

1 DOI:10.1016/S1002-0160(17)60441-7

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3 **Title: THE CONTRASTED IMPACT OF LAND ABANDONMENT ON SOIL**
4 **EROSION IN MEDITERRANEAN AGRICULTURE FIELDS**

5 **Running title: IMPACT OF ABANDONMENT ON SOIL EROSION**

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17 HIGHLIGHTS

- 18 ✓ 105 rainfall simulations experiments shed light into soil erosion after abandonment
- 19 ✓ Citrus, olive, vineyards and almonds fields were studied in SE Spain.
- 20 ✓ After the abandonment erosion decreased in olive and citrus, was similar in vineyards,
- 21 and increased in almonds orchards.
- 22 ✓ Vegetation recovery is the key factor to control soil detachment once abandonment
- 23 takes place.
- 24 ✓ Vegetation recovery is more successful in terraced agriculture fields where soil
- 25 erosion is negligible after abandonment

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27

28 ABSTRACT

29

30 Abandonment of agricultural land results in on- and off-site consequences on soil system and

31 there is a need to evaluate the impact on soil erosion to understand the ecosystem's changes.

32 The aim of this research is to assess the impact of abandonment in four Mediterranean crops

33 (vineyards, almonds, citrus and olives) on soil and water losses. To achieve this goal, 105

34 rainfall simulation experiments were conducted in agriculture fields (vineyards in Málaga,

35 almonds in Murcia, and citrus and olive in Valencia) and on the paired abandoned plots. After

36 abandonment, soil detachment decreased drastically in the olive and citrus orchards,

37 meanwhile vineyards did not show any difference and almonds registered higher erosion rates

38 after the abandonment. Terraced orchards of citrus and olives recovered a dense vegetation

39 cover after the abandonment, meanwhile the sloping terrain of almonds and vineyards

40 enhanced the development of crusts and rills and a negligible plant cover that resulted in high

41 erosion rates. The contrasted response of the abandonment is discussed.

42 **KEY WORDS:** Soil erosion; Mediterranean crops; abandonment; vegetation cover; terraces;

43 rainfall simulation

44

45 INTRODUCTION

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

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

69 Vegetation recovery is a fact after abandonment, which is characterised by changes in the
70 biomass and also in the floristic composition. Herbs and shrub recover fast (<5 years) after the

71 abandonment (Lasanta et al., 2015). However, vegetation recovery is by far slower in semi-
72 arid areas as well as Mediterranean territories, where water is the key resource for plant
73 recovery (Cammeraat et al., 2010; Ries, 2010; Ruiz-Sinoga and Martinez-Murillo, 2009). In
74 cultivated fields, the removal of the weeds by tillage or herbicides results in extremely high
75 erosion rates (Cerdà et al., 2010; Prosdocimi et al., 2016a). Farmers promote bare soils to
76 reduce the amount of water used by weeds and catch crops and this increase the soil and water
77 losses by surface wash due to the lack of vegetation (Martínez-Murillo et al., 2016).
78 Agriculture fields are perceived as tidy and, therefore, seen by farmers as the way their
79 orchards should look (Keesstra et al., 2016; Sastre et al., 2016). This situation enhances that
80 recent abandoned soils show high bulk densities and low aggregate stability (Bienes et al.,
81 2016; Verbist et al., 2007) and high soil and water losses (Shi et al., 2010; Yazdanpanah et al.,
82 2016; Ries et al. 2014a). Once the soil is not plough, bulk density increase, surface crusts
83 develop and overland flow take place and soil erosion reach high rates (Robledano-Aymerich
84 et al., 2014). However, the vegetation recovery can reduce the raindrop impact, reduce the
85 surface wash velocity, increase the infiltration rates and as a consequence reduce the soil
86 losses (Keesstra et al., 2016; Breton et al., 2016). The successful recovery of the vegetation
87 after abandonment needs a proper integrated extensive livestock to preserve the abandoned
88 land and avoid forest fires (Mataix et al., 2015) as is relevant to understand the carbon cycles
89 and the ecosystem services offered by the soils (Peregrina et al., 2016; Szalai et al., 2016;
90 Novara et al., 2017). The fate of the abandoned land also will determine the soil erosion rates
91 such as other land use changes do. Then, there is an interaction between the vegetation and
92 the erosion processes.

93 Climate conditions and culture development in the Mediterranean contribute to high erosion
94 rates as a consequence of millennia old ploughing management that resulted in physical,
95 biological and chemical soil degradation (Al-Kaisi et al., 2005; Gómez et al., 1999; Govers et
96 al., 1994). The most recent scientific literature shows many examples of high erosion rates. In

97 Persimmon orchards in Easter Spain, Cerdà et al., (2016) recorded soil depth lowering of 0.5
98 mm in 1-hour during 10-year return period storm events as a consequence of raindrop impact
99 and surface wash. Similar response was noted by Keesstra et al., (2016) in soils planted with
100 apricot trees applying herbicide treatments arranging 1.8 and 45.5 times more erosion than
101 tillage and covered, respectively. By conducting rill experiments in extensive plantations of
102 almonds with bare soils from Southeast Spain on badland morphologies, Wirtz et al., (2013)
103 measured sediment concentration values up to 401.5 g L⁻¹. Prosdocimi et al., (2016a) and
104 Rodrigo-Comino et al., (2016a) demonstrated that vineyards with bare soils enhance larger
105 amounts of sediment yield and high runoff discharges.

106 All the above mentioned examples from the Mediterranean demonstrate that is necessary to
107 develop successful land management policies and assess the soil degradation processes at the
108 pedon scale to understand the soil quality, the detachment of soil particles and the runoff
109 initiation (Nearing et al., 1999; Khaledian et al., 2016). It is also well accepted that should be
110 nature-based solutions, such as grass covers, catch crops, or geotextiles involved in the new
111 agriculture to solve the lack of sustainability (Giménez Morera et al., 2010; Feng et al., 2016;
112 Palese et al., 2015). Experiments with small portable rainfall simulators are considered as a
113 useful tool for measuring the soil erosion processes and the mechanism such as splash, inter-
114 rill erosion and runoff generation (Iserloh et al., 2013a, 2013b). Rainfall simulators offer the
115 possibility to quantify the soil detachment and runoff initiation with high accuracy and under
116 low frequency – high magnitude rainfall events. This research aims to determine the effect of
117 agriculture abandonment on soil erosion in four different traditional crops in the
118 Mediterranean belt: vineyards, almonds, citrus and olives. This will inform policy makers
119 where should be designed a programed abandonment to avoid non-sustainable soil erosion
120 rates.

