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Long-term effectiveness of sustainable land management practices to control runoff, soil erosion, and nutrient loss and the role of rainfall intensity in Mediterranean rainfed agroecosystems

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ABSTRACT

Mediterranean environments are especially susceptible to soil erosion and to inappropriate soil management, leading to accelerated soil loss. Sustainable Land Management (SLM) practices (such as reduced tillage, no-tillage, cover crops, etc.,) have the potential to reduce soil, organic carbon (OC), and nutrient losses by erosion. However, the effectivity of these practices is site-dependent and varies under different rainfall conditions. The objective of this paper was to evaluate the effects of SLM practices – in two rainfed systems (a wheat field and an almond orchard) representative of a large area of the driest Mediterranean regions - on runoff, soil erosion, particle size distribution, and OC and nutrient (N and P) contents in sediments. The influence of the rainfall characteristics on the effectiveness of the SLM practices was also evaluated. The SLM implemented were: reduced tillage (RT) in the wheat field and almond orchard and reduced tillage combined with green manure (RTG) in the almond orchard; these were compared to conventional tillage, the usual practice in the area. Open erosion plots were set up to monitor the effects of SLM on soil carbon and nutrients and on soil erosion after each rainfall event over six years (2010–2016). The results show that the SLM practices evaluated resulted in increased organic carbon (OC) and nutrients (N and P) contents in the soil, and reduced runoff, erosion, and mobilization of organic carbon and nutrients in sediments. Reductions in runoff of 30% and 65% and decreases in erosion of 65 and 85% were found in the wheat field and almond orchards, respectively. In addition, the total OC, N, and P losses in the wheat field were reduced by 56%, 45%, and 64%, respectively, while in the almond field the OC, N, and P losses were reduced by 90% under RT and by 85% under RTG.

The beneficial effect of the SLM practices on soil erosion was observed within 18 months of their implementation and continued throughout the six years of the study. Furthermore, the effectiveness of tillage reduction with respect to erosion control and carbon and nutrients mobilization was highest during the most intense rainfall events, which are responsible for the highest erosion rates in Mediterranean areas. Our results support the key role of SLM practices under semiarid conditions as useful tools for climate change mitigation and adaptation, given the expected increase in high-intensity rainfall events in semiarid areas.

1. Introduction

Soil erosion results in the loss of soil, nutrients, and organic carbon (OC) and therefore in a decrease in the productivity of soil and its ability to sustain life. The loss of soil nutrients and OC is often particularly related to sheet erosion processes that preferentially transport the finest soil fraction containing most OC and nutrients (Franzluebbers, 2002; Martínez-Mena et al., 2002; Koiter et al., 2017). While this process affects soils globally, Mediterranean environments - characterized by scarce and torrential precipitation, long drought periods, shallow soils, and scarce plant cover - are especially susceptible to soil erosion and to inappropriate soil management, leading to accelerated soil loss (Schwilch et al., 2012; Durán Zuazo et al., 2014). Since the majority of soil loss by water erosion occurs during high-intensity storms on sloping agricultural land, and the frequency of extreme rainfall is expected to increase under climate change (Groisman

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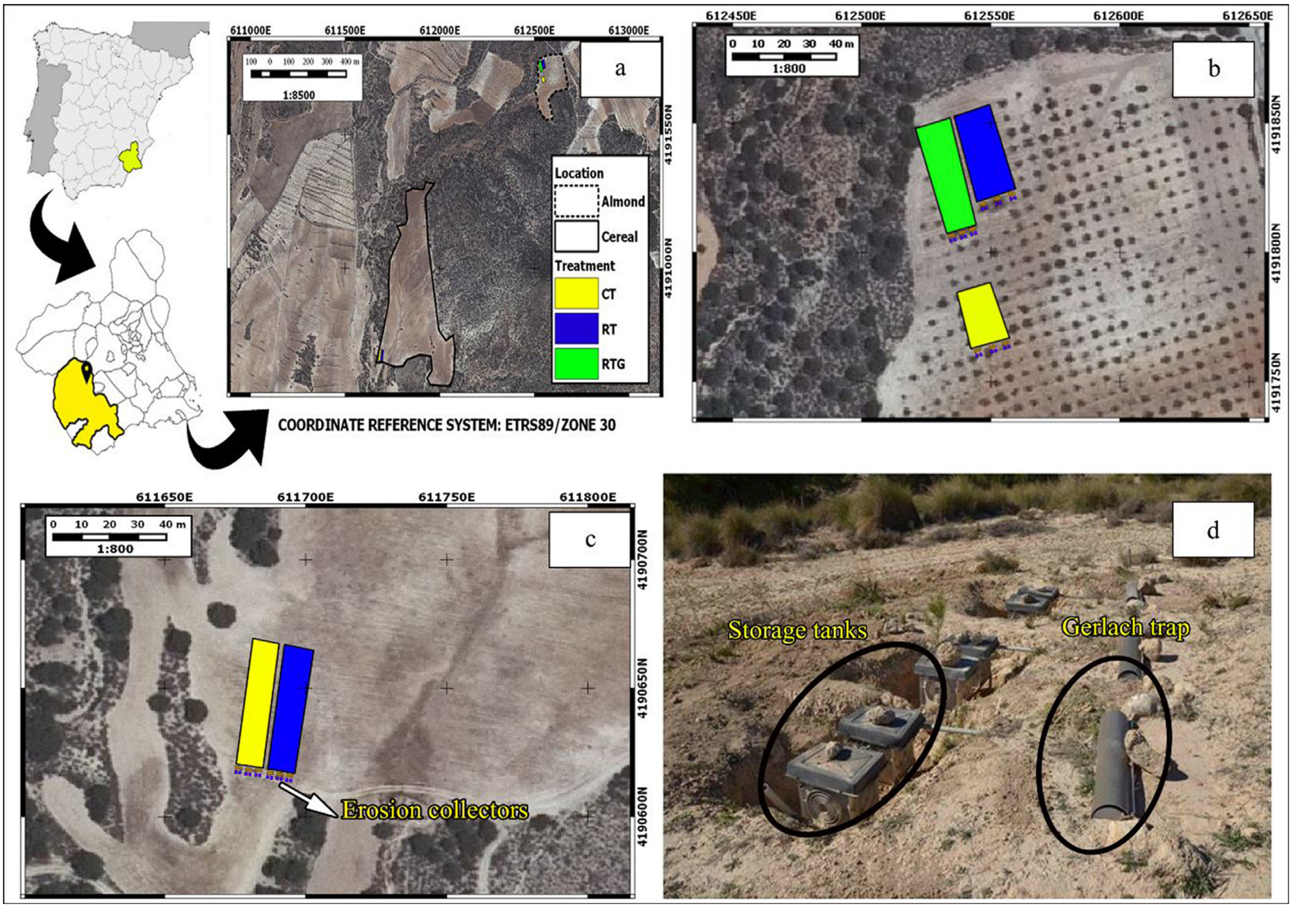

Fig. 1. Location of the study area and experimental fields within the farm (a); location of the experimental plots at the almond tree orchard (b) and cereal (c) and erosion collector systems detail (d),

et al., 2005; Eekhout et al., 2018), these areas require erosion control measures (Dodds et al., 2008; Rodrigo-Comino et al., 2017).

