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Pinus halepensis M. versus *Quercus ilex* subsp. *Rotundifolia* L. runoff and soil erosion at pedon scale under natural rainfall in Eastern Spain three decades after a forest fire

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ABSTRACT

Afforestation aims to recover the vegetation cover, and restore natural ecosystems. The plant species selected for restoration will determine species richness and the fate of the ecosystem. Research focussing on the impact of vegetation recovery on soil quality are abundant, especially on fire affected land and where rehabilitation, afforestation and restoration projects were carried out. However, little is known about how different plants species affect soil erosion and water losses, which are key factors that will impact the fate of the afforested land. Aleppo pine (*Pinus halepensis* M.) is the species commonly used for afforestation in the Mediterranean and is very successful when natural recovery takes place, however, the original forests were composed of Holm oaks (*Quercus ilex subsp. rotundifolia* L.). There is little information about the hydrological and erosional impact of this change of vegetation cover stimulated by a millennia old forest use in the Mediterranean, and a century old afforestation policies and natural recovery as a consequence of land abandonment. To get insights in the effect of plant species on runoff generation and soil erosion, individual trees should be selected. Plots of 1 m^2 are necessary to identify homogeneous patches, and were installed under Aleppo pine (4 plots) and *Holm* oaks (4 plots) in a 30 (34)-years old plant cover recovered after a forest fire that took place in 1979. A raingauge was installed in the study site to characterize the rainfall. The soil erosion plots were built with metal borders and each plot drained to a collector (gutter) and a 60 L container to store the surface runoff. Runoff was measured after each rainfall event and sediment concentration was determined by desiccation. Results show that Aleppo pine covered soils yield six times more runoff (232 mm, 8.31%) than Holm oaks (40 mm, 1.4%) during the experimental period of 2010–2014, when rainfall amount 2,721.1 mm. Runoff sediment concentration was higher in the Aleppo pine plots (4.9 g l^{-1}) than in the Holm oaks plots (2.6 g l^{-1}). Soil erosion rate was ten times higher in Aleppo pine (2.6 Mg ha^{-1} y^{-1}) than in Holm oaks (0.26 Mg ha^{-1} y^{-1}).

1. Introduction

Forest fires are recurrent features on our Planet (Pausas and Keeley, 2009) and they are a key issue to take into account when designing proper forest management (Fernandes and Rigolot, 2007). In Mediterranean ecosystems, due to the natural conditions (sufficient vegetation to be burned in combination with a long dry summer); and also because of human activities, fires are widespread phenomena (Pausas and Fernández-Muñoz, 2012). Recurrent forest fires induce accelerated soil erosion rates (Martínez-Murillo et al., 2016), higher runoff discharges (van Eck et al., 2016), soil properties changes (Mora et al., 2016), and plant and fauna disturbances (Végvári et al., 2016; Wang et al., 2016). To restore fire-affected land, afforestation is applied to reduce soil erosion risk during the periods that is called the post-fire window

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of disturbance (Moody and Martin, 2001), but also natural recovery (Keesstra, 2007) can contribute to restore the ecosystems services (Novara et al., 2016). The plant species selection during the restoration/afforestation will determine the future state of the ecosystems that were affected by fire, and soil and water losses are one of the most important parameters that will affect ecosystem evolution (Moreira et al., 2011). Again, the success of a chosen afforestation strategy will depend on selecting the right species or to thin the new seedlings of a less favourable species (Wallace and Good, 1995).

Agricultural land abandonment is widespread in the European Mediterranean due to socio-economic changes (Lasanta-Martínez et al., 2005). The abandonment can result in a successful natural vegetation recovery such as Arnaez et al. (2011) demonstrated, as vegetation recovery is successful in many mountainous areas affected by agriculture abandonment (Pueyo and Beguería, 2007). Recovery of plant biomass and new arriving species usually result in hydrological and erosional changes (García-Ruiz and Lana-Renault, 2011), but also in alterations in the flora and fauna composition (Chauchard et al., 2007; Sirami et al., 2008). Land degradation processes often also affect agricultural land once abandoned. This is due to the fact that abandonment is not planned and usually shows high erosion rates for some years such, especially in dry Mediterranean areas (Cerdà, 1997a,b; Romero-Díaz et al., 2017), which is why afforestation projects are carried out after land abandonment. The European Union Common Agrarian Policies have the objective to achieve sustainable management after abandonment through restoration strategies. However, which plants should be used for the most successful restoration strategy is a key issue, which is still not solved. Furthermore, abandoned land also needs soil conservation strategies to promote sustainable development as has been listed in the United Nations Sustainable Development Goals in which soil has been shown to be a key component of the Earth System (Keesstra et al., 2016a). Soil plays an important role in the fertility and stability of the forest by highlighting microorganisms, which accomplish reactions to release soil nutrients for vegetation development. Moreover, plant species alter soil properties through material derived from plant remains, root exudates and quantity or quality of leaves and plant material. The link between the above-ground tree species composition and processes such us soil erosion or runoff is still not fully understood and this is the gap this paper wish to cover.

Afforestation aims to improve vegetation cover, and restore degraded ecosystems to improve ecosystems services (Chazdon, 2008). The plant species selected for restoration will determine species richness, soil properties, sediment and water yield, carbon sequestration and the ecosystem's fate (Lucas Borja et al., 2011; Lang et al., 2014), and this is found also in the Mediterranean Type-Ecosystems too (Andrés and Ojeda, 2002). Usually, afforestation projects are designed to restore vegetation cover with the purpose to reduce soil and water losses (Soutar, 1989; Smith, 1992; Porto et al., 2009). Most of them are successful, although some afforestation projects have resulted in higher erosion rates (Romero-Diaz et al., 2010) and in some occasions soils need to be amended to improve the vegetation cover recovery and thus reduce soil erosion (Hueso-González et al., 2015). A key issue to achieve success is to find the appropriate species for afforestation efforts (Villacís et al., 2016). Most of the research carried out to evaluate the success of restoration projects is focussed on plant characteristics and soil quality after some years (Cortina et al., 1995; Chen et al., 2000; Cao et al., 2007). However, little information exists about the effects of different plant species on soil and water losses, although soil erosion is a key factor in the success of restoration projects and a necessity to be able to assess the sustainability of forest management (Hartanto et al., 2003).

Holm oak is the natural forest cover in many areas of the Western Mediterranean basin, and the Iberian Peninsula was covered with dense vegetation before humans induced large-scale deforestation and forest degradation. Research on strategies and development of afforestation with Holm oak is well advanced (Benayas, 1998), and on several experimental sites restoration efforts have proved to be successful (Benayas and Camacho-Cruz, 2004; Cerrillo et al., 2005; Núñez et al., 2006). Aleppo pine has been used as an easy-to-establish forest after disturbances in the Mediterranean, and has been implemented on many places and is now covering a large territory (Schiller and Cohen, 1998; Maestre et al., 2003; Maestre and Cortina, 2004). In fact, the success of Aleppo pine is extraordinary in the Mediterranean Type Ecosystems, as after the introduction by afforestation it has also colonized large areas (Osem et al., 2011) and some authors consider this expansion similar to the behaviour of an invasive species (lavi et al., 2005). However, the use of Aleppo pine is widespread after land abandonment, forest fires, and quarries restoration (Ortiz et al., 2012), for a large part in arid environments (Schiller and Atzmon, 2009). The objective when the afforestation takes place is the recovery of the vegetation cover and soils, and this was researched intensively in the last two decades (Roldan et al., 1996; Garcia et al., 2000; Querejeta et al., 2001; Bellot et al., 2004; Rincón et al., 2006). To properly understand the ecosystems services of the plants it is necessary to research into their effects on soil and water losses.

The objective of this paper is to compare runoff and sediment yield under Aleppo pine and Holm oak that recovered after forest fires. In this research we focused on the long-term effects on the differences these species induce to the soil system, as the measurements are done 30–34 years after the forest fire. The research is carried out to understand the runoff initiation and sediment detachment at plot scale ($< 1\ m^2$), and to shed light on the effect of the plant species on the hydrological and erosional processes.