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122 2. MATERIALS AND METHODS

123 2.1. Study areas

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

127 The vineyards plots were selected in Almáchar, Málaga. Altitude ranges from 300 to 400
128 m.a.s.l. Vines were cultivated following the steep slope angles ($>30^\circ$) with the grape variety
129 *Muscat of Alexandria*. Conventional ploughing was conducted for millennia. Clear signals of
130 soil erosion in form of rills were surveyed (Rodrigo-Comino et al., 2016b). Mean annual
131 rainfall is 520 mm and mean annual temperature 17.2°C. Total organic carbon ranged from
132 3.1 to 3.5% on silty soils (72.2%). The parent material is Palaeozoic dark schist and soils can
133 be described as *Eutric Leptosol* (IUSS Working Group WRB, 2014). Soils are characterized
134 by high stone content and shallowness less than 30 cm (Rodrigo-Comino et al., 2017).

135 The almond orchards are located in Salada and Campo de Murcia municipalities, province of
136 Murcia. Both study sites received the same traditional soil tillage and were cultivated with
137 almonds. The soils in Salada are developed in marls and show low organic matter content
138 ($<0.5\%$). The grain sizes are clay (27.3%), silt (42.1%) and sand (30.6%). Mean annual
139 temperature is 11.6°C and the mean annual rainfall 414 mm. The Campo de Murcia study
140 sites is characterized by marls and limestones and soils with high silt contents (79.4%), but
141 lower clay particles (9.9%). Total organic carbon content is low (2.8% and 3.3%). Mean
142 temperature is 17.8°C, and mean annual rainfall 258.8 mm.

143 The olive plantation of Moixent is located in the southwest Valencia province at 350 m.a.s.l.
144 on agriculture terraces without inclination. *Manzanilla* is the olive's variety, and tillage is
145 used for millennia in this traditional rainfed agriculture region. Two abandoned fields of 5 and
146 20 years were selected to compare with the active one. The traditional management consisted
147 of four ploughs per year in the active field. Soil grain size is 30.3% sand, 42.1% silt and
148 20.6% clay. The total organic carbon ranged between 1% (cultivated) and 3.2% (abandoned

149 20 years ago), with values around 1.5% in the 5-years abandoned orchards. The parent
150 materials are marls. Rills can be found after thunderstorms in the ploughed active soils, but
151 not in the abandoned ones where the vegetation recovery is very fast. Total annual rainfall
152 reaches up to 390 mm, with minimum and maximum in August and October, respectively.
153 Citrus farms were selected at La Granja de la Costera municipality, located in the south of
154 Valencia province. The orchards are flood irrigated and herbicides are use to avoid weeds and
155 keep the soil bare. The mean annual rainfall is 590 mm and the parent material is limestones.
156 The soils are characterized by the lack of rock fragments and the widespread presence of
157 surface crust when under agriculture use due to the widespread use of herbicides in the citrus
158 plantations. Organic carbon content varies between 1.2% (cultivated) and 5.4% (abandoned
159 10-years), with 2.1 % in the abandoned after 5-years. Soils grain size is 20.6%, 42.1%, 32.3%
160 for clay silt and sand, respectively.

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162 **2.2. Small portable rainfall simulator characteristics and procedures in laboratory**

163 The rainfall simulator is a nozzle type, which was described by Cerdà (1999) and Iserloh et al.
164 (2012) and is widely used in Europe (e.g. Iserloh et al., 2013a). A calibrated and reproducible
165 rainfall of 40 mm h⁻¹ is sprayed from a height of 2 m by a Lechler 460 608 nozzle on a 0.28
166 m² circular test plot. The simulator is covered by a rubber tarpaulin to avoid external
167 influences such as wind. Duration of the experiments was 30 minutes, divided into six
168 intervals of five minutes to collect the runoff discharge and take samples to determine the
169 sediment concentration (SC). The collected runoff water in each bottle was filtered separately
170 with fine-meshed filter paper. The filters were dried to constant weight at 105 °C and weighed
171 for getting soil loss for each 5-minute intervals. Roughness was measured by chain method
172 (Saleh, 1993).

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174 **2.3. Statistical analysis**

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

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183 **3. RESULTS**

184 **3.1. Plot characteristics**

185 Plot characteristics showed differences between study sites as they represent different
186 cropping systems (Table 2). The lowest slope values were registered in the olive and citrus
187 crops with 0° and the highest in the vineyards between 31.3° (cultivated) and 33.6°
188 (abandoned). The contrasted slope angles are due to the different farmers' strategies. In
189 Valencia (Moixent and Granja de la Costera study sites), the slopes were terraced, but in
190 Málaga (Almáchar) and Murcia (Salada and Campo de Murcia) the slopes were plough
191 without any conservation strategy. Average vegetation cover (VC) in cultivated areas showed
192 minimum values close to 1.5-13% in vineyards and almonds, and 0% in olives and oranges
193 due to the tillage and herbicides. The highest values (95%) were reached in abandoned olives
194 (20 years) and oranges (10 years) due to the successful natural re-vegetation. Vegetation
195 cover ranged between 1.7% (almonds in Campo de Murcia) and 54.7% (olives abandoned 20-
196 years in Moixent). Regarding the rock fragment cover, high values were observed, reaching
197 the highest (87.7%) in the vineyards. The highest roughness values were observed in the
198 olives and oranges with values of 116. Regarding time to runoff (T_r), vineyard, almond and
199 orange crops showed the highest values, which were 644 s, 660 s and 955 s, respectively.
200 Abandoned areas with vineyards and almonds registered quicker runoff than the soils under

201 cultivation, meanwhile the soils abandoned in oranges and olives orchards shown a delayed
202 runoff initiation due to the successful vegetation recovery and also as a consequence of the
203 litter layer developed by the herbs and shrubs.

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205 **3.2. Vineyards**

206 Fourteen rainfall simulations on cultivated and nine on abandoned vineyards were carried out
207 (Fig. 2). The vineyards (Fig. 2a) showed a total average SL about 9.4 g m^{-2} with a maximum
208 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
209 abandoned vineyards (Fig. 2b), average SL was 7.2 g m^{-2} with maximal values of 23.9 g m^{-2} .
210 Average runoff reached higher values (2.2 L m^{-2}) than on the cultivated one. However, SC
211 showed lower mean values (2.7 g L^{-1}). We measured low runoff discharge (10.4%).

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213 **3.3. Almonds**

214 In Salada, ten rainfall simulations were conducted (Fig. 3). The performed rainfall simulations
215 in almonds crops (Fig. 3a) showed an average sediment load of 37.4 g m^{-2} with maximum
216 values of 56.7 g m^{-2} . Runoff reached an average value of 10 L m^{-2} with high values of 13.9 L
217 m^{-2} . In Campo de Murcia research site, a total of 12 rainfall simulations (Fig. 4) were
218 conducted in plots with abandoned and active almond fields. Average SL on almonds (Fig.
219 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
220 was low (3.4%). In the abandoned crop fields (Fig. 4b), higher average SL (2.1 g m^{-2}) was
221 measured.

