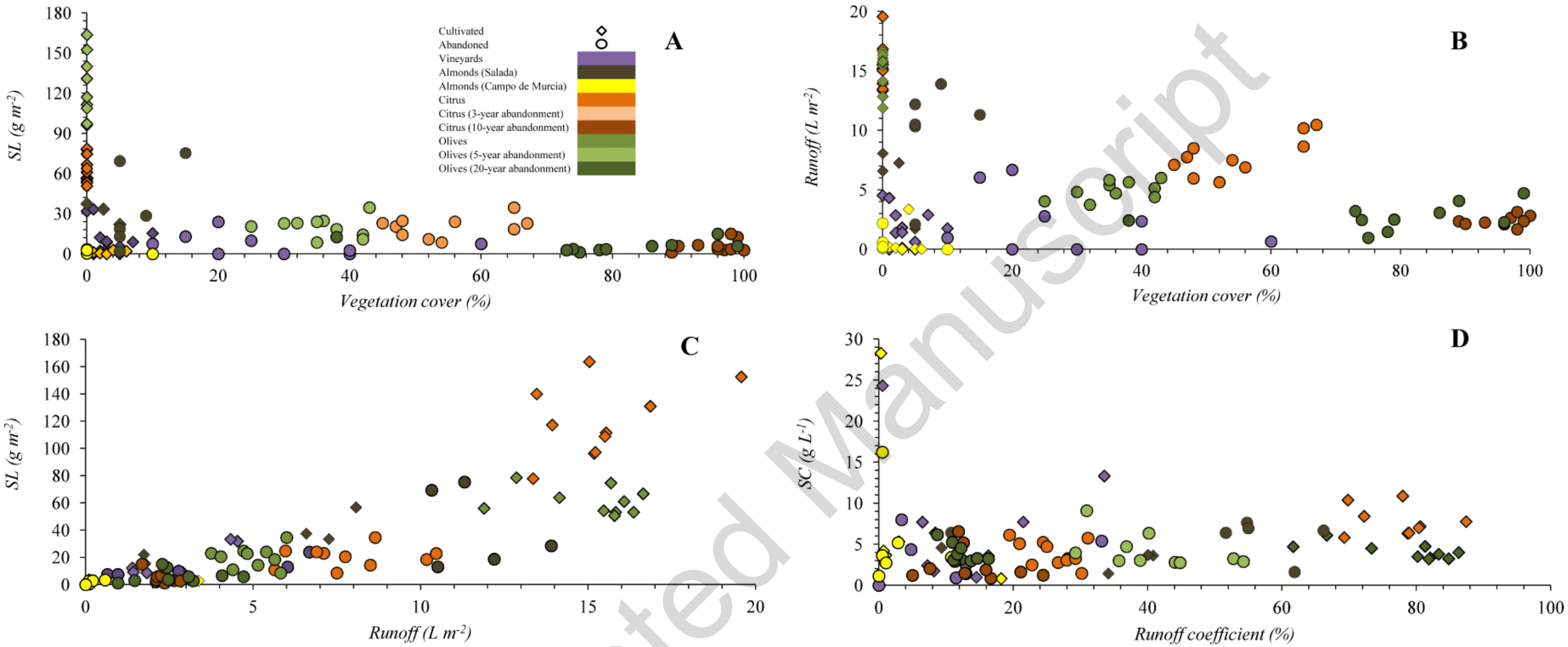

Runoff
Infiltration coefficient
Runoff coefficient
a
b
c
%
Runoff (L m-2)
SL(g m-2)
SC (g L-1)
Time (minutes)
Sediment load (SL)
Sediment concentration (SC)

Fig. 6



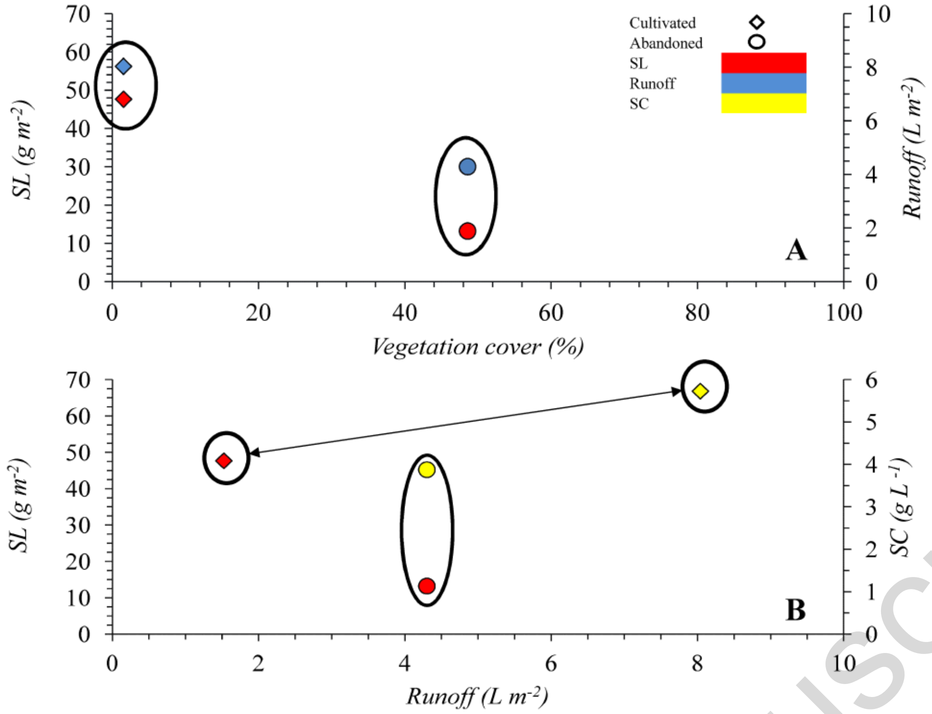
Sediment load
g m-2
180
150
120
90
60
30
0
V-c
V-ab
A-c
A-ab
A2-c
A2-ab
O-c
O-ab3
O-ab10
Ol-c
Ol-ab5
Ol-ab20
Cultivated
Abandoned
Runoff
L m-2
20
16
12
8
4
0
Sediment concentration
g L-1
30
25
20
15
10
5
0

Fig. 7



A
B
C
D
Cultivated
Abandoned
Vineyards
Almonds (Salada)
Almonds (Campo de Murcia)
Citrus
Citrus (3-year abandonment)
Citrus (10-year abandonment)
Olives
Olives (5-year abandonment)
Olives (20-year abandonment)
SL (g m-2)
Runoff (L m-2)
SC (g L-1)
Vegetation cover (%)
Runoff coefficient (%)

Fig. 8



Cultivated
Abandoned
SL
Runoff
SC
A
SL (g m-2)
Runoff (L m-2)
Vegetation cover (%)
B
SL (g m-2)
SC (g L-1)
Runoff (L m-2)

Fig. 9