2. Material and methods

The Sierra de Enguera range was selected in Southwest Valencia province, Eastern Spain, 750 m.a.s.l. (38° 55′N, 00° 50′W), as a representative of the Mediterranean mountains affected by land abandonment and forest fires. The climate is typical Mediterranean (Csa: Köppen) with a mean annual temperature of 12.7 °C as registered in the nearby meteorological station of Las Arenas Enguera. January is the coldest month (9.8 °C) and August is the warmest (25.7 °C). Rainfall is characterised by the Mediterranean Summer drought, with 540 mm of mean annual rainfall from 1942 till 2004, but with only 57 mm on average from June till August, when the highest evapotranspiration rates occur. The highest rainfall intensities were recorded from September till December, when rainfall events of 100 mm day^{-1} are recurrent every 5 years. Cretaceous carbonate rocks are the main parent material in the study area. The plots were installed on Limestones, which are found in 95% of the Sierra de Enguera. Rock fragments are always present and cover 30% of the studied slope. Rock outcrops in the hillslope occupy 5% of the surface. The soils are classified as Inceptisols (Soil Survey Staff, 1999). The vegetation is composed of a mixture of Mediterrranean Maquia species, with *Pinus halepensis* M. and *Quercus ilex subsp. Rotundifolia* L. Within the shrubs *Pistacia lentiscus* L., *Erica multifora* L., *Juniperus oxycedrus* Sibth. & Sm., *Quercus coccifera* L. and *Rosmarinus officinalis* L. are the most abundant. *Brachypodium restusum* (Pers.) P. Beauv is the unique herb that is widespread on the studied hillslope. In 1979 a forest fire burnt the Macizo del Caroig for four days (July 19th–22nd 1979) and burnt 44,000 ha. The plots were established in 2009 and the measurements started in 2010. We selected an area with natural recovery to avoid the effect of ploughing and heavy machinery that can disturb the soils and alter the topography and then the natural flows. The experimental research lasted five years, from 2010 until 2014. Eight plots were constructed with aluminium sheets that acted as borders, which were 1 mm thick × 50 mm in height × 100 mm long (x4) to achieve a plot of 1 m^2 that will be only affected by the canopy of the a single specie. The eight plots were selected in the same slope, but under different canopy cover: *Pinus halepensis* M. (4 plots) versus *Quercus ilex subsp. rotundifolia* L. (4 plots). Due to the mixture of plants in a Mediterranean maquia, the canopy of different species would affect larger plots and it would be not possible to isolate the effect of each specie separately if the plots had been made larger. Runoff was collected from the plots by a collector (gutter) of 150 × 1000 mm into a 40 mm diameter pipe into a container of 60 L (Fig. 1). After each rainfall event the container was replaced, and transported to the laboratory to measure runoff discharge and sediment concentration. Soil erosion rates and runoff coefficients were calculated for each rainfall event. Events were separated when six hours without rainfall were recorded. The rainfall was measured with a raingauge and compared with the nearby meteorological station (AEMET, Agencia Estatal de Meteorología) located 5 km from the study site. Soil and vegetation description and sampling was done in December 2009 before the experiments were initiated and repeated twice (summer and winter) a year. Twenty soil samples were collected in the study area to determine the grain size, organic matter and bulk density. Soil organic matter was determined by the Walkley-Black method (Walkley and Black, 1934). Bulk density was measured using the ring method. Grain size was determined with the pipette method (Deshpande and Telang, 1950). All the samples were collected at a soil depth 0–2 cm to characterize the layer that determines runoff and the sediment detachment rates.

The statistical analysis was performed in order to evaluate the difference in runoff and erosion between Aleppo pine and Holm oak plots. Descriptive statistical tests, as mean, standard deviation and coefficient of variation, were calculated. Differences in runoff, runoff coefficient, sediment concentration and erosion rates variables were analysed using a generalised linear mixed model with binomial distribution. The forest stand type (i.e. Aleppo pine or Holm oak) was fitted as fixed effect, the plot and rainy event as random effect. The ANOVA results for the generalised linear mixed are also summarized. All statistical analyses were run in R 3.2.0 (R Core Team, 2015). The generalised linear mixed models used the lme4 package (Bates et al., 2015).

3. RESULTS

3.1. Results

3.1.1. Soil and vegetation cover

Aleppo pine is widespread in the Sierra de Enguera due to natural recovery but also due to afforestation projects. In contrast, Holm oaks are found in patches was it has sprouted after the fire. The Holm oak and Aleppo pine vegetation successfully recovered after 30–34 years since the forest fire. The *Holm oak* sprouted successfully and achieved an average height of 2.5 m (ranging from 2.1 till 4.3 m) and the *Aleppo pine* reached an average height of 4.6 m, ranging from 3.0 till 10.4 m. In the *Aleppo pine* plot a litter layer of pine needles with a cover of 76% and an average depth of 3.2 mm was found (ranging from 0 till 9 mm) and *Holm oak* showed a 96% covered plot with plant canopy, with a litter cover of 23.1 mm, ranging from 9 till 47 mm. The soil texture is a sandy clay loam, with a high gravel and cobble content for both the *Aleppo pine* and *Holm oak* plots. However, the soil organic matter shows higher values in the *Holm oak* (9%) than on the *Aleppo pine* (7%). pH, Electrical Conductivity and Calcium carbonate content were very similar for the two covers (Table 1). The high calcium carbonate content (48%) is due to the Limestone parent material, that also determines high soil pH (8.1–8.7) and Electrical Conductivity (135 $\mu S\ cm^{-1}$).

3.1.2. Rainfall

The total accumulated rainfall during the five-year experimental period was 2721.1 mm. The rainfall distribution along the experimental period can be seeing in Tables 2 and 3 for daily and event rainfall distribution, respectively. The wettest year was 2012 with 593.7 mm and the driest 2014 with 422.4 mm. The number of rainy days ranged from 52 in 2010 till 33 in 2014. The mean annual rainfall was 544 mm, which is similar (550 mm) to the long-term average measured from 1942 till 2016. This tells us that the experimental period is representative for the study

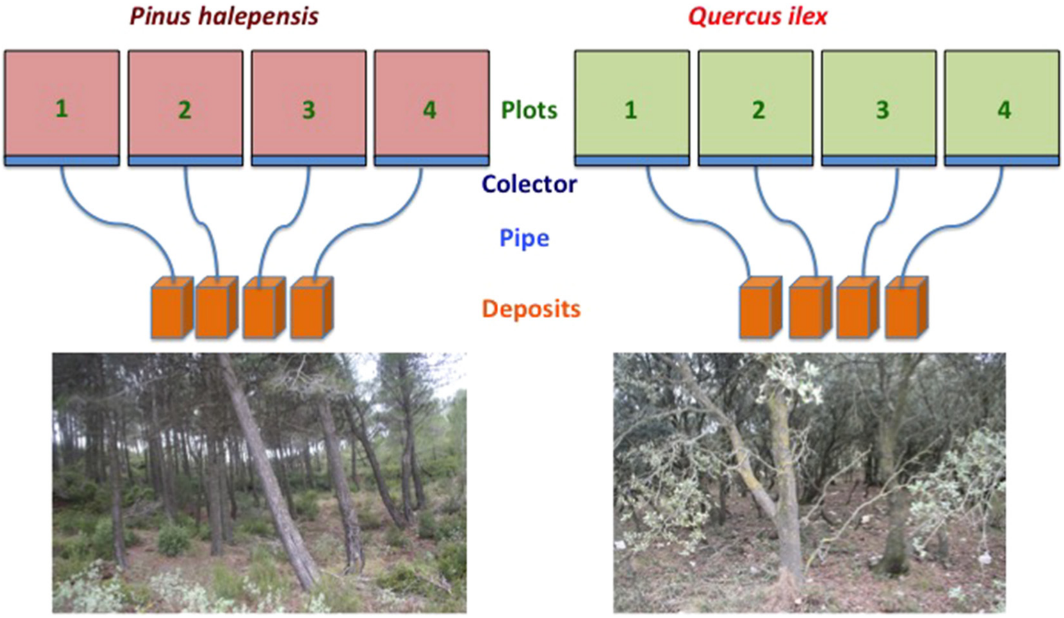

Fig. 1. View of the experimental layout.

Table 1
Soil properties at the study site cobbles; gravel; sand, silt and clay; soil organic matter (SOM), pH, Electrical Conductivity (EC) and Calcium carbonate ($CaCO_3$). Sand: 2–0.05 mm; silt: 0.05–0.002 mm; clay: <0.002. Gravel: 2–66 mm. Cobble: >64 mm.