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223 **3.4. Oranges**

224 Thirty experiments carried out in citrus orchards are summarised in figure 5. In the cultivated
225 area (Fig. 5a), the mean SL reached 119.6 g m^{-2} . On 3- and 10-year old abandoned land, the
226 values decreased to 20.2 g m^{-2} (Fig. 5b) and 6 g m^{-2} (Fig. 5c). The runoff on the cultivated

227 land was in average 15.4 L m^{-2} . On abandoned lands, results were between 2.7 L m^{-2} (10-
228 years abandonment) and 5 L m^{-2} (3-years abandonment). This results in a SC of about 7.8 g L^{-1}
229 in average, on active orchards, and 2.4 g L^{-1} (10-years abandonment) and 2.4 g L^{-1} (3-years
230 abandonment) on abandoned land.

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232 **3.5. Olives**

233 The results of the 30 rainfall simulations are given in figure 6. On the conventional olive
234 orchards, a total average SL of 33.75 g m^{-2} and maximum values of about 61.3 g m^{-2} were
235 measured, while the mean runoff reached 15.1 L m^{-2} . The maximum observed runoff was
236 16.64 L m^{-2} . The mean SC was 4.1 g L^{-1} with a runoff coefficient of 78.1%. Mean total SL
237 values reached 31.5 g m^{-2} . Mean runoff value was 7.9 L m^{-2} and mean sediment concentration
238 was 4.2 g L^{-1} . On the 30-years abandoned olive plot, runoff was measured after 20 minutes
239 (Fig. 6c). The total SC was 3.9 g L^{-1} , with a total runoff coefficient of 12.3 %. During the
240 experiment, the mean total maximum SL and runoff amounts were 11.07 g m^{-2} and 3.14 L m^{-2} ,
241 respectively.

242 **3.6. Comparison between cultivated and abandoned areas**

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244 The results of 105 rainfall simulations are shown in figure 7 for comparison of cultivated and
245 abandoned lands. In cultivated areas, the total average of sediment load (SL) reached 47.71
246 g m^{-2} , the mean runoff 8.03 L m^{-2} and the mean sediment concentration about 7.21 g L^{-1} . In
247 the abandoned areas, total mean values decreased drastically. The mean soil loss was 15.57
248 g m^{-2} , the mean runoff 4.39 L m^{-2} and the mean sediment concentration 3.88 g L^{-1} . Maximum
249 values were also higher in the cultivated areas, reaching on the citrus orchard a total soil loss
250 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
251 then a clear impact of the process of abandonment of agriculture land: a reduction in the soil
252 losses. The main reason of the soil erosion control is due to the increase in the infiltration

253 rates that results also in an ecological shift in the abandoned land (Lasanta et al., 2006;
254 Romero-Díaz et al., 2007). From the point of view of the soil erosion, the vegetation recovery
255 act as a sink of sediments and water and this will result in the lost of connectivity (López-
256 Vicente et al., 2013) and as a consequence lower erosion rates and runoff discharge. However,
257 some authors found a decrease in the soil quality and then an increase in the soil erosion rates
258 after abandonment (Cerdà, 1997). This is due to the arid climatic conditions that slow the
259 vegetation recovery, but also the steep slope angles that activate the soil erosion and the lost
260 of water. This active erosion process is a relevant factor in the low vegetation cover in Málaga
261 and Murcia study sites. We also found that the abandonment in the southern locations is not
262 more a land use change into the low intensity grazing, although this results in an increase in
263 trampling and vegetation cover reduction and plant species change (and as a consequence
264 higher erosion rates is enhanced (Romero-Díaz et al., 2017).

265 With the box plots shown in figure 7, we demonstrate high differences by regarding the total
266 amounts, the maximum values and the variability of the results between the study sites. Thus,
267 to compare the total averages of rainfall simulation results with environmental plot
268 characteristics on every observed land uses, a T-test was applied (Table 3). Total mean values
269 of runoff, time to runoff generation and roughness did not show any statistically significant
270 difference between cultivated and abandoned areas. However, SL, SC, angle slopes,
271 vegetation and stone covers showed high statistically differences, confirming that one or more
272 environmental plot characteristics could potentially operate as key factor. By applying a
273 Spearman rank coefficient between the plot characteristics and soil and runoff losses, we have
274 observed which factor could enhance soil erosion processes. In the Table 4, cultivated areas
275 showed high statistical significance ($p < 0.001$) between the increase of the runoff and the
276 decrease of slope gradient, vegetation and stone covers, and with an increase of the roughness.
277 An increase of the SL showed also a high correlation with the decrease of the slope,
278 vegetation and stone covers, being much higher if roughness also increases. For the

279 abandoned areas (Table 5), a delay in the time to runoff generation showed a high statistical
280 significance with increasing vegetation cover and roughness. This is due to the impact of
281 vegetation on soil erosion and runoff generation.

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283 **4. DISCUSSION**

284 The process of abandonment can be considered as a world-wide change associated to a
285 progressive abandonment of traditional agricultural practices, which is enhancing land
286 degradation processes by increasing sediment and water yield (García-Ruiz and Lana-Renault,
287 2011; Ruiz-Sinoga and Martínez-Murillo, 2009; Ries 2010). However, we found that not
288 always the abandonment results in higher soil erosion rates. The increase in soil erosion was
289 true for the sloping terrain affected by grazing in abandoned almond orchards in Murcia and
290 vineyards in Málaga. However, in general abandoned lands generated much lower volume of
291 sediment and runoff as we found in olive and citrus in Spain as before found other researchers
292 in La Rioja (Arnáez et al., 2011). Regarding several researches focused on this topic,
293 pedological factors (such as roughness or texture) and parent materials were the most highly
294 related factors to explain the soil erosion by water (Cerdà, 1997). Slope inclination is also a
295 key issue to understand the fate of the soil losses in agriculture land (Koulouri and Giourga,
296 2007).

297 Figure 8 show several differences related to SL and runoff between the different types of
298 crops with vegetation cover. Regarding this, we noted that there was a delayed time to runoff
299 generation in abandoned areas, being specifically higher the time to runoff generation in the
300 abandoned olive and orange crops due to the higher vegetation cover. Similar results were
301 also obtained in Greece (Kairis et al., 2013) and other study areas from Spain (Espejo et al.,
302 2013; Gómez et al., 2009; Sastre et al., 2016) in olive orchard plantations.

303 During our experiments, at pedon scale, we observed micro-ponds that acted as sinks in the
304 agriculture land due to the high roughness such as was found in other research (Cerdà, 2001;
305 Rodrigo-Comino et al., 2016a). Then, we highly encourage researching the impact of
306 abandonment in the micro-topography and the advances in the use of photogrammetric
307 techniques such as Structure from Motion will be of help (Hänsel et al., 2016). At larger
308 scales, similar results were also obtained showing connectivity mechanisms (Zhang et al.,
309 2013), therefore, we claim the need of researching to shed light into the scale and connectivity
310 via mapping techniques or connectivity index (López-Vicente et al., 2013; Masselink et al.,
311 2016). Moreover, we need further experimental approaches to investigate challenging
312 processes like wind-driven rain erosion (Marzen et al., 2015, 2016) or animal trampling
313 (Pulido-Fernández et al., 2013; Schnabel et al., 2013) and their relation to land degradation.