Sustainable Land Management (SLM) practices which include a wide range of techniques, such as reduced tillage, no-tillage, cover crops, etc., have the potential to reduce soil, OC, and nutrient losses by erosion (Francia Martinez et al., 2006; Maetens et al., 2012; Almagro et al., 2016; Garcia-Franco et al., 2018). These usually aim to increase plant cover (native or introduced), buffer raindrop impact, and increase soil roughness. Moreover, the incorporation of plant residues into the soil promotes the recycling of nutrients and OC, avoiding the impoverishment of agricultural soils and increasing their water retention capacity. In addition, the vegetation and soil biological activity favours the formation and stabilization of aggregates by secreting cementing agents such exudates, microbial secretions, etc., increasing the soil the resistance to erosion (García-Fayos, 2004; Ramos et al., 2011; Porta et al., 2013). The incorporation into the soil of green manure, for different types of soils and crops, has been found to have positive effects on the hydraulic properties of the soil, increasing macroporosity and hydraulic conductivity (Ruiz-Colmenero et al., 2013; Haruna et al., 2018; Biddoccu et al., 2017; Álvarez et al., 2017), and on other properties related to soil quality and stability (Almagro et al., 2017).

In spite of these benefits, SLM practices are not very commonly adopted by farmers because they do not observe consistent improvements in crop yields and consider that spontaneous or introduced plants may compete with crops for water and nutrients (Alcántara et al., 2011; Martínez-Mena et al., 2013). Moreover, few economic contributions exist from European Common Agricultural Policy (CAP) to stimulate farmers in applying SLM (Taguas and Gómez, 2015).

Understanding the rainfall/runoff/erosion relationships and related nutrient dynamics is of great relevance in terms of soil quality, especially in soils with low organic matter content that are susceptible to erosion and degradation. Studies comparing soil, water, and nutrient loss rates in cropping systems under sustainable management practices to those under conventional management are crucial to emphasize the potential SLM to promote long-term soil conservation practices. The results from such studies can guide farmers in the decision making process and help them to choose the most suitable measure to reduce soil degradation while increasing soil quality. Furthermore, this kind of information would help policy-makers to adopt decisions for soil and water conservation in the framework of the European Common Agricultural Policy (CAP).

The response of agroecosystems to different management practices depends on the local biophysical, climatic and socioeconomic conditions, (Schwilch et al., 2015; SMARTSOIL, 2015; Sanz et al., 2017). In this regard, there is a need to widen the spectrum of studies, to cover different environmental (e.g., climate, soil type) and socioeconomic (e.g., crop type, market price fluctuations, subsidies) conditions, taking into account different temporal scales (short, medium or long-term experiments). In this sense, despite globally there are many erosion plot data available for different locations, there is a lack of long-term studies testing the effectiveness of SLM practices towards the reduction of runoff and soil erosion rates, and the associated OC and nutrients loss, while improving soil physico-chemical properties. Also, few studies exist on particle size distribution and enrichment in the eroded sediment and on its variation along rainfall intensity at the event scale. Such studies are even less frequent in rainfed orchard systems.

Thus, this work integrates the changes in soil properties, runoff, erosion and nutrients mobilization in relation to the rainfall characteristics after six years of sustainable land management practices implementation in two organic rainfed systems (wheat and an almond orchard) representative of a large area of the driest Mediterranean regions.

The specific objectives were (i) to assess the effectiveness of sustainable management practices (SLM): reduced tillage (RT) and reduced tillage combined with green manure (RTG) in the improvement of several soil properties, thereby reducing runoff, erosion, and associated losses of OC and nutrients (N and P), and (ii) to evaluate the influence of the rainfall characteristics on the effectiveness of these SLM practices with regard to the control of runoff, erosion, and nutrient mobilization..

2. Material and methods

2.1. Study site

In 2009, a field experiment was established at the "Alhagüeces" farm near Zarzadilla de Totana, 60 km west of the city of Murcia, Spain, in "Rambla de Torrealvilla" (37°51′59″N, 1°43′11″W; 839 m.a.s.l). Two different crops in two different locations (1 km apart) within the same farm were used for the study (Fig. 1): an annual herbaceous crop, wheat (*Triticum* sp.) and a perennial woody crop, almonds (*Prunus dulcis* Mill.). Both crops are cultivated here under organic rainfed conditions, with no fertilization. The wheat was first sown in 2001 and is produced in a rotational system in which each crop is followed by one year fallow when the soil is completely bare, mainly during summer when the torrential rains usually occur and the risk of erosion is highest in these areas. The almonds trees were planted in 1999 with a tree spacing of 7 × 7 m.

The average annual rainfall is 330 mm, concentrated in spring and autumn. The mean annual temperature is 16.6 °C, and the mean potential evapotranspiration reaches 800 mm yr^{-1} (calculated by the Thornthwaite method), so the mean annual water deficit is around 500 mm. July and August are the driest months. The soils are classified as a *Calcaric Regosol,* developed from marls, and a *Cambic Calcisol,* developed from colluviums (IUSS Working Group WRB, 2015), for the wheat and almond field, respectively. The soil texture is silty-clay loam (30.9%, 59.1% and 10.0% for clay, silt, and sand, respectively) and loam (18.1%, 49.5% and 32.5% for clay, silt, and sand, respectively) for the wheat and almond field, respectively. Both soils have high contents of $CaCO_3$ (~45%), low electrical conductivity (< 200 µS cm^{-1}), and pH values around 8.8. In addition, the surface stone percentage oscillates between 20% (wheat) and 60% (almond).

2.2. Experimental design

The soil use management practices compared in this trial were (i) conventional tillage (CT), the usual practice in the farm, and reduced tillage (RT) in the wheat fields; and (ii) conventional tillage (CT), reduced tillage (RT) and reduced tillage plus green manure (RTG) in the almond field.

Wheat field:

*CT was plowed with a moldboard plow to 40 cm depth following harvest in June, leaving the land fallow for one year. During the fallow period, the land was plowed three more times with a chisel plow before the seeding in the next autumn.
*RT was not plowed after harvest, leaving the stubble during the fallow year, until the next autumn, when the land was prepared for seeding with a chisel plow (0.20 m).