Aleppo pine	Cobbles	Gravel	Sand	Silt	Clay	SOM	pH	EC	$CaCO_3$
	%	%	%	%	%	%		$\mu S\ cm^{-1}$	%
1	3.45	22.65	48.35	30.25	21.4	5.45	8.4	134	47.65
2	2.98	24.32	49.75	24.65	25.6	7.26	8.6	136	48.92
3	4.98	29.21	40.65	30.01	29.34	8.45	8.7	148	45.35
4	7.65	19.65	44.35	25.02	30.63	5.96	8.5	125	48.74
5	8.25	17.84	49.35	27.25	23.4	6.84	8.3	127	50.21
6	7.77	15.69	50.01	24.65	25.34	7.48	8.2	145	46.27
7	3.48	14.79	40.28	30.01	29.71	5.48	8.4	168	49.25
8	5.98	20.12	46.66	24.65	28.69	6.98	8.6	132	44.69
9	5.66	14.03	47.21	29.5	23.29	8.57	8.1	115	49.58
10	4.65	19.98	49.74	28.48	21.78	6.65	8.3	120	52.35
Average	**5.49**	**19.83**	**46.64**	**27.45**	**25.92**	**6.91**	**8.41**	**135**	**48.30**
STD	**1.92**	**4.67**	**3.69**	**2.49**	**3.45**	**1.09**	**0.19**	**15.48**	**2.34**
VC (%)	**35.03**	**23.56**	**7.92**	**9.06**	**13.32**	**15.80**	**2.27**	**11.47**	**4.85**
Holm oak									
1	4.65	21.35	47.15	21.32	31.53	8.65	8.40	134	48.25
2	8.32	19.32	46.32	26.50	27.18	7.98	8.10	165	49.38
3	7.59	14.25	49.54	32.52	17.94	9.74	8.50	124	47.32
4	6.84	18.65	50.24	21.78	27.98	9.65	8.20	123	46.21
5	7.59	17.14	51.30	27.98	20.70	7.89	8.40	158	52.64
6	8.65	10.92	56.34	26.48	17.20	9.41	8.60	142	54.29
7	4.85	16.48	42.26	25.42	32.33	8.66	8.70	123	47.29
8	7.26	14.98	48.24	23.65	28.10	8.22	8.10	142	42.66
9	8.65	15.7	45.02	28.54	26.44	9.48	8.00	120	46.38
10	7.84	19.41	44.98	29.48	25.54	10.65	8.20	115	43.21
Average	**7.22**	**16.82**	**48.14**	**26.37**	**25.49**	**9.03**	**8.32**	**134.6**	**47.76**
STD	**1.43**	**3.04**	**3.97**	**3.49**	**5.26**	**0.89**	**0.23**	**16.87**	**3.66**
VC (%)	**19.75**	**18.07**	**8.25**	**13.24**	**20.62**	**9.90**	**2.82**	**12.53**	**7.67**

Table 2
Precipitation at the study site per year. Total year rainfall, number of rainy days, maximum rainfall in one day and % of the annual rainfall during the day of the maximum daily rainfall.

Year	(mm) Annual rainfall	(n°) Rainy days	(mm) Maximum daily	(%) Maximum daily
Daily rainfall				
2010	554.2	53	45	8.12
2011	590.4	52	93	15.75
2012	593.7	40	90	15.16
2013	560.4	35	111	19.81
2014	422.4	33	48.1	11.39
Total	2721.1	213	111	4.08
Event rainfall				
2010	554.2	40	45	8.12
2011	590.4	31	145.5	24.64
2012	593.7	25	176.8	29.78
2013	560.4	28	111	19.81
2014	422.4	26	72.9	17.26
Total	**2721.1**	**150**	**176.8**	**6.50**

Table 3
Rainfall distribution per day and per event.

Rainfall				
Day (mm)	n°	%	mm	%
<5	83	38.97	225.1	8.27
5–10	50	23.47	346.7	12.74
10–15	27	12.68	320	11.76
15–30	29	13.62	585	21.50
30–60	19	8.92	700.3	25.74
60–100	4	1.88	433	15.91
>100	1	0.47	111	4.08
Event (mm)				
<5	48	31.79	131.1	4.82
5–10	27	17.88	192	7.06
10–15	26	17.22	312.2	11.47
15–30	25	16.56	516.6	18.98
30–60	14	9.27	507.5	18.65
60–100	7	4.64	526.9	19.36
>100	4	2.65	534.8	19.65

area, but there is no information for extreme climatic years. The maximum daily rainfall recorded was 111 mm February 28th 2013, which is 19.81% of the year total rainfall and 4.08% of the five years total precipitation. From the historical data it was found that the driest year recorded was 1979 with 202.5 mm and 1959 with 1059 mm was the wettest one. This shows a high inter-annual variability that was not found during the five experimental years.

From 2010 till 2014 the total number of rainfall events (the period between samplings of runoff and sediments) was 150, ranging from 40 in 2010 till 26 in 2014. The total rainfall per event ranged from 45 mm in 2010 to 176.8 mm in 2012. The largest rainfall event took place in 2012 due to five consecutive rainy days from November 11th till November 15th 2012 with 90, 4, 37, 38.8 and 7 mm in five consecutive days. This rainfall event amounts 30% of the total rainfall of 2012 and 6.5% of the 5-years experimental period (Table 2).

The rainfall distribution when ordered by daily intensities shows that low intensity events (< 5 mm day^{-1}) are 39% of the total, while days with high intensity (greater than 100 mm day^{-1}) are very rare as only took place once in the five years we studied (1 out of 213 rainfall days). However, this extraordinary rainfall day contributed with 4% of the total rainfall of 5 years. The four rainfall days with more than 60 mm day^{-1} resulted in 16% of the total rainfall. For the rainfall events the differences are larger, the rainfall volume reached 39% of the total rainfall in events of more that 60 mm (7 events). And 20% for the ones larger than 100 mm (4 events). On the other hand, 48 events with less than 5 mm only contributed 5% of the total rainfall (Table 3).

3.2. Runoff

The average yearly runoff discharge for the five experimental years was 232 L in Aleppo pine and 40 L in Holm oak (Table 4). The interanual variability ranged from 18.8 L (2010) till 70 L (2012) in Aleppo pine, and from 0.9 (2010) till 17 L (2012) in Holm oak. The runoff discharge for the four plots in Aleppo pine ranged from 221 till 251 L, and from 36 till 46 L in Holm oak, for the five years experimental period (Table 4).

The total runoff measured was 8.31% of the rainfall in Aleppo pine and 1.39% in Holm oak for average values. For the whole period, runoff ranged in Aleppo pine from 3.02 for plot 3 in 2010 till 13.47% for plot 1 in 2012. For Holm oak, runoff ranged from 0.05% in plot 2 during 2014 till 3.19% in plot 3 during 2012. After corroborating the variance was normal and homogeneous ($p < 0.05$), the ANOVA factor indicated there were significant differences between Aleppo pine and Holm oak plots regarding runoff and runoff coefficient. In all cases, p values were equal to 0.000.

3.3. Runoff sediment concentration

Sediment concentration in runoff was higher in the Aleppo pine plots (4.88 g l^{-1}) than in the Holm oak plots (2.63 g l^{-1}) for the whole experimental period (Table 4). There were clear interannual variations that ranged from 1.1 (2014) until 4.4 (2013) for Holm oak, and from 3 (2014) till 8 (2013) g l^{-1} for Aleppo pine. The variability within plots and years is shown in table 5. The total sediment yields show that the total amount of soil delivered was 1285 g in Aleppo pine plots and 128 gr in Holm oak plots during the four years of measurements. Those values ranged from 55 (2010) till 513 gr (2013) for Aleppo pine and from 1.5 (2010 and 2014) till 128 gr (2012 and 2013) for Holm oak. And the variability within plots show that Aleppo pine contributed with more sediments (48–575 gr) than the Holm oak plots (1.4–64 gr). After corroborating the variance was normal and homogeneous ($p < 0.05$), the ANOVA factor indicated there were significant differences between Aleppo pine and Holm oak plots regarding sediment concentration. In all cases, p values were equal to 0.000.

3.4. Soil erosion

Soil loss was ten times higher in the Aleppo pine (2.57 Mg ha^{-1} y^{-1}) than in the Holm oak plots (0.26 Mg ha^{-1} y^{-1}) (Table 6). The interannual variability in the Holm oak plots ranged from 0.02 (2010 and 2014) until 0.49 Mg ha^{-1} y^{-1} (2012 and 2013), for Aleppo pine the values ranged from 0.48 (2010) till 5.75 Mg ha^{-1} y^{-1} (2013). Within the plots and years the variability ranged from 0.48 Mg ha^{-1} y^{-1} (plot 3 year 2010) till 5.75 Mg ha^{-1} y^{-1} (plot 3 year 2013) for Aleppo pine and from 0 Mg ha^{-1} y^{-1} (plot 2 year 2014) till 0.64 Mg ha^{-1} y^{-1} (plot 2, year 2013) for Holm oak (see

Table 4
Runoff rates per plot, year and total of the five years experimental period (2010–2014) for Aleppo pine (4 plots) and Holm oak (4 plots).