314 In this way, with the high statistical significance between runoff and SL (in abandoned and
315 cultivated areas), we have demonstrated that the cultivated areas generate Hortonian overland
316 flow under high magnitude – low frequency rainfall events (see figure 8 and 9). The citrus and
317 olives terraced orchards planted recover faster the vegetation after the abandonment, and this
318 resulted in an increase in the infiltration rates and a decrease in the surface runoff and soil
319 losses as a consequence of the soil quality improvements. Meanwhile, the sloping terrain of
320 almonds and vineyards enhance the development of crusts and rills and a negligible
321 vegetation cover resulted in high erosion rates as a consequence of Hortonian runoff
322 generated during the simulated rains. When surface wash is active, there is the risk that the
323 failure of the terraces will increase the connectivity but due to the successful natural
324 vegetation recovery the disconnection established by the terraces is maintained after the
325 abandonment. In the sloping almond orchards and vineyards, the connectivity is enhanced by
326 the rill and crust formation, and surface wash more active (Lesschen et al., 2008).

327 Our research confirmed that the vegetation cover is the key factor to determine the fate of the
328 abandonment and the erosion rates. The vegetation recovery in the orange and olive terraced
329 orchards is the key factor to determine the high infiltration rates and negligible soil erosion.
330 Vegetation can function as natural filter enhancing infiltration, and avoid soil crusting
331 development and enhance aggregate formation (Keesstra et al., 2012; Bienes et al., 2016;
332 Ruiz-Sinoga and Martínez-Murillo, 2009). Governmental policies must promote plant
333 recovery after abandonment. For the regions that the recovery is poor such as the ones we
334 have seen in Murcia and Málaga with almonds and vineyards crops, we recommend to
335 actively use strategies to reduce the soil erosion after the abandonment, and we suggest to
336 avoid grazing during the first years after the abandonment. Straw covers or the use of organic
337 materials such as compost (Cerdà et al., 2016; Prosdocimi et al., 2016b), strip grass cover
338 (Novara et al., 2011; Sastre et al., 2016) or geotextiles and organic amendments (Fernández-
339 Calviño et al., 2016; Giménez-Morera et al., 2010; Yazdanpanah et al., 2016)) can reduce soil
340 losses and improve the soil quality, which is the first step to avoid non-sustainable soil
341 erosion rates.

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343 **5. CONCLUSIONS**

344 Sloping fields of almond orchards and vineyards showed the highest soil loss and runoff rates
345 which are due to the bare soils and the lack of vegetation cover. In terraced orange and olive
346 plantations, after the abandonment, and due to the natural plant recovery, soil erosion
347 decreased drastically in both plots and soil erosion was low after 3- and 10-years in the citrus
348 and 5- and 20-years after the abandonment in olive. As older the age of abandonment as lower
349 the soil losses. In almond orchards and vineyards, after the abandonment, the vegetation
350 recovery was low and resulted in an increase of soil erosion rates after land abandonment.
351 High slope inclinations in the almond and vineyard plantations contribute to increase the soil
352 losses after the abandonment such as the rill and crust formations show in the spare vegetated

353 soils, meanwhile in the flat terraces of the olive and orange orchards, the dense vegetation
354 cover resulted in an improvement in the soil properties and as a consequence in the soil
355 erosion rates reduction. This contrasted response to the abandonment in Mediterranean crops
356 suggest that the abandonment should be programmed and managed with soil erosion control
357 strategies for some years to avoid the degradation of the land.

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359 **AKNOWLEDGEMENTS**

360 We acknowledge the farmers for providing access to the study areas. Finally, we also thank
361 the Spanish Ministry of Education, Culture and Sport (Spain), for the Scholarships awarded to
362 J. Rodrigo Comino and C. Martínez-Hernández . The research reported here received funding
363 from the European Union Seventh Framework Programme (FP7/2007-2013) under grant
364 agreement n° 603498 (RECARE project). To Saskia Keesstra, Pedro I. Domingo, Lorena
365 Sánchez and the Degree and Masters courses from Trier University, for her contribution to the
366 field work in the studied areas.

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617 Table 1. 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 schists 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

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

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Table 2. 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

626 c: cultivated; ab: abandoned; (): years of abandonment; Tr: time to runoff generation; V: vineyards
 627 (Almáchar-Málaga); A: almonds (Salada-Murcia); A2: almonds (Campo de Murcia); O: oranges (La
 628 Granja de la Costera-Valencia); Ol: Olives (Moixent-Valencia).
 629

630 Table 3. 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

631 R: Runoff; SL: Sediment load; SC: Sediment concentration; Tr: Time to runoff generation; S: Slope;
632 Vc: Vegetation cover; Rc: Rock cover; Rg: Roughness.

633

634 Table 4. Spearman rank coefficient between environmental plot characteristics and rainfall simulation
635 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								

636 R: Runoff; SL: Sediment load; SC: Sediment concentration; S: Local slope; Vc: Vegetation cover; Rc:
637 Rock cover; Rg: Roughness; Tr: Time to runoff generation. *Cells with grey colors mean $p > 0.001$

638
639 Table 5. Spearman rank coefficient between environmental plot characteristics and rainfall simulation
640 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								

647 R: Runoff; SL: Sediment load;
648 SC: Sediment concentration; S: Local slope; Vc: Vegetation cover; Rc: Rock cover; Rg: Roughness; Tr: Time to runoff generation.
649 *Cells with grey colors mean $p > 0.001$