Almond field:

*Conventional tillage consisted of chisel plowing (0.20 m depth) using a cultivator, from three to five times a year after important rainfall events.
*RT consisted of chisel plowing (0.20 m depth) using a cultivator, twice a year (autumn/spring), to control weeds.
*RTG consisted of a mix of vetch (*Vicia sativa* L.) and common oat (*Avena sativa* L.) in a proportion of 3:1, at 150 kg ha^{-1}. The green manure (or cover crop) was seeded yearly in the autumn and incorporated into the soil with a cultivator in May-June.

In 2009, open plots were arranged in the field following a split-plot experimental design with three replicates (sub-plots) per treatment. The size of each replicate varied between 44 and 265 m^2 (wheat) and between 25 and 126 m^2 (almond) with the long side of each one following the direction of the maximum slope. The average plot slope was 10–12% in both crop fields. At the end of each sub-plot a sediment trap Gerlach (Gerlach, 1964) was connected to two storage tanks (40 L) resulting in a total of six (3 replicates × 2 treatments) and nine sediment traps (3 replicates × 3 treatments) in the wheat and almond fields, respectively (Fig. 1). The first tank, with a five-slot divisor, was set up to collect runoff and sediments. After every erosion event, sampling of the sediments in the tanks was carried out after thorough stirring. All the sediment accumulated in the Gerlach trap and five aliquots of 1 L each, from different depths in each tank, were taken. The sediment was filtered, oven-dried at 60 °C, weighed to determine the suspended sediment concentration, and stored for further analysis. The sediment concentrations were averaged and multiplied by the total runoff to calculate the total soil loss after each erosion event. The annual OC, N, and P losses by erosion (in g m^{-2} $year^{-1}$) were calculated as the sum of the net OC or nutrient export after every erosion event during one year divided by the drainage area of each erosion plot. To assess the OC and nutrient losses by erosion in each tillage treatment, the enrichment ratios ($ER_{OC}/ER_N/ER_P$) were calculated as the relationship between the OC, N, or P concentration in the collected sediment and the OC, N, or P concentration measured in the source soil after each erosive event (Gachene et al., 1997). A total of 34 erosion events occurred between 12th January 2010 and 30th December 2015 and are presented in this study.

Soil sampling was carried out for each field and treatment six years after their implementation (year 2015). A randomized soil sampling trial was design to assess the effects of the different management practices tested on several soil properties. Nine composite soil samples per treatment (three per replicate: 18 and 27 for the wheat and almond fields, respectively) were collected in the plow layer (0–20 cm depth) and stored for further analyses in the laboratory.

2.3. Soil and sediment physical and chemical analysis

The size distribution of the soil and transported sediment in the field (effective size distribution) was compared with equivalent measurements of the same samples after chemical and mechanical dispersion (ultimate size distribution), to investigate the detachment and transport mechanisms involved in sediment mobilization. The particle size distribution of the effective soil and sediment was measured using a Coulter LS200 laser diffraction device. After determining the particle size distribution of the effective sediment, subsamples were treated with hydrogen peroxide to remove organic matter before being dispersed in sodium hexametaphosphate, using ultrasonic dispersion. The ultimate particle size distribution was measured, as well, using the Coulter LS200 laser diffraction equipment, which analyzes particle sizes from 0.4 to 2000 µm diameter. From this the effective mean weight diameter (MWDe) and the dispersed mean weight diameter (MWDd) were inferred. By comparing the particle size distribution of the detached sediment with that of the matrix soil, it is possible to assess the degree to which certain particle size classes (clay, silt, or sand particles) have been removed or enriched in the detached sediment. Thus, enrichment ratios (ER) greater than 1.0 reflect a greater proportion of a given class size in the transported material than in the matrix soil, while ER values less than 1.0 represent depletion: a given class represents a greater proportion in the matrix soil than in the transported material. The ratio MWDe/MWDd was used as an indicator of how the particles

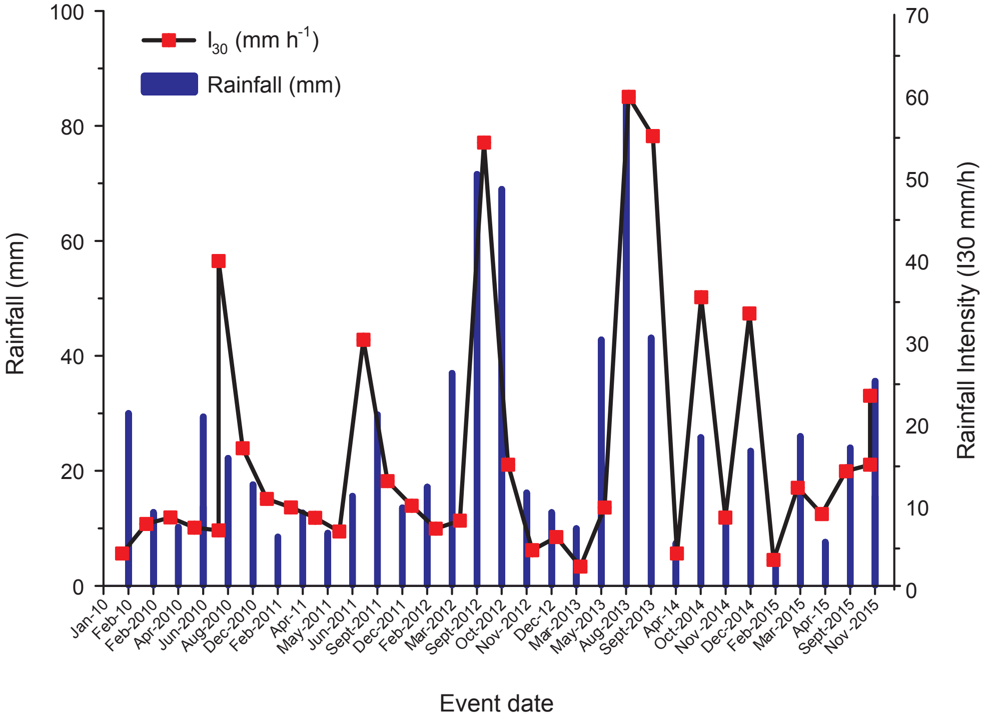

Fig. 2. Rainfall depth (mm) and maximum intensity in 30 min (I_{30}, mm h^{-1}) of events recorded during the study period.

were eroded and transported by the flow. An effective/dispersed ratio of 1 indicates that the sediment is transported as primary particles, while a ratio > 1 indicates that they are moving as aggregates (Martínez-Mena et al., 2002).

The composited soil and sediment samples were homogeneized, air-dried, grounded and passes through a 2 mm sieve before chemical analyses were performed. The soil and sediment OC (SOC; g kg^{-1}) and total N (g kg^{-1}) were analyzed using a N/C Analyzer (Flash 1112 EA, Thermo-153 Finnigan, Bremen, Germany) after grinding the samples. Before the analysis of SOC, carbonates were eliminated using 2 M HCl. Available phosphorus (P) was extracted with 0.5 N $NaHCO_3$ at pH 8.5, using the method of Olsen et al. (1954).