Runoff			*Aleppo pine*					*Holm oak*		
(L)	1	2	3	4	Average	1	2	3	4	Average
2010	22.25	19.16	16.76	17.12	**18.82**	1.40	0.50	0.62	1.14	**0.92**
2011	56.53	53.39	59.17	54.10	**55.80**	11.41	10.36	9.31	8.09	**9.79**
2012	80.00	65.52	60.14	74.15	**69.95**	17.01	17.34	18.93	15.96	**17.31**
2013	62.00	60.92	70.14	63.90	**64.24**	13.46	14.37	6.81	9.00	**10.91**
2014	22.27	22.31	27.63	20.25	**23.12**	2.24	0.23	0.85	1.25	**1.14**
Total	**243.06**	**221.30**	**233.83**	**229.53**	**231.93**	**45.52**	**42.80**	**36.52**	**35.45**	**40.07**
Runoff (%)										
2010	4.02	3.46	3.02	3.09	**3.40**	0.25	0.09	0.11	0.21	**0.17**
2011	9.58	9.04	10.02	9.16	**9.45**	1.93	1.75	1.58	1.37	**1.66**
2012	13.47	11.04	10.13	12.49	**11.78**	2.87	2.92	3.19	2.69	**2.92**
2013	11.06	10.87	12.52	11.40	**11.46**	2.40	2.56	1.22	1.61	**1.95**
2014	5.27	5.28	6.54	4.79	**5.47**	0.53	0.05	0.20	0.30	**0.27**
Mean	**8.68**	**7.94**	**8.45**	**8.19**	**8.31**	**1.60**	**1.48**	**1.26**	**1.23**	**1.39**

Table 5
Sediment concentration and yield per plot, year and total of the five years experimental period (2010–2014) for Aleppo pine (4 plots) and Holm oak (4 plots).

Sed Conc			Aleppo pine				Holm	oak		
(gr l^{-1})	**1**	**2**	**3**	**4**	**Mean**	**1**	**2**	**3**	**4**	**Mean**
2010	4.63	2.85	2.40	2.80	**3.17**	1.15	2.76	2.60	1.30	**1.95**
2011	5.45	4.22	5.05	5.25	**4.99**	2.89	2.76	2.33	3.38	**2.84**
2012	4.92	5.84	4.98	5.41	**5.29**	2.78	2.73	2.59	3.22	**2.83**
2013	7.43	8.28	8.20	8.01	**7.98**	4.68	4.45	3.95	4.69	**4.44**
2014	3.23	2.94	2.72	2.97	**2.97**	1.22	0.00	1.76	1.44	**1.11**
Mean	**5.13**	**4.83**	**4.67**	**4.89**	**4.88**	**2.54**	**2.54**	**2.64**	**2.81**	**2.63**
Sed Yield (gr)										
2010	69.92	54.58	47.61	47.87	**55.00**	1.60	1.39	1.62	1.49	**1.53**
2011	308.39	225.14	298.99	283.98	**279.13**	32.95	28.60	21.70	27.32	**27.64**
2012	393.84	382.67	299.48	401.10	**369.27**	47.38	47.30	48.96	51.42	**48.76**
2013	460.97	504.46	575.36	511.99	**513.19**	62.91	63.89	26.87	42.25	**48.98**
2014	71.84	65.56	75.28	60.19	**68.22**	2.74	0.00	1.49	1.81	**1.51**
Mean	**1304.97**	**1232.4**	**1296.73**	**1305.1**	**1284.8**	**147.58**	**141.18**	**100.65**	**124.28**	**128.42**

Table 6
Soil erosion per plot. year and total of the five years experimental period (2010–2014) for Aleppo pine (4 plots) and Holm oak (4 plots).

Sed Conc			Aleppo pine					Holm oak		
(gr l-1)	1	2	3	4	Average	1	2	3	4	Average
2010	0.70	0.55	0.48	0.48	**0.55**	0.02	0.01	0.02	0.01	**0.02**
2011	3.08	2.25	2.99	2.84	**2.79**	0.33	0.29	0.22	0.27	**0.28**
2012	3.94	3.83	2.99	4.01	**3.69**	0.47	0.47	0.49	0.51	**0.49**
2013	4.61	5.04	5.75	5.12	**5.13**	0.63	0.64	0.27	0.42	**0.49**
2014	0.72	0.66	0.75	0.60	**0.68**	0.03	0.00	0.01	0.02	**0.02**
Mean	**2.61**	**2.47**	**2.59**	**2.61**	**2.57**	**0.30**	**0.28**	**0.20**	**0.25**	**0.26**

Table 7
Contribution (%) of the largest soil erosion events for Aleppo pine and Holm oak plots.

Soil erosion		Aleppo	pine				Holm oak			
(%)	Pinus1	Pinus2	Pinus3	Pinus4	Average	Quercus1	Quercus2	Quercus3	Quercus4	Average
10 events	45.75	46.53	45.44	46.19	45.98	49.10	49.14	48.58	49.26	49.02
5 events	29.26	34.11	31.14	35.32	32.46	39.40	40.30	32.62	41.60	38.48
2 events	14.99	17.41	15.19	16.05	15.91	18.27	19.34	19.79	19.36	19.19
1 event	9.03	9.46	8.30	8.40	8.80	9.27	10.84	11.42	10.34	10.47

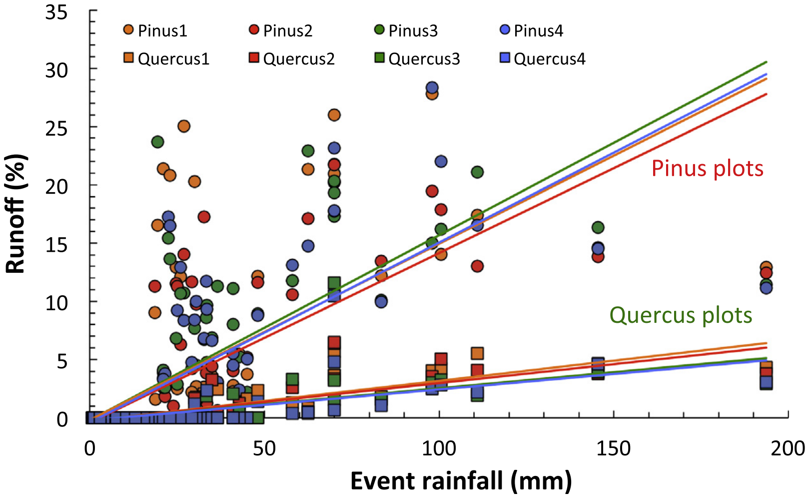

Fig. 2. Relationship between Event rainfall and Event runoff for the four Aleppo pine plots and the four Holm oak plots.

table 4). After corroborating the variance was normal and homogeneous ($p < 0.05$), the ANOVA factor indicated there were significant differences between Aleppo pine and Holm oak plots regarding erosion rate. In all cases, p values were equal to 0.000 (see Table 7).

4. Discussion

4.1. Rainfall-runoff relationship and runoff initiation thresholds

The fact that rainfall determines runoff is a well known by the scientific community (Chen et al., 2016; Mathias et al., 2016). However, there are other factors than also affect runoff generation such as vegetation cover (Sharpley, 1985; Pardini et al., 2017). At the research site of Sierra de Enguera runoff generation was highly dependent on the rainfall, but there was a clear impact of the type of vegetation (Fig. 2) as the contrasted response between Aleppo pine and Holm oak plots showed. Runoff was rarely measured in Holm oak plots. Only 10 out of 150 rainfall events (213 rainy days, 2721.1 mm in five years) generated runoff in the four plots under the cover of Holm oak. Runoff in those 10 rainfall events was on average 9.09% of the total rainfall. All this rainfall events were high in magnitude as they surpass 58 mm event^{-1} and four of them surpass 100 mm event^{-1}. Ten more rainfall events generated runoff in one or two of the four plots of Holm oak, what totalize 20 rainfall events (out of 151) with runoff, four times per year. Those rainfall events were always higher than 30 mm event^{-1} and the runoff generated was 1.44% of the rainfall. Then, all rainfall events below 30 mm event^{-1} (131 out of 151) did not generated runoff in any of the four plots. The runoff spatial variability can be a consequence of the plants interception and throughfall. Molina and del Campo (2012) demonstrated that the Aleppo pine forest without thinning resulted in 56% throughfall, which can explain also the high rainfall threshold necessary to achieve runoff as interception is very high. Silva and Rodríguez (2001) also found similar behaviour in Oak and Pine forest in Northeastern Mexico.