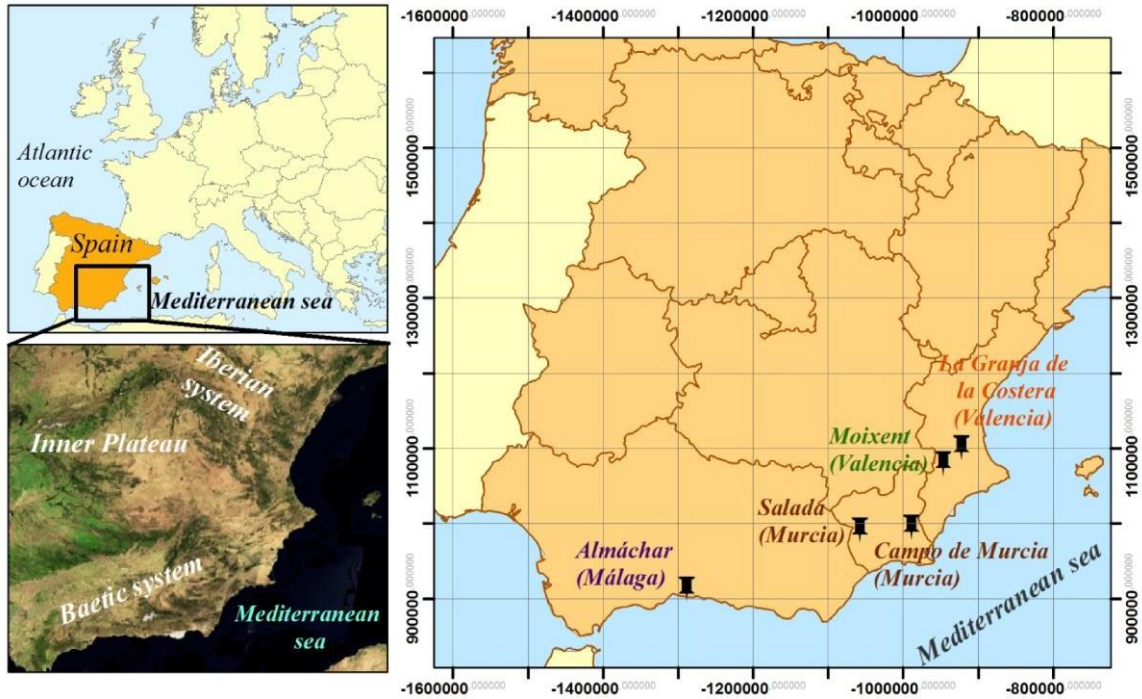
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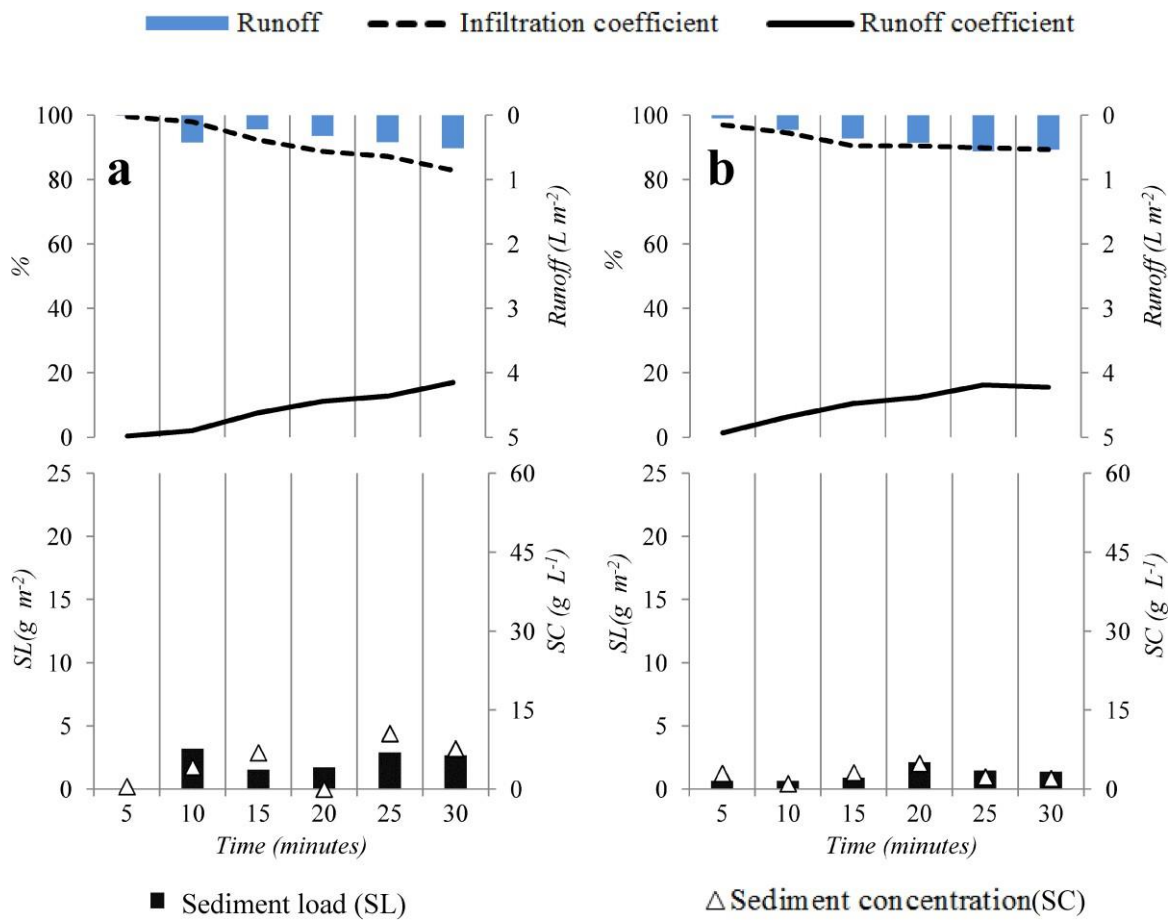
654 **List of figures**