2.4. Rainfall erosivity

Rainfall erosivity was estimated using rainfall data from a rain gauge connected to a data logger (HOBO event, 12 cm length, Massachusetts, USA) in the experimental farm, which recorded values every five minutes. Rainfall events greater than 1 mm were considered.

From the daily rainfall dataset, the intensity of events (I) and the maximum intensity in 30 min (I_{30}) were calculated (both in mm h^{-1}). The kinetic energy (KE) associated with the rainfall, in J m^{-2} mm^{-1}, was calculated from Eq. (1), according to Wischmeier and Smith (1978), as:

$$KE = 0.119 + 0.0873 \times \log10(I1_{60}) \tag{1}$$

where I_{60} is the maximum rainfall intensity in sixty minutes.

The values obtained from Eq. (1) were used to calculate the rainfall erosivity index (RE) for storms, in J m^{-2} h^{-1}, which is proportional to the product of the total storm energy (KE) and the maximum 30-min intensity (I_{30}), according to Wischmeier and Smith (1978):

$$RE = KE \times I_{30} \tag{2}$$

The events were classified in three classes according to their RE values: Class I: $RE \leq 25$, Class II: $25 < RE \leq 90$, and Class III: $RE > 90$, representing low, medium, and high erosive events, respectively, according to the rainfall characteristics of this area (Martínez-Mena et al., 2001).

2.5. Statistical analyses

The data were examined for normality by the Kolmogorov–Smirnov test and for homogeneity of variances by the Levenés test. Due to the lack of normality of most of the studied variables, non-parametric tests were used. To compare management practices and rainfall event classes within each crop, the non-parametric Kruskal-Wallis test was used. Moreover, non-parametric Spearman correlation coefficients were calculated to study the relationships among climatic parameters, erosion and runoff rates, the OC, N, and P transported in sediments, and the sediment MWD (effective and dispersed) in each crop. All statistical analyses were performed using R software and significance was set at $p < 0.05$.

3. Results

3.1. Climatic characteristics during the study period

The total rainfall during the six-year period (2010–2015) was 1464.1 mm, the mean annual precipitation (237 mm) being lower than the mean value of the long historical period registered in nearby climate stations (367 mm; 1940–2007; SIAM). The year 2010 had an exceptionally high annual accumulated rainfall (400 mm), while the driest year was 2014 (136.80 mm), its rainfall being 68% lower than the mean annual value. Between 34% and 88% of the total annual rainfall (the highest percentages corresponded to the years with the highest rainfall intensity) caused runoff and erosion in both studied fields (Fig. 2).

The events recorded during the study period were classified as a function of their rainfall Eerosivity (RE) values as: Class I: $RE \leq 25$ (mean P and I_{30} of 14 mm and 7 mm h^{-1}, respectively), representing 58.8% of the total events; Class II: $25 < RE \leq 90$ (mean P and I_{30} of 34 mm and 19 mm h^{-1}, respectively), 14.7% of the total events; and Class III: $RE > 90$ (mean P and I_{30} of 41 mm and 35 mm h^{-1}, respectively), 26.47% of the total events.

Table 1
Means and standard errors of several soil and sediment characteristics at the different sustainable land management practices (SLM) and fields.

		Soil					Sediment				
	SLM	MWDd µm	MWDe µm	OC g Kg^{-1}	N g Kg^{-1}	P mg Kg^{-1}	MWDd µm	MWDe µm	OC g kg^{-1}	N g Kg^{-1}	P mg kg^{-1}
Wheat	CT	21.0 ± 2.2	266.6 ± 1.1	5.9 ± 0.3b	0. 7 ± 0.02a	3.46 ± 0.16b	47.1 ± 17.1	190.9 ± 13.7	14 ± 2a	1.2 ± 0. 1a	21.05 ± 5.5a
	RT	34.2 ± 3.1	224.4 ± 1.3	8.5 ± 0.4a	0. 8 ± 0.07a	5.02 ± 0.31a	44.7 ± 8.7	229.8 ± 23.2	16 ± 1b	1.6 ± 0. 1b	31.61 ± 3.4b
Almond	CT	130 ± 6.5	524.8 ± 13.4	19.4 ± 1.3b	1.4 ± 0.2b	40.19 ± 4.58a	247.9 ± 54.4b	573.9 ± 62.8	35 ± 2	3.9 ± 0.6	73.91 ± 7.5
	RT	250.2 ± 7.4	507.1 ± 19.8	23.8 ± 1.0a	1.9 ± 0.2a	53.20 ± 6.76a	504.6 ± 66.4a	600.3 ± 75.6	41 ± 3	3.8 ± 0.3	92.5 ± 12.9
	RTG	190.3 ± 7.2	544.3 ± 11.5	25.6 ± 1.4a	2.3 ± 0.1a	30.64 ± 2.32a	444.6 ± 61.3a	639.6 ± 70.5	38 ± 2	3.7 ± 0.4	80.29 ± 7.4

CT: conventional tillage; RT: reduced tillage; RTG: reduced tillage combined with green manure. MWDe: effective mean weight diameter; MWDd: ultimate mean weight diameter; OC: organic carbon; N: nitrogen; P: phosphorus. Different letters within columns means significant differences among management practices within each field at $p < 0.05$ according to the non-parametric Kruskal Wallis Test.

A total of 34 events of runoff and erosion were recorded: 35% occurred in the autumn, 29% in spring, 21% in winter, and 15% in summer. Summer was the season with the highest percentage of erosive events (80% of the events belonging to RE classes II and III). In fact, the most erosive event (RE: 690.84 J mm m^{-2} h^{-1}) was recorded in August 2013, with 84 mm of rainfall and an I_{30} of 60 mm h^{-1}. This event had a return period of six years. Winter displayed the lowest rainfall erosivity of all the seasons (100% of the events belonging to RE class I) (Fig. S1).

3.2. *Influence of management practices on soil physical and chemical characteristics*

The soil of the wheat field with a higher clay and a lower sand content showed lower values of both MWDd and MWDe with respect to the soil of the almond field (Table 1). The MWDe was also lower for the wheat field than for the almond field. No differences in the ultimate (MWDd) or effective (MWDe) particle size distribution were observed between the management practices in the same crop.

The wheat field soil had lower SOC (< 1%), N (~0.1%), and P (~5 mg kg^{-1}) contents than the almond field soil (~2%, 0.2%, and 40 mg kg^{-1}, respectively; Table 1). Six years after its implementation, RT had increased the SOC relative to that in CT, by 44% and 23% for the wheat and almond crops, respectively. For the RTG treatment increments in SOC of about 32% with respect to the CT were observed. However, changes in the soil N content were only observed in the almond field with increments of about 26 and 39% in RT and RTG, respectively, compared to CT. Soil P concentration increased under RT only in the wheat field by about 45%, compared to CT (Table 1).