The influence of plant species on runoff was also assessed under simulated rainfall by Cerdà and Doerr (2005) who both agree that Mediterranean species show contrasting results. Later, Xu et al. (2008) found that plant morphology is important for the partitioning of rainfall and De Baets et al. (2007) showed that root characteristics are relevant to understand soil erosion processes on vegetated soils. To isolate these processes, the effect of individual plants on runoff generation has been studied in semiarid areas (Cerdà, 1997a), which showed that plants interact with soils and develop sinks for runoff and sediments. Our findings demonstrate then that Holm oak is more prone to act as sinks than Aleppo pine. This knowledge about the influence of plants on water resources is used for the design of green roofs (Nagase and Dunnett, 2012) or to control soil erosion rates in agriculture land (Rodrigo Comino et al., 2016; Keesstra et al., 2016b). However, the selection of plants in Mediterranean type ecosystems for afforestation did not pay attention to role of plants as a soil erosion control, meanwhile the growth pace or the establishment success are relevant issues (Broncano et al., 1998; Bocio et al., 2004).

For Aleppo pine plots, the runoff initiation threshold was 18 mm event^{-1}, after which at least one plot generated runoff. Eight rainfall events generated runoff in some plots (but not all four of them) and contributed with a runoff of 15.45% of the rainfall. Thirty times in five years, runoff was generated with rainfall events larger than 18.7 mm event^{-1} and on average 32.7% of the rainfall transformed into runoff. Holm oak plots always generated low runoff discharges. The largest recorded runoff discharge took place on March 20th 2012, after 70 mm in one day, with triggered a runoff rate of 20.3% on average for the four plots and ranged from 15.5% in plot one till 26.8% in plot three. The Aleppo pine plots generated runoff in much larger volumes. The largest event took place on March 20th 2012 too, with an average runoff coefficient of 68% and with plot runoff discharges ranging from 61 till 82% of the rainfall (70 mm).

The comparison of the rainfall events between Aleppo pine and Holm oak show a contrasting response in terms of the volume of rainfall after which runoff is initiated (thresholds) and also the total amount of runoff discharges generated. Our study was developed at the pedon scale, but this information can be of interest to understand runoff generation at slope and watershed scale. Low runoff rates generated by oaks forest soil were also found recently by Thompson et al. (2016) when measuring the runoff rates in Eucalypts and Oaks in California. However, the scientific literature does not show any other information about soil erosion in oak forests. This is probably due to the fact that it is well accepted that oaks protect the soils from the raindrop impact, generate deep and organic matter rich soils, which favours infiltration and avoids surface runoff. Our research in the Sierra de Enguera confirms this assumption. On the other hand, Aleppo pine was found to promote water repellent layers such as found by other authors (Keesstra et al., 2017; Wang et al., 2017)) and favour runoff and soil erosion. Our results confirm that runoff rates are higher in Aleppo pine covered soils than on the ones covered by Holm oak. There is a clear relationship between rainfall and runoff along the five years researched (Fig. 3). The cumulative rainfall and cumulative runoff discharge along the five experimental years clearly shows the contrasted response of the Aleppo pine and Holm oak plots.

4.2. Soil erosion

At the monitored plots at the Sierra de Enguera, there is an increase in soil losses when the rainfall increases, which also results in higher runoff discharges (Fig. 4). For the Holm oak plots soil erosion only takes place when the rainfall intensity is higher than

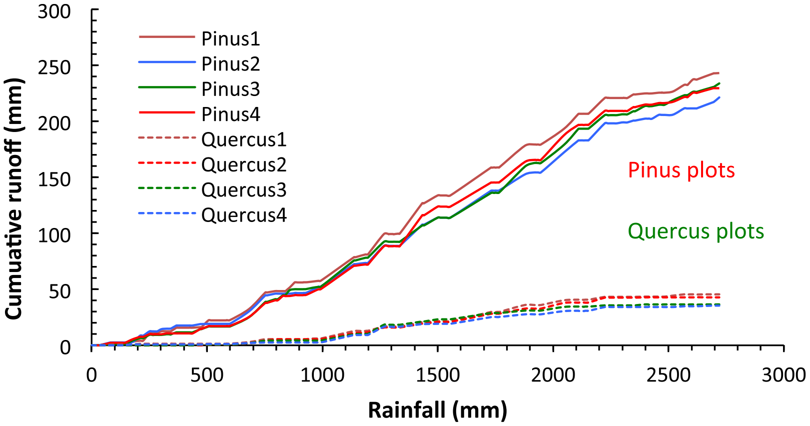

Fig. 3. Evolution of the cumulative runoff per plot along the 5 years of study.

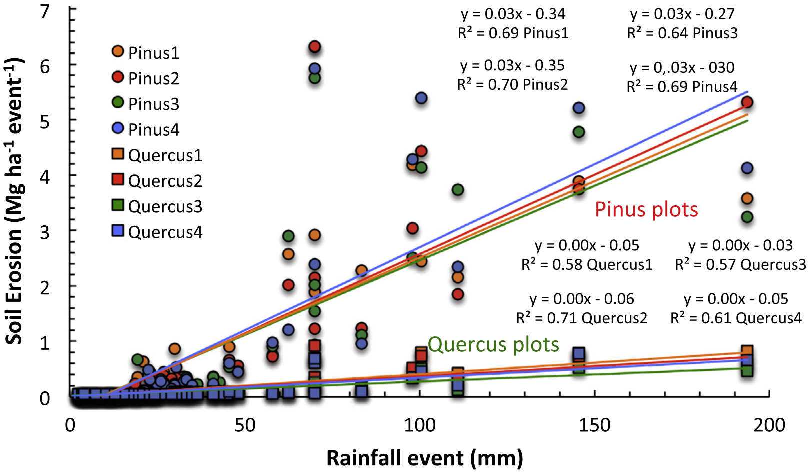

Fig. 4. Relationship between Rainfall and soil erosion per event.

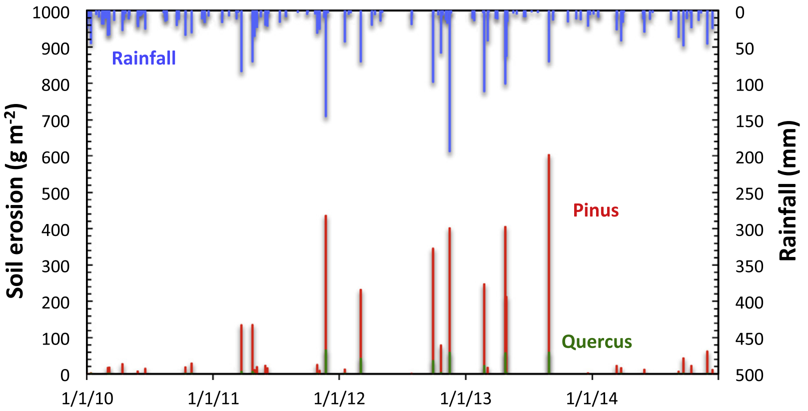

Fig. 5. Rainfall and soil erosion (average of four plot for Aleppo pine and four plots for Holm oak) changes along the 5 experimental years in Sierra de Enguera study sites.

30 mm day^{-1}, and this is why only during 7 rainfall events the rainfall was transformed into runoff that provoked erosion. In the Aleppo pine plots runoff was triggered after rainfall events of more than 18.7 mm day^{-1} and this is a key difference to understand the runoff generation and sediment detachment. There is a clear relationship between rainfall and soil erosion, however this relationship is delayed in Holm oak plots, as there is not soil erosion in rainfall events lower than 30 mm. In Aleppo pine plots the runoff initiated with more than 18.7 mm and then more events are found in the relationships between rainfall and runoff. Table 6 shows the contribution of the largest rainfall events (1, 2, 5 and 10 largest events out of 151), and it is clear that rare events are the ones that trigger most of the soil losses. The ten largest erosion events (out of 151) contribute with close to 50% of the sediment yield, and 1 soil erosion event caused 10% of the total erosion. Due to the scarce erosion events on the Holm oak plots, the largest events are responsible for an even larger percentage of the total soil lost from the plots in the whole study time than on the plots covered by Aleppo pine.