655 Fig. 1. Study areas.



656

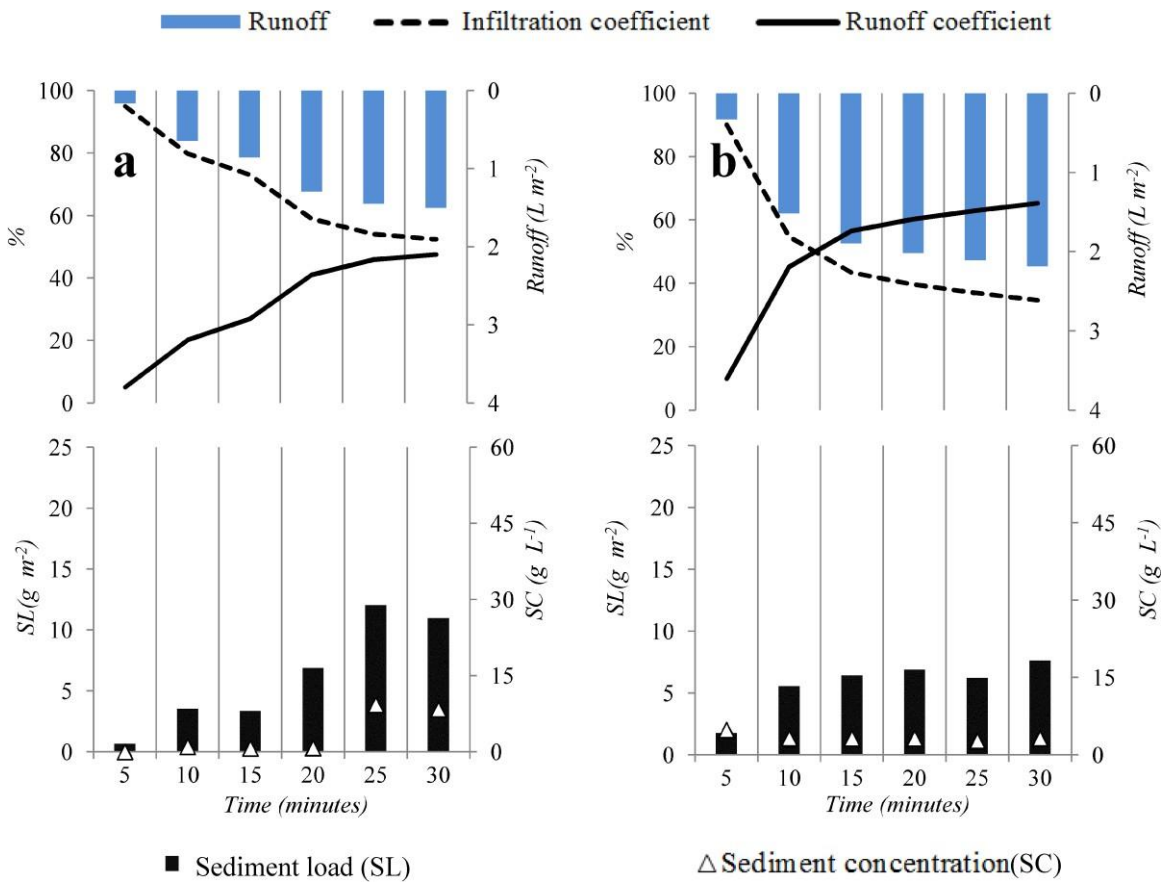
657 Fig. 2. Rainfall simulations in cultivated and abandoned vineyards (Almáchar, Málaga). a:
658 cultivated plot; b: abandoned plot.



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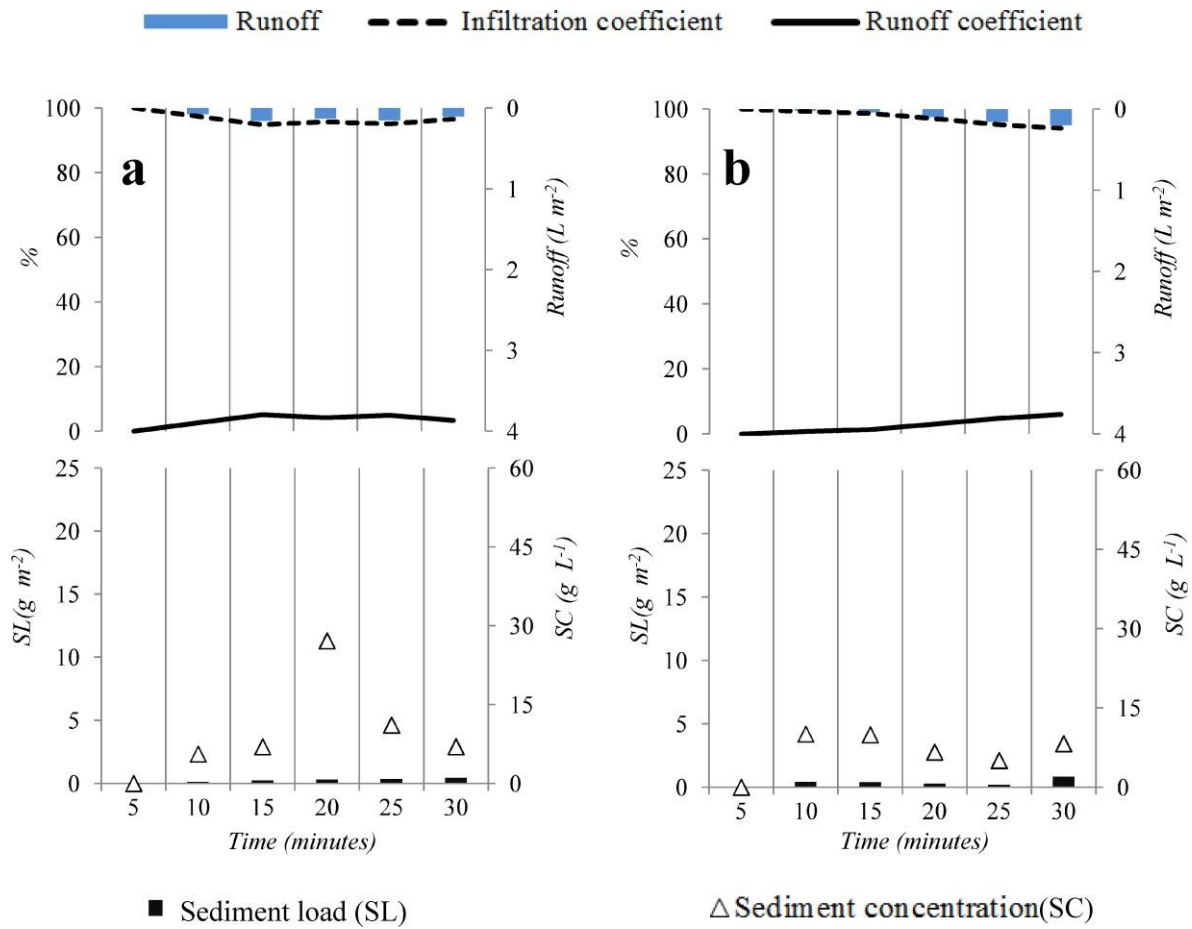
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662 cultivated plot; b: abandoned plot.