3.3. *Sediment and water losses*

For the two crops, conventional management showed similar values of mean runoff (~0.40 mm) and total runoff for the whole study period (~10 mm). However, the mean and total values for erosion (Fig. 3f, 3e, and S2) and sediment concentration were much higher for the wheat than for the almond field (the mean values were five-fold higher in the wheat field as shown in Fig. 3c and 3d. In general, reduced tillage showed mean runoff and erosion values higher in the wheat field than in the almond field (Fig. 3 (indicated with lower case letters in the graphs) and S2).

The effectiveness of the SLM practices in the control of runoff and erosion was apparent within 18 months of their implementation, in both crops, and continued through the six years of the study (Fig. S2).

The mean runoff values were similar in the wheat field independently of the treatment. However, a decrease of about 53% in the mean sediment concentration values in RT, compared to CT was observed. In the almond field, a significant decrease of about 62% in the mean runoff under the RT treatments (RT and RTG) with respect to CT was found but no significant differences in the sediment concentration values between RT and CT were found (Fig. 3d). With reduced tillage treatments (RT and RTG) a decrease of about 66% in the erosion rates in both crops, compared to CT, was detected (Fig. 3e and 3f).

The mean values of the runoff (Fig. 3a and 3b), sediment concentration (Fig. 3c and 3d), and erosion rates (Fig. 3e and 3f) increased with increasing rainfall erosivity in most of the treatments tested, in both crops (Fig. 3). However, the effectiveness of the RT treatments regarding runoff and erosion control for the distinct rainfall erosivity scenarios depended on the crop. In the wheat field the greatest reduction in runoff (50%) was found for the least erosive rainfall events (class I), while the greatest reduction in erosion was higher for the most erosive events (class III) (Fig. 4a). By contrast, in the almond field the reduction in runoff with the RT and RTG treatments was similar independent of the rainfall erosivity, while the greatest reduction in erosion was found for the most erosive events (classes II and III) (Fig. 4b and 4c).

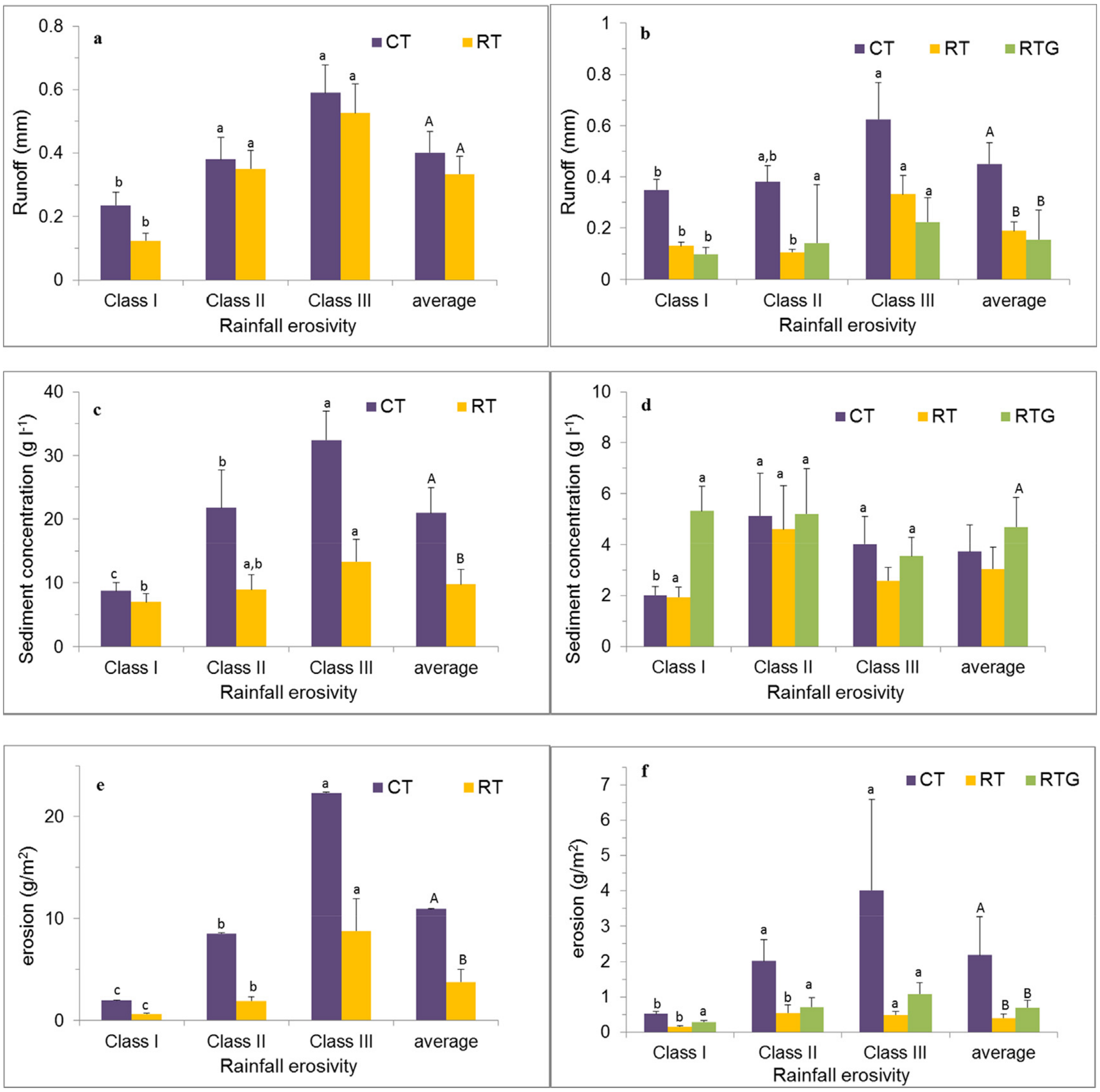

Fig. 3. Mean and standard error values of runoff (a, b), sediment concentration (c, d) and erosion (e, f) per erosivity class in the wheat (left) and almond (right) fields. Different lowercase letters indicate significant differences per erosivity class within each type of soil management practice at $p < 0.05$, according to the non-parametric Kruskal Wallis test. Different uppercase letters in the mean bars indicate significant differences among soil management practices. Note that the scale on the y-axis is different for wheat and almonds.

3.4. *Sediment particle size distribution and enrichment ratios*

In the wheat field the enrichment ratios of the finest particles (ER_{clay} and ER_{silt}) were close to 1 while those of the coarsest particles (ER_{sand}) were greater than 1, independently of the soil management. In the almond field, enrichment of the coarsest particles (ER_{sand}) (values about 1.7) was observed for the RT treatment, while ERclay was below 1 and ER_{silt} and ER_{sand} were close to 1 for the CT treatment (Table 2). Regardless of the crop or management, there were no differences in the sediment enrichment ratio for clay, silt, or sand among the distinct rainfall erosivity classes considered (Table 2).