Although the eight plots that supplied data for this paper show a positive relationship between rainfall and soil erosion rates, the Holm oak plots protect the soil well, and only under intense rainfall events some erosion takes place. On the other hand, soil covered by Aleppo pine is more vulnerable to soil erosion and the measured erosion rates on the studied plots is much higher (Fig. 5). The contrasting behaviour of the soil erosion rates between Aleppo pine and Holm oak is due to differences in soil erodibility (higher sediment concentration in Aleppo pine) but mainly due to the impact of runoff discharge that is more abundant in Aleppo pine than Holm oak (Fig. 5). The reason of this higher runoff discharge is due to the fact that Aleppo pine covered soils are affected by a water repellent behaviour such as Cerdà and Doerr (2005) already described under rainfall simulation experiments where time to ponding and time to runoff can be measured, and also the infiltration envelops shed light on this water repellent behaviour underneath of Aleppo pine covers.

4.3. Long-term effects of forest fires

A forest fire affected the study sites in 1979, 30–34 years prior to the measurements. Then, our measurements can be seen as an experiment to assess the long-term impact of forest fires. Previous research showed that fire favours runoff and soil losses (van Lear et al., 1985; Forsyth et al., 2006; Waterloo et al., 2007; Cao et al., 2015). However, the planting of pines after the fire has been found by other researchers as the origin of higher erosion rates in the years following the fire (Inbar et al., 1998) and also induced heterogeneity in the rainfall-erosion relationships which is probably caused by the severe water repellency during the dry periods, on the contrary to th (Kutiel et al., 1995). Cerdà and Doerr (2005) already reported that soils covered with Aleppo pine act as a source of runoff, which is especially true after forest fires because the ash coming from Aleppo pine is more water repellent than other species (Bodí et al., 2011).

Our research at Sierra de Enguera was done in a Maquia vegetation cover where Oaks and Aleppo pines are found in patches. To assess the fluxes of water and sediment on a larger scale it is important to realize that different plant species can affect soil hydrology in a different way and some species act as sinks and others as sources of runoff and sediments (Cerdà, 1997a; Reid et al., 1999). In this Maquia ecosystem the Aleppo pine patches will act as a source of sediments and water as they generate runoff more often and under lower rainfall events than Holm oak. The patches covered by Holm oak will only act as a source of surface runoff in two rainfall events per year, meanwhile Aleppo pine is actively contributing with runoff around 7 times per year, and the discharges in each event are higher. Most likely this is due to water repellency issue as was found by other researchers recently in Tropical and Wet Mediterranean climates (Benito Rueda et al., 2016; Alanís et al., 2017).

The active contribution of Aleppo pine as a source of water and sediments in comparison to Holm oak is shown in Fig. 5 where the 5-year measurements of rainfall and soil erosion (averages of four plots) confirm that the highest rainfall event trigger soil erosion and Aleppo pine patches are the most active source areas. The role of Aleppo pine in increased runoff was also found and published by professor Inbar et al. (1997). Soon after also other researchers from the Mediterranean supported their findings in areas afforested with *Pinus helepensis* (Chirino et al., 2006). However, the discussion about the effects of *Pinus* sp. on surface runoff is much older. Already in the 1980s Hudson et al. (1983) found similar results in a forest in Honduras. Therefore, the importance of the scientific research carried out here demonstrate that in a Mediterranean climatic setting soil erosion is enhanced when comparing naturally recovered Aleppo pine with Holm oak after a forest fire. If the final objective of forester, landscape managers or politicians is to conserve the water and soil resources, Holm oak can give much better services to society, as less runoff and erosion will be generated. However, less runoff means also lower river discharges, which can cause a shortage in water for irrigation, industry and human use. These low river discharges can finally cause hydrological and geomorphological changes such as Beguería et al. (2006) and García-Ruiz et al. (2010) demonstrated in the Pyrenees, where a reduction in runoff discharges was found due to Pinus sp plantations and recovery (Améztegui et al., 2010).

5. Conclusions

Soils covered with Aleppo pine yield six times more runoff than Holm oak. Soil erosion rates were ten times higher in Aleppo pine than in Holm oak. The results show that Holm oak is more efficient in reducing soil and water losses, while an Aleppo pine cover results in higher losses. This information should be relevant to design restoration and rehabilitation programs after agriculture land abandonment or disturbances such as forest fires.

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References

Alanís, N., Hernández-Madrigal, V.M., Cerdà, A., Muñoz-Rojas, M., Zavala, L.M., Jordán, A., 2017. Spatial gradients of intensity and persistence of soil water repellency under different forest types in central Mexico. Land Degrad. Dev. 28 (1), 317–327.

Améztegui, A., Brotons, L., Coll, L., 2010. Land-use changes as major drivers of mountain pine (Pinus uncinata Ram.) expansion in the Pyrenees. Glob. Ecol. Biogeogr. 19 (5), 632–641.

Andrés, C., Ojeda, F., 2002. Effects of afforestation with pines on woody plant diversity of Mediterranean heathlands in southern Spain. Biodivers. Conserv. 11 (9), 1511–1520.

Arnaez, J., Lasanta, T., Errea, M.P., Ortigosa, L., 2011. Land abandonment, landscape evolution, and soil erosion in a Spanish Mediterranean mountain region: the case of Camero Viejo. Land Degrad. Dev. 22 (6), 537–550.

Bates, D., Maechler, M., Bolker, B.M., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 61 (1), 1–48.

Beguería, S., López-moreno, J.I., Gómez-villar, A., Rubio, V., Lana-renault, N., García-ruiz, J.M., 2006. Fluvial adjustments to soil erosion and plant cover changes in the Central Spanish Pyrenees. Geografiska Annaler: Series A, Phys. Geograp. 88 (3), 177–186.

Bellot, J., Maestre, F.T., Chirino, E., Hernández, N., de Urbina, J.O., 2004. Afforestation with Pinus halepensis reduces native shrub performance in a Mediterranean semiarid area. Acta oecologica 25 (1), 7–15.

Benayas, J. M. R. (1998). Growth and survival in Quercus ilex L. seedlings after irrigation and artificial shading on Mediterranean set-aside agricultural land. In Annales des Sciences Forestieres (Vol. 55, No. 7, pp. 801–807). EDP Sciences.

Benayas, J.M.R., Camacho-Cruz, A., 2004. Performance of Quercus ilex saplings planted in abandoned Mediterranean cropland after long-term interruption of their management. For. Ecol. Manage. 194 (1), 223–233.

Benito Rueda, E., Rodríguez-Alleres, M., Varela Teijeiro, E., 2016. Environmental factors governing soil water repellency dynamics in a Pinus pinaster plantation in NW Spain. Land Degrad. Dev. 27 (3), 719–728. http://dx.doi.org/10.1002/ldr.2370.

Bocio, I., Navarro, F.B., Ripoll, M.A., Jiménez, M.N., De Simón, E., 2004. Holm oak (Quercus rotundifolia Lam.) and Aleppo pine (Pinus halepensis Mill.) response to different soil preparation techniques applied to forestation in abandoned farmland. Ann. For. Sci. 61 (2), 171–178.

Bodí, M.B., Mataix-Solera, J., Doerr, S.H., Cerdà, A., 2011. The wettability of ash from burned vegetation and its relationship to mediterranean plant species type, burn severity and total organic carbon content. Geoderma 160 (3–4), 599–607. http://dx.doi.org/10.1016/j.geoderma.2010.11.009.

Broncano, M., Riba, M., Retana, J., 1998. Seed germination and seedling performance of two Mediterranean tree species, holm oak (shape Quercus ilex L.) and Aleppo pine (shape Pinus halepensis Mill.): a multifactor experimental approach. Plant Ecol. 138 (1), 17–26.

Cao, L., Liang, Y., Wang, Y., Lu, H., 2015. Runoff and soil loss from Pinus massoniana forest in southern China after simulated rainfall. CATENA 129, 1–8.

Cao, S., Chen, L., Xu, C., Liu, Z., 2007. Impact of three soil types on afforestation in China's Loess Plateau: Growth and survival of six tree species and their effects on soil properties. Landscape and Urban Planning 83 (2), 208–217.

Cerdà, A., 1997b. Soil Erosion After Land Abandonment in a Semiarid Environment of Southeastern Spain. Arid Soil Res. Rehabil. 11 (2), 163–176.

Cerdà, A., Doerr, S.H., 2005. Influence of Vegetation Recovery on Soil Hydrology and Erodibility Following Fire: An 11-Year Investigation. Int. J. Wildland Fire 14 (4), 423–437. http://dx.doi.org/10.1071/WF05044.