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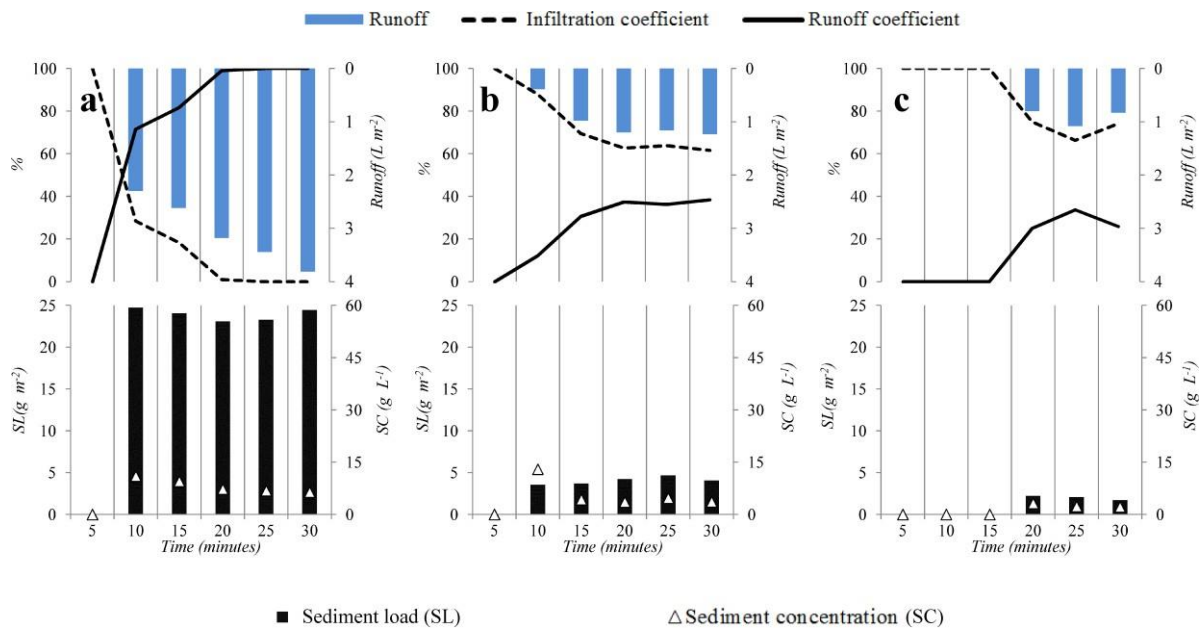
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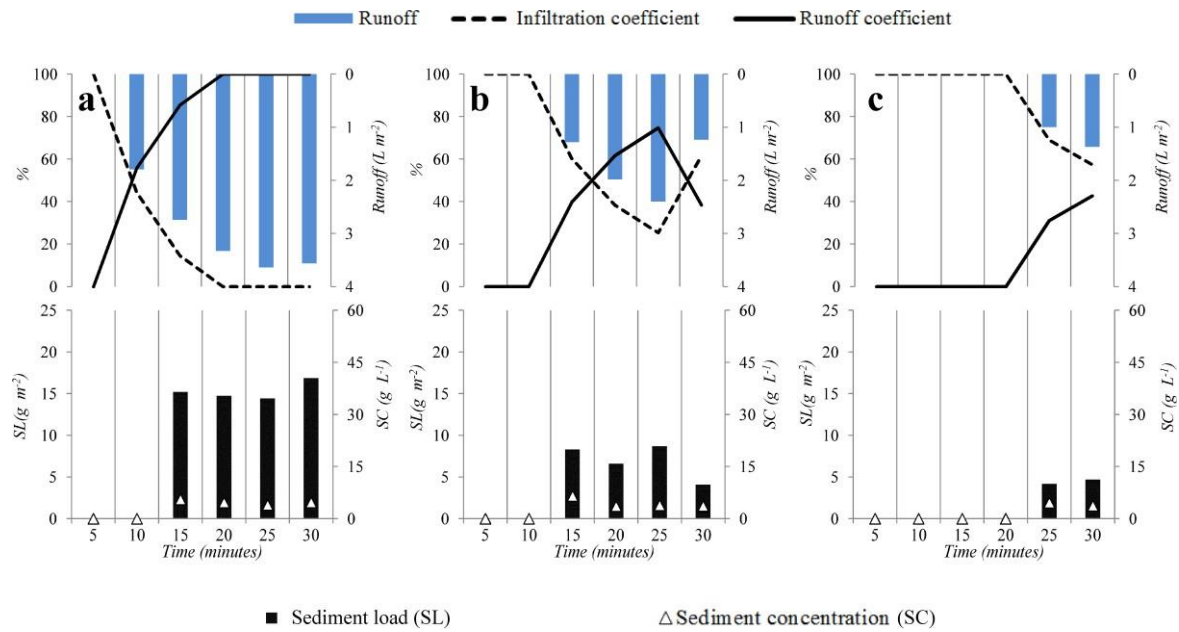
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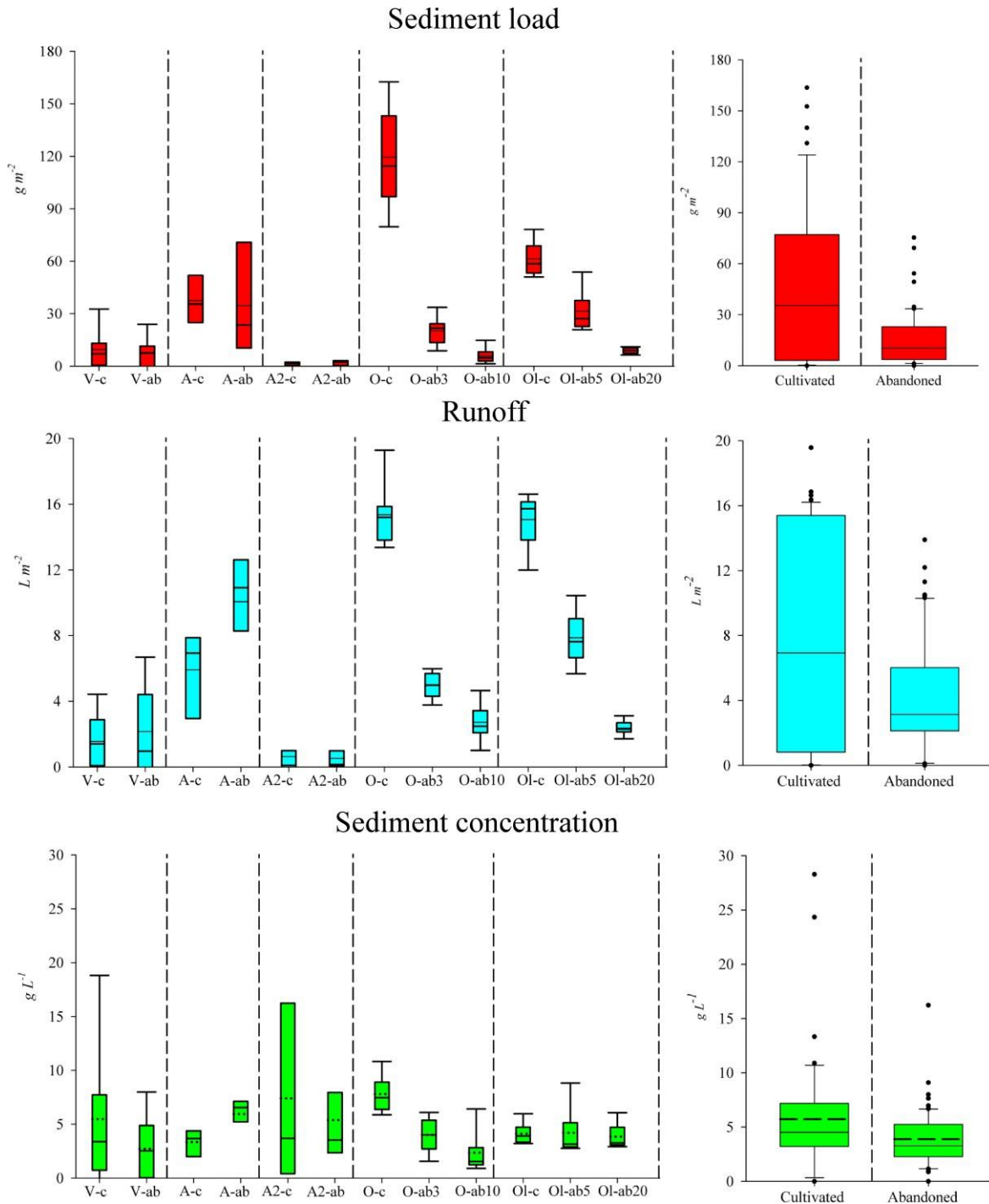
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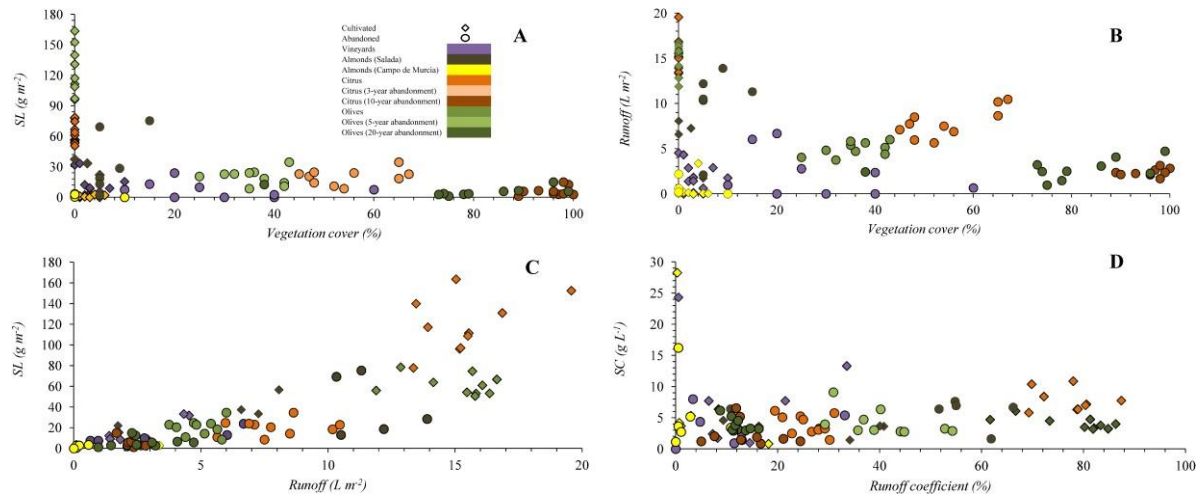
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 680 (Campo de Murcia); O: oranges (La Granja de la Costera-Valencia); Ol: Olives (Moixent-
 681 Valencia).