In the wheat field, the effective and disperse mean weight diameter values of the sediment were similar for the two soil management (mean values of ~210 and 45 µm for MWDe and MWDd, respectively). In the case of the almond field, we found similar mean values of MWDe (~600 µm) for the distinct types of soil management, but the MWDd values were lower for CT (about 250 µm) than for reduced tillage (~470 µm; RT and RTG) (Table 1).

Neither MWDd nor the aggregation ratio differed according to the rainfall erosivity class, independently of the crop and the soil management treatment. In contrast, the MWDe was lower for erosive events of classes II and III than for the less erosive events (class I), regardless of the soil management, in both crops, although the differences were only statistically significant in the case of the almond field (Table 2).

Sediment was transported as aggregate in both fields, independently of the soil management, the mean aggregation ratio (MWDe/MWDd) being 7.64 ± 0.60 and 2.18 ± 0.35 in the wheat and almond fields, respectively. The aggregation ratios were similar among the tillage treatments in both crops (Table 2).

3.5. *OC, N and P losses*

Conventional management showed lower concentrations of OC, N and P than RT in the wheat field sediments. In the almond field no differences were detected in the OC (about 4%) or N (about 4%) concentration between the soil management practices, but the P concentration in the sediment was lower in CT than in the RT treatment (Table 1).

The enrichment ratio (ER) for OC, N, and P (*i.e.*, the ratio between the concentration in the transported sediment to that in the plow layer) was generally > 1, independently of the soil management or crop (Fig. 5). In the wheat field, the ER_{OC}, ER_N and ER_P enrichment ratios

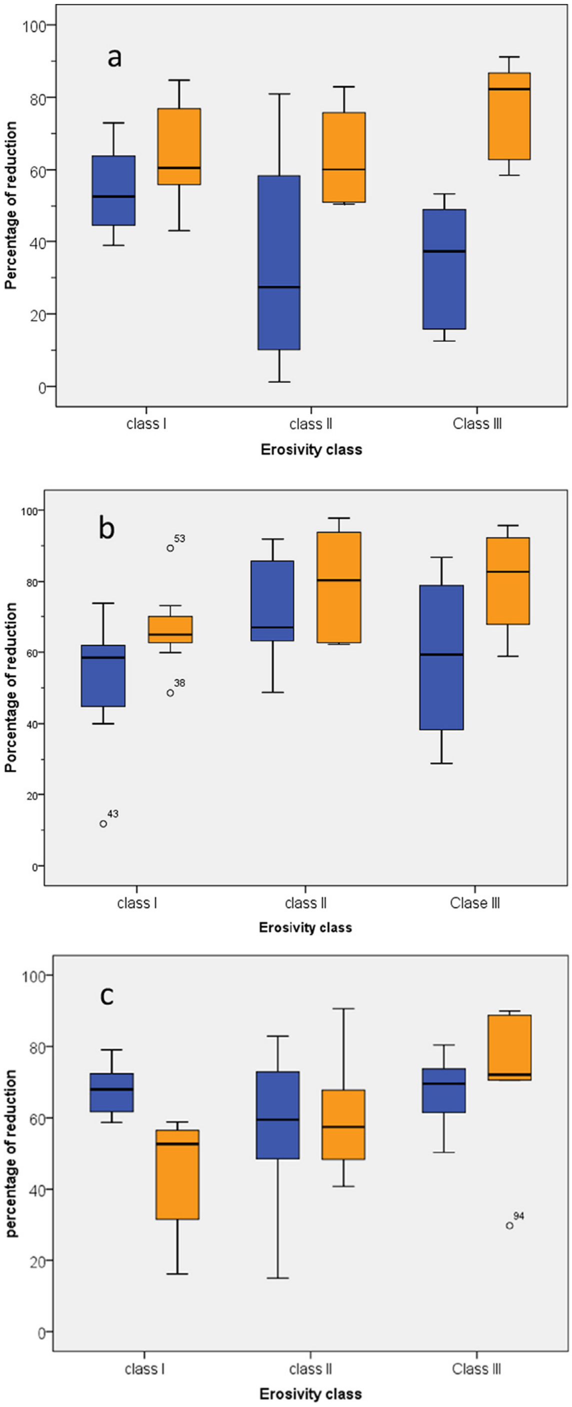

Fig. 4. Effectiveness of reduced tillage (RT) in wheat and almonds (a, b) and of reduced tillage plus green manure (RTG) in almonds (c) in the control of runoff (blue) and erosion (orange), according to the rainfall erosivity classes.

were lower for CT than for RT (Fig. 5a). By contrast, in the almond field the ER_{OC} and ER_N values were lower under RT and RTG than under CT, while ER_P did not differ between the management treatments (Fig. 5b).

In the wheat field, the highest enrichment of OC was observed for the rainfall events of lowest erosivity (class I) under CT, while for RT there was no effect of rainfall erosivity on OC enrichment. Contrastingly, the highest enrichment of N and P was observed for the most erosive events (class III), with both conventional and reduced tillage management. In the almond field, no differences in ER_{OC}, ER_N or ER_P among the rainfall erosivity classes were found - except for RTG, where the enrichment ratios were highest for the most erosive events (classes II and III) (Fig. 5d and f).

The total OC, N and P eroded during the six-year period followed the same trend, being higher under CT (19.8, 2.8 and 0.05 kg ha^{-1} for OC, N, and P, respectively) than under RT (7.8, 1.2 and 0.02 kg ha^{-1} for OC, N, and P, respectively) in the wheat field. In the almond field, the total eroded OC, N and P under CT (13.6, 1.2, and 0.03 kg ha^{-1} for OC, N, and P, respectively) were higher than under RT (0.9, 0.08 and 0.001 kg ha^{-1}) and RTG (4.0, 0.43 and 0.01 kg ha^{-1}).

3.6. *Relationship between climatic characteristics and erosive response*

Positive significant correlations between climatic characteristics and the hydrological and erosive responses, across managements, were observed in both fields. In general, the significance of the correlations was higher in the wheat field than in the almond field (Table 3), and both, the erosive and hydrological responses were correlated much more closely with the rainfall intensity than with the rainfall depth. The correlations between erosion and rainfall erosivity were stronger in conventional tillage than in reduced tillage, independently of the crop (wheat: $r = 0.70$ versus $r = 0.33$, $p < 0.001$, for conventional and reduced tillage, respectively; almond: $r = 0.39$ versus $r = 0.20$, $p < 0.05$, for conventional and reduced tillage, respectively). For RTG in the almond field there was no significant correlation between the rainfall intensity and erosion rates.