Cerdà, 1997a. The Effect of Patchy Distribution of *Stipa Tenacissima* L. on Runoff and Erosion. J. Arid Environ. 36 (1), 37–51. http://dx.doi.org/10.1006/jare.1995.0198.

Cerrillo, R.M.N., Fragueiro, B., Ceaceros, C., del Campo, A., de Prado, R., 2005. Establishment of Quercus ilex L. subsp. ballota [Desf.] Samp. using different weed control strategies in southern Spain. Ecol. Eng. 25 (4), 332–342.

Chauchard, S., Carcaillet, C., Guibal, F., 2007. Patterns of land-use abandonment control tree-recruitment and forest dynamics in Mediterranean mountains. Ecosystems 10 (6), 936–948.

Chazdon, R.L., 2008. Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320 (5882), 1458–1460.

Chen, C.R., Condron, L.M., Davis, M.R., Sherlock, R.R., 2000. Effects of afforestation on phosphorus dynamics and biological properties in a New Zealand grassland soil. Plant Soil 220 (1), 151–163.

Chen, L., Sela, S., Svoray, T., Assouline, S., 2016. Scale dependence of Hortonian rainfall-runoff processes in a semiarid environment. Water Resour. Res. 52 (7), 5149–5166.

Chirino, E., Bonet, A., Bellot, J., Sánchez, J.R., 2006. Effects of 30-year-old Aleppo pine plantations on runoff, soil erosion, and plant diversity in a semi-arid landscape in south eastern Spain. CATENA 65 (1), 19–29.

Cortina, J., Romanya, J., Vallejo, V.R., 1995. Nitrogen and phosphorus leaching from the forest floor of a mature Pinus radiata stand. Geoderma 66 (3–4), 321–330.

De Baets, S., Poesen, J., Knapen, A., Barberá, G.G., Navarro, J.A., 2007. Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant Soil 294 (1–2), 169–183.

Deshpande, V.V., Telang, M.S., 1950. Pipet method of sedimentation analysis. Rapid determination of distribution of particle size. Anal. Chem. 22 (6), 840–841.

Fernandes, P.M., Rigolot, E., 2007. The fire ecology and management of maritime pine (Pinus pinaster Ait.). For. Ecol. Manage. 241 (1), 1–13.

Forsyth, A.R., Bubb, K.A., Cox, M.E., 2006. Runoff, sediment loss and water quality from forest roads in a southeast Queensland coastal plain Pinus plantation. For. Ecol. Manage. 221 (1), 194–206.

García-Ruiz, J.M., Lana-Renault, N., 2011. Hydrological and erosive consequences of farmland abandonment in Europe, with special reference to the Mediterranean region–a review. Agric. Ecosyst. Environ. 140 (3), 317–338.

García-Ruiz, J.M., Lana-Renault, N., Beguería, S., Lasanta, T., Regüés, D., Nadal-Romero, E., Alatorre, L.C., 2010. From plot to regional scales: interactions of slope and catchment hydrological and geomorphic processes in the Spanish Pyrenees. Geomorphology 120 (3), 248–257.

Garcia, C., Hernández, T., Roldán, A., Albaladejo, J., Castillo, V., 2000. Organic amendment and mycorrhizal inoculation as a practice in afforestation of soils with Pinus halepensis Miller: effect on their microbial activity. Soil Biol. Biochem. 32 (8), 1173–1181.

Hartanto, H., Prabhu, R., Widayat, A.S., Asdak, C., 2003. Factors affecting runoff and soil erosion: plot-level soil loss monitoring for assessing sustainability of forest management. For. Ecol. Manage. 180 (1), 361–374.

Hudson, J., Kellman, M., Sanmugadas, K., Alvarado, C., 1983. Prescribed burning of Pinus oocarpa in Honduras I. Effects on surface runoff and sediment loss. For. Ecol. Manage. 5 (4), 269–281.

Hueso-González, P., Martínez-Murillo, J.F., Ruiz-Sinoga, J.D., Lavee, H., 2015. Overland flow generation mechanisms affected by topsoil treatment: Application to soil conservation. Geomorphology 228, 796–904.

Inbar, M., Tamir, M.I., Wittenberg, L., 1998. Runoff and erosion processes after a forest fire in Mount Carmel, a Mediterranean area. Geomorphology 24 (1), 17–33.

Inbar, M., Wittenberg, L., Tamir, M., 1997. Soil erosion and forestry management after wildfire in a Mediterranean woodland, Mt. Carmel, Israel. Int. J. Wildland Fire 7 (4), 285–294.

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B., Fresco, L.O., 2016a. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. Soil 2, 111–128. http://dx.doi.org/10.5194/soil-2-111-2016.

Keesstra, S., Pereira, P., Novara, A., Brevik, E.C., Azorin-Molina, C., Parras-Alcántara, L., Jordán, A., Cerdà, A., 2016b. Effects of soil management techniques on soil water erosion in apricot orchards. Sci. Total Environ. 551–552, 357–366. http://dx.doi.org/10.1016/j.scitotenv.2016.01.182.

Keesstra, S., Wittenberg, L., Maroulis, J., Sambalino, F., Malkinson, D., Cerdà, A., Pereira, P., 2017. The influence of fire history, plant species and post-fire management on soil water repellency in a Mediterranean catchment: The Mount Carmel range, Israel. CATENA 149, 857–866.

Keesstra, S.D., 2007. Impact of natural reforestation on floodplain sedimentation in the Dragonja basin, SW Slovenia. Earth Surf. Proc. Land. 32 (1), 49–65. http://dx.doi.org/10.1002/esp.1360.

Kutiel, P., Lavee, H., Segev, M., Benyamini, Y., 1995. The effect of fire-induced surface heterogeneity on rainfall-runoff-erosion relationships in an eastern Mediterranean ecosystem. Israel. Catena 25 (1), 77–87.

Lang, A.C., Oheimb, G., Scherer-Lorenzen, M., Yang, B., Trogisch, S., Bruelheide, H., Härdtle, W., 2014. Mixed afforestation of young subtropical trees promotes nitrogen acquisition and retention. J. Appl. Ecol. 51 (1), 224–233.

Lasanta-Martínez, T., Vicente-Serrano, S.M., Cuadrat-Prats, J.M., 2005. Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. Appl. Geogr. 25 (1), 47–65.

Lavi, A., Perevolotsky, A., Kigel, J., Noy-Meir, I., 2005. Invasion of Pinus halepensis from plantations into adjacent natural habitats. Appl. Veg. Sci. 8 (1), 85–92.

Lucas Borja, M.E., Candel, D., Jindo, K., Moreno, J.L., Andrés, M., Bastida, F., 2011. Soil microbial community structure and activity in monospecific and mixed forest stands, under Mediterranean humid conditions. Plant Soil 354, 359–370. http://dx.doi.org/10.1007/s11104-011-1072-8.

Maestre, F.T., Cortina, J., 2004. Are Pinus halepensis plantations useful as a restoration tool in semiarid Mediterranean areas? For. Ecol. Manage. 198 (1), 303–317.

Maestre, F.T., Cortina, J., Bautista, S., Bellot, J., 2003. Does Pinus halepensis facilitate the establishment of shrubs in Mediterranean semi-arid afforestations? For. Ecol. Manage. 176 (1), 147–160.

Martínez-Murillo, J.F., Hueso-González, P., Ruiz-Sinoga, J.D., Lavee, H., 2016. Short-term experimental fire effects in soil and water losses in southern of Spain. Land Degrad. Dev. 27 (5), 1513–1522. http://dx.doi.org/10.1002/ldr.2504.

Mathias, S.A., McIntyre, N., Oughton, R.H., 2016. A study of non-linearity in rainfall-runoff response using 120 UK catchments. J. Hydrol. 540, 423–436.

Molina, A.J., del Campo, A.D., 2012. The effects of experimental thinning on throughfall and stemflow: a contribution towards hydrology-oriented silviculture in Aleppo pine plantations. For. Ecol. Manage. 269, 206–213.

Moody, J.A., Martin, D.A., 2001. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. Earth Surf. Proc. Land. 26 (10), 1049–1070.

Mora, J.L., Armas-Herrera, C.M., Guerra, J.A., Arbelo, C.D., Rodríguez-Rodríguez, A., Notario del Pino, J.S., 2016. A comparative study of long-term effects on fire-affected volcanic soils in two different ecosystems in the canary islands. Land Degrad. Dev. 27 (5), 1489–1500. http://dx.doi.org/10.1002/ldr.2458.