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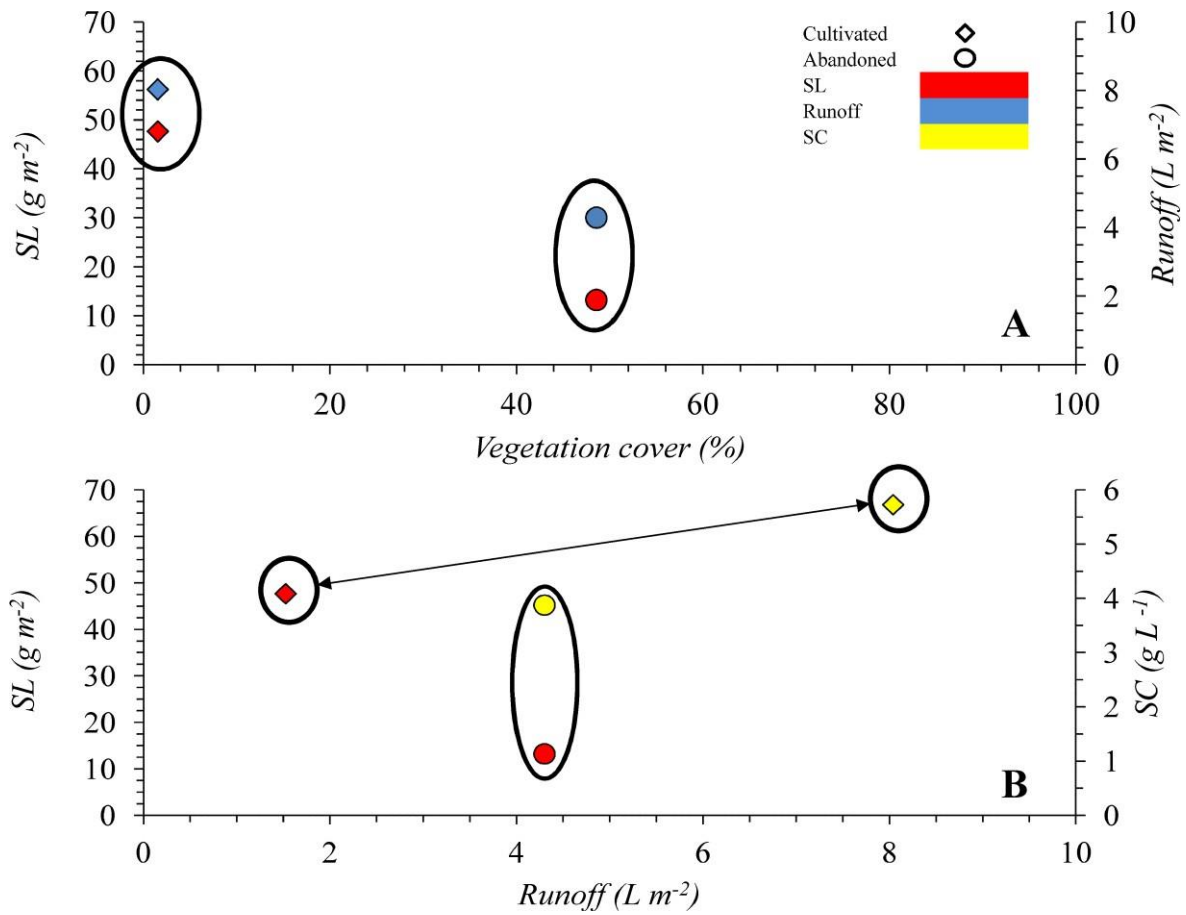
684 Fig. 8. Scatter plots with sediment load (SL), runoff, runoff coefficient, sediment
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688 abandonment; Tr: time to runoff generation; V: vineyards (Almáchar-Málaga); A: almonds
689 (Salada-Murcia); A2: almonds (Campo de Murcia); O: oranges (La Granja de la Costera-
690 Valencia); Ol: Olives (Moixent-Valencia).



691

692

693 Fig. 9. Scatter plots with sediment load (SL), runoff, sediment concentration (SC) and
694 vegetation cover.



695