The climatic variables were correlated significantly and positively with ERclay (wheat) or ER_{silt} (almond) and negatively with ERsand in both fields. For the almond crop, highly negative relationships between the climatic variables and MWDe were observed, while MWDe was also had a strongly significant negatively correlation with total runoff and with the OC, N, and P concentrations in the sediment (Table 3). The climatic variables were significantly and positively correlated with the OC, N, and P concentrations in the sediment for almond, but only with P for the wheat field.

The correlations between the OC and N concentrations in the sediment and the total soil loss were significant and negative for the wheat field, while a significant and positive correlation was observed for P at the almond site (Table 3). When the different forms of management were separated, negative relationships between the OC or N concentration in the sediment and the total soil loss ($r = -0.37$ and $r = -0.32$, $p < 0.01$, for OC and N, respectively) were found for CT in the wheat, and positive ones ($r = 0.45$ and $r = 0.27$, $p < 0.01$, for OC and N, respectively) were found in the almond. No significant correlations between these variables existed under the reduced tillage regimes. However, positive and significant correlations between the P concentration in the sediment and the total erosion were observed for CT in the wheat ($r = 0.28$, $p < 0.05$) and for reduced tillage at the almond site ($r = 0.29$, $p < 0.05$).

4. Discussion

4.1. *Effect of RT and RTG on runoff and erosion*

The average annual erosion rates in the wheat field (360 kg ha^{-1} and 110 k ha^{-1} for conventional and reduced tillage, respectively) are within the range reported by other authors (Kosmas et al., 1997; Maetens et al., 2012). The average annual values of erosion in the almond site (7.8 kg ha^{-1} and 1.2 kg ha^{-1} for conventional and reduced tillage, respectively) are lower than those reported by some authors (Gómez et al., 2009; Durán Zuazo et al., 2014; Sastre et al., 2017), but in the same range as those reported by others (Ruiz-Colmenero et al., 2011; Kairis et al., 2013). The high variability in the natural conditions, the spatial and temporal scale, and the complexity of ecosystem interactions as well as the design of the erosion plots (Boix-Fayos et al., 2005) can explain the wide range of erosion rates found in the literature for semiarid Mediterranean areas.

Reduced tillage (RT), in both crops, and green manure

Table 2

Mean and standard errors of clay, silt and sand enrichments in eroded sediment and aggregation ratio per erosivity class in each field and corresponding sustainable management practice (SLM).

	SLM	Variable	Rainfall erosivity class		
			Class I	Class II & III	Mean
Wheat	CT	ER_{sand}	1.41 ± 0.35	1.02 ± 0.1	1.2 ± 0.04
		ER_{silt}	0.99 ± 0.03	1.00 ± 0.03	1 ± 0.01
		ER_{clay}	0.89 ± 0.07	0.91 ± 0.07	0.9 ± 0.01
		MWD_e	194.9 ± 18.4	182.7 ± 18.3	188.3 ± 12.7
		MWD_d	33.8 ± 2.8	61.9 ± 35.9	48.5.1 ± 18.6
		Ratio	6.53 ± 1. 08	7.89 ± 1.14	7.2 ± 0.8
	RT	ER_{sand}	1.24 ± 0.21	1.13 ± 0.22	1.2 ± 0.03
		ER_{silt}	1.02 ± 0.03	1.01 ± 0.02	1.0 ± 0.01
		ER_{clay}	0.89 ± 0.03	0.95 ± 0.05	0.9 ± 0.01
		MWD_e	269.0. ± 22.2	197.1 ± 35.5	229.8 ± 28.2
		MWD_d	43.3 ± 13.4	34.5 ± 6.2	38.7 ± 6.9
		Ratio	8.6 ± 1.24	7.78 ± 3.4	8.2 ± 0.9
Almond	CT	ER_{sand}	1.32 ± 0.21	0.95 ± 0.19	1.09b ± 0.04
		ER_{silt}	0.87 ± 0.12	1.15 ± 0.09	1.04a ± 0.02
		ER_{clay}	0.77 ± 0.07	0.67 ± 0.10	0.72 ± 0.02
		MWD_e	771.5 ± 45.1a	430.2 ± 79.4b	573.91 ± 62.7
		MWD_d	330.2 ± 88.5	196.6 ± 66.7	247.1 ± 54.4
		Ratio	3.28 ± 1.07	2.96 ± 1.11	3.1 ± 0.22
	RT	ER_{sand}	1.80 ± 0.24	1.74 ± 0.25	1.76a ± 0.06
		ER_{silt}	0.64 ± 0.13	0.67 ± 0.14	0.66b ± 0.03
		ER_{clay}	0.51 ± 0.08	0.53 ± 0.09	0.52 ± 0.02
		MWD_e	744.5 ± 81.9a	420.1 ± 110.1b	600.3 ± 70.5
		MWD_d	501.3 ± 96.5	507.1 ± 103.8	504.61 ± 61.1
		Ratio	1.37 ± 0.62	1.22 ± 0.13	1.3 ± 0.12
	RTG	ER_{sand}	1.72 ± 0.17	1.49 ± 0.26	1.61a ± 0.04
		ER_{silt}	0.65 ± 0.09	0.80 ± 0.12	0.73b ± 0.02
		ER_{clay}	0.61 ± 0.09	0.63 ± 0.16	0.62 ± 0.02
		MWD_e	841.9 ± 32.7a	415.0 ± 101.3b	639.6 ± 16.2
		MWD_d	481.74 ± 81.5	407.54 ± 95.9	444.6 ± 16.4
		Ratio	2.05a ± 0.30	1.17b ± 0.33	1.7 ± 0.08

CT: conventional tillage; RT: reduced tillage; RTG: reduced tillage combined with green manure. ER_{sand}, ER_{silt} and ER_{clay}:enrichment of sand, silt and clay, respectively. MWD_e: effective mean weight diameter; MWD_d: ultimate mean weight diameter; Ratio: MWD_e/MWD_d. Different lowercase letters indicate significant differences per erosivity class within each type of soil management practice at $p < 0.05$, according to the non-parametric Kruskal Wallis test.

incorporation (RTG), in the almond tree crop, supposed a reduction in the total runoff (between 30 and 65%) and total erosion (between 63 and 80%) with respect to the CT, in both fields. Similar reductions in total runoff and erosion due to RT management have been reported previously for different types of crop (Ruiz-Colmenero et al., 2013; Preiti et al., 2017). In addition, the reductions in soil erosion with RTG that we found under almond were comparable to those reported by other researchers (Ordoñez-Fernández et al., 2007; Espejo-Pérez et al., 2013; Biddoccu et al., 2017).