Moreira, F., Viedma, O., Arianoutsou, M., Curt, T., Koutsias, N., Rigolot, E., Mouillot, F., 2011. Landscape–wildfire interactions in southern Europe: implications for landscape management. J. Environ. Manage. 92 (10), 2389–2402.

Nagase, A., Dunnett, N., 2012. Amount of water runoff from different vegetation types on extensive green roofs: Effects of plant species, diversity and plant structure. Landscape and Urban Planning 104 (3), 356–363.

Novara, A., Keesstra, S., Cerdà, A., Pereira, P., Gristina, L., 2016. Understanding the Role of Soil Erosion on co2-c Loss using 13c Isotopic Signatures in Abandoned Mediterranean Agricultural Land. Sci. Total Environ. 550, 330–336. http://dx.doi.org/10.1016/j.scitotenv.2016.01.095.

Núñez, J.A.D., Serrano, J.S., Barreal, J.A.R., de Omeñaca González, J.A.S., 2006. The influence of mycorrhization with Tuber melanosporum in the afforestation of a Mediterranean site with Quercus ilex and Quercus faginea. For. Ecol. Manage. 231 (1), 226–233.

Ortiz, O., Ojeda, G., Espelta, J.M., Alcañiz, J.M., 2012. Improving substrate fertility to enhance growth and reproductive ability of a Pinus halepensis Mill. afforestation in a restored limestone quarry. New Forest. 43 (3), 365–381.

Osem, Y., Lavi, A., Rosenfeld, A., 2011. Colonization of Pinus halepensis in Mediterranean habitats: consequences of afforestation, grazing and fire. Biol. Invasions 13 (2), 485–498.

Pardini, G., Gispert, M., Emran, M., Doni, S., 2017. Rainfall/runoff/erosion relationships and soil properties survey in abandoned shallow soils of NE Spain. J. Soils Sediments 17 (2), 499–514.

Pausas, J.G., Fernández-Muñoz, S., 2012. Fire regime changes in the Western Mediterranean Basin: from fuel-limited to drought-driven fire regime. Climatic change 110 (1), 215–226.

Pausas, J.G., Keeley, J.E., 2009. A burning story: the role of fire in the history of life. Bioscience 59 (7), 593–601.

Porto, P., Walling, D.E., Callegari, G., 2009. Investigating the effects of afforestation on soil erosion and sediment mobilisation in two small catchments in Southern Italy. CATENA 79 (3), 181–188.

Pueyo, Y., Beguería, S., 2007. Modelling the rate of secondary succession after farmland abandonment in a Mediterranean mountain area. Landscape and Urban Planning 83 (4), 245–254.

Querejeta, J.I., Roldán, A., Albaladejo, J., Castillo, V., 2001. Soil water availability improved by site preparation in a Pinus halepensis afforestation under semiarid climate. For. Ecol. Manage. 149 (1), 115–128.

R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org/>.

Reid, K.D., Wilcox, B.P., Breshears, D.D., MacDonald, L., 1999. Runoff and erosion in a piñon–juniper woodland influence of vegetation patches. Soil Sci. Soc. Am. J. 63 (6), 1869–1879.

Rincón, A., Ruíz-Díez, B., Fernández-Pascual, M., Probanza, A., Pozuelo, J.M., de Felipe, M.R., 2006. Afforestation of degraded soils with *Pinus halepensis* Mill.: effects of inoculation with selected microorganisms and soil amendment on plant growth, rhizospheric microbial activity and ectomycorrhizal formation. Appl. Soil. Ecol. 34 (1), 42–51.

Rodrigo Comino, J., Iserloh, T., Lassu, T., Cerdà, A., Keesstra, S.D., Prosdocimi, M., Brings, C., 2016. Quantitative comparison of initial soil erosion processes and runoff generation in spanish and german vineyards. Sci. Total Environ. 565, 1165–1174. http://dx.doi.org/10.1016/j.scitotenv.2016.05.163.

Roldan, A., Querejeta, I., Albaladejo, J., Castillo, V., 1996. Growth response of Pinus halepensis to inoculation with Pisolithus arhizus in a terraced rangeland amended with urban refuse. Plant Soil 179 (1), 35–43.

Romero-Díaz, A., Ruiz-Sinoga, J.D., Robledano-Aymerich, F., Brevik, E.C., Cerdà, A., 2017. Ecosystem responses to land abandonment in Western Mediterranean Mountains. CATENA 149, 824–835.

Romero-Diaz, A., Belmonte-Serrato, F., Ruiz-Sinoga, J.D., 2010. The geomorphic impact of afforestations on soil erosion in Southeast Spain. Land Degrad. Dev. 21 (2), 188–195.

Schiller, G., Atzmon, N., 2009. Performance of Aleppo pine (Pinus halepensis) provenances grown at the edge of the Negev desert: a review. J. Arid Environ. 73 (12), 1051–1057.

Schiller, G., Cohen, Y., 1998. Water balance of Pinus halepensis Mill. afforestation in an arid region. For. Ecol. Manage. 105 (1), 121–128.

Sharpley, A.N., 1985. Depth of surface soil-runoff interaction as affected by rainfall, soil slope, and management. Soil Sci. Soc. Am. J. 49 (4), 1010–1015.

Silva, I.C., Rodríguez, H.G., 2001. Interception loss, throughfall and stemflow chemistry in pine and oak forests in northeastern Mexico. Tree Physiol. 21 (12–13), 1009–1013.

Sirami, C., Brotons, L., Burfield, I., Fonderflick, J., Martin, J.L., 2008. Is land abandonment having an impact on biodiversity? A meta-analytical approach to bird distribution changes in the north-western Mediterranean. Biol. Cons. 141 (2), 450–459.

Smith, C.M., 1992. Riparian afforestation effects on water yields and water quality in pasture catchments. J. Environ. Qual. 21 (2), 237–245.

Soil Survey Staff, 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys United States Department of Agriculture Handbook Natural Resources Conservation Service Number 436, 871pp + maps.

Soutar, R.G., 1989. Afforestation and sediment yields in British fresh waters. Soil Use Manag. 5 (2), 82–86.

Thompson, A., Davis, J.D., Oliphant, A.J., 2016. Surface runoff and soil erosion under eucalyptus and oak canopy. Earth Surf. Proc. Land.

van Eck, C., Nunes, J., Vieira, D., Keesstra, S., Keizer, J., 2016. Physically-based modelling of the post-fire runoff response of a forest catchment in central Portugal: using field vs. remote sensing based estimates of vegetation recovery. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2507.

Van Lear, D.H., Douglass, J.E., Cox, S.K., Augspurger, M.K., 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina Piedmont. J. Environ. Qual. 14 (2), 169–174.

Végvári, Z., Valkó, O., Deák, B., Török, P., Konyhás, S., Tóthmérész, B., 2016. Effects of land use and wildfires on the habitat selection of great bustard (otis tarda l.)-implications for species conservation. Land Degrad. Dev. 27 (4), 910–918. http://dx.doi.org/10.1002/ldr.2495.

Villacís, J., Casanoves, F., Hang, S., Keesstra, S., Armas, C., 2016. Selection of forest species for the rehabilitation of disturbed soils in oil fields in the Ecuadorian Amazon. Sci. Total Environ. 566, 761–770.

Walkley, A.I., Black, A., 1934. An examination of degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–37.

Wallace, H.L., Good, J.E.G., 1995. Effects of afforestation on upland plant communities and implications for vegetation management. For. Ecol. Manage. 79 (1), 29–46.

Wang, B., Wang, Y., Wang, L., 2017. The effects of erosional topography on soil properties in a Pinus massoniana forest in southern China. J. Soil Water Conserv. 72 (1), 36–44.

Wang, C., Wang, G., Wang, Y., Rafique, R., Ma, L., Hu, L., Luo, Y., 2016. Fire alters vegetation and soil microbial community in alpine meadow. Land Degrad. Dev. 27 (5), 1379–1390. http://dx.doi.org/10.1002/ldr.2367.

Waterloo, M.J., Schellekens, J., Bruijnzeel, L.A., Rawaqa, T.T., 2007. Changes in catchment runoff after harvesting and burning of a Pinus caribaea plantation in Viti Levu. Fiji. Forest Ecology and Management 251 (1), 31–44.

Xu, X.L., Ma, K.M., Fu, B.J., Song, C.J., Liu, W., 2008. Influence of three plant species with different morphologies on water runoff and soil loss in a dry-warm river valley SW China. Forest Ecol. Manag. 256 (4), 656–663.