The reduction in runoff and erosion with decreasing tillage intensity is due, in part, to the development of a vegetation cover during autumn and winter months (spontaneous or introduced with green planting). Its growth is possible due to the lower frequency of tillage together with the enhancement of several soil properties that improve the soil infiltration capacity (Álvarez et al., 2017; Haruna et al., 2018) and soil structure (increase in aggregate stability), making the soil more resistant to erosion (García-Fayos, 2004; Porta et al., 2013). In the almond field the increase in the vegetation cover percentage with the reduced tillage treatments (RT and RTG) was about 40% with respect to CT; however, the incorporation of green manure did not result in an increase in the vegetation cover percentage compared to reduced tillage alone (Almagro et al., 2016), explaining the slight differences observed in the soil erosion rates between the RT and RTG treatments.

The decrease in erosion under the wheat crop with RT was due, besides the increase in vegetation cover (the biomass increased by between 25 and 30% with RT, compared to CT; data not shown), to the suppression of moldboard plowing. This is a very aggressive technique that causes the turning of the soil, leaving on the surface the sub-surface material, which, in general, is of lower quality than the surface horizon (structural stability, permeability, nutrients, etc.), causing an increase in soil erodibility (de Alba et al., 2008).

In this study, an improvement in some soil quality indicators (SOC, N, and P concentrations) due to the management practices was also observed six years after their implementation, in both crops, suggesting that not only the vegetation cover, but also the soil quality might have an influence on controlling erosion in these areas. In addition, soil improvement was already detected in the reduced tillage treatments (RT and RTG), compared to conventional management, four years after their implementation, in the case of the almond field (Almagro et al., 2017).

In our conditions, reduced tillage was more effective at reducing soil losses than runoff volume, for both crops, which is in line with other reports that cover crops, either sown or spontaneous, are more effective at reducing soil losses than runoff volume (Shi et al., 2013; Repullo-Ruibérriz de Torres et al., 2018). However, in our almond orchard, the incorporation of green manure generated slightly higher (although not significantly so, statistically) average sediment concentrations than the RT and CT treatments, due probably to the influence of other local factors that have not been taken into account in this work (*i.e.*, microtopographical variables, sources of the sediments, spatial distribution of the vegetation cover etc.).

The erosive response was more sensitive to the intensity of the precipitation than to its depth, in both fields, highlighting the great importance of rainfall erosivity with respect to erosion in semiarid areas, as found in previous works (González-Hidalgo et al., 2007; Martínez-Mena et al., 2008). This has important implications in the light of the climate change projections of decreasing annual precipitation and increasing precipitation intensity, as was also highlighted by

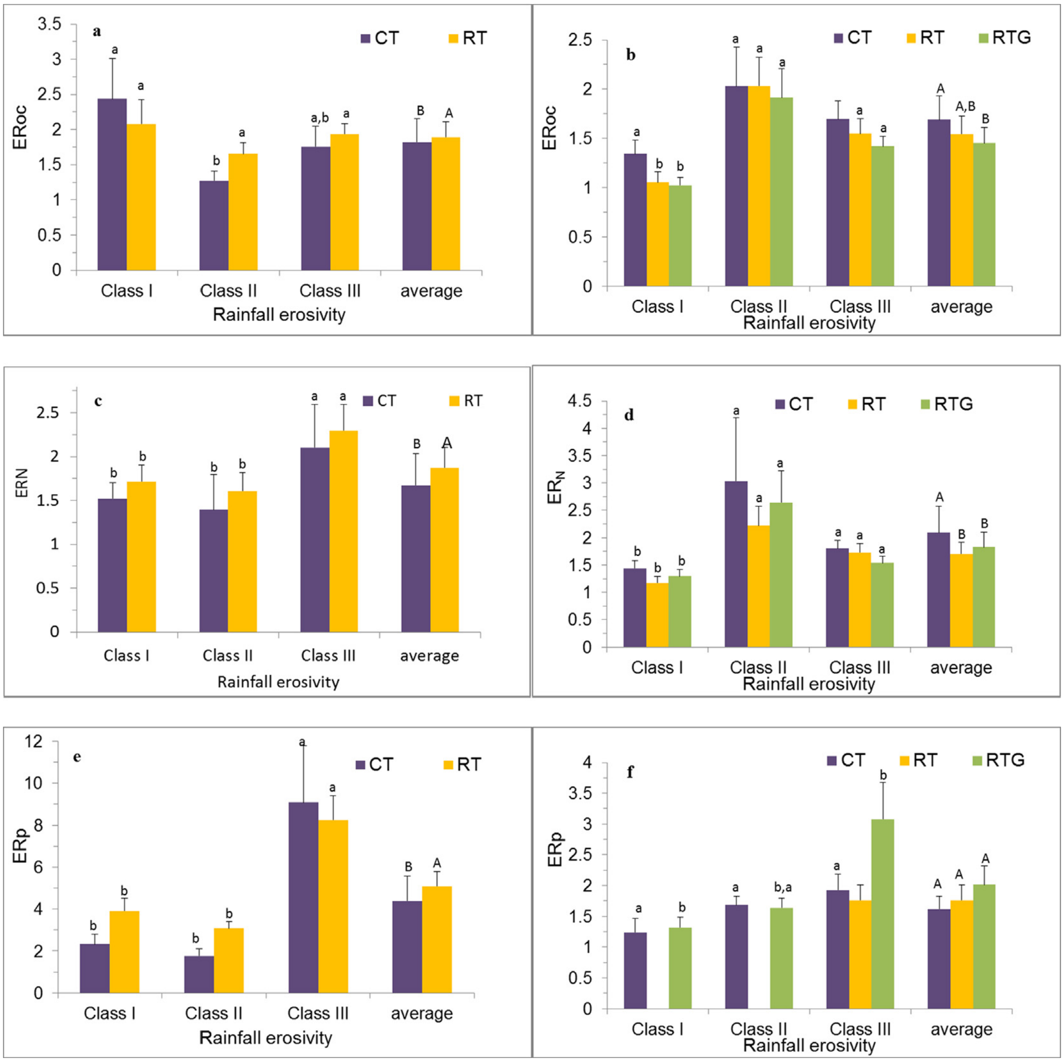

Fig. 5. Mean and standard error values of the enrichment ratios of OC (ER_{OC}) (a,b), N (ER_N) (c, d), and P (ER_P) (e, f) per erosivity class in the wheat (left) and almond (right) fields. Different lowercase letters indicate significant differences per erosivity class within each type of soil management practice at $p < 0.05$, according to the non-parametric Kruskal Wallis test. Different uppercase letters in the mean bars indicate significant differences among soil management practices.

Eekhout et al. (2018).

The decrease in runoff with reduced tillage for the wheat crop oscillated between 18% and 50%, the greatest reduction occurring during the less erosive rainfall events (class I; Fig. 4a). The fact that the less erosive events were more frequent in winter (Fig. S1), when the soil was protected by vegetation, could explain the higher effectiveness of this management at this time rather than in summer and autumn, when there is only stubble on the field and the most erosive events usually occur. Nevertheless, the decrease in total erosion due to reduced tillage of wheats was still slightly greater for the most erosive events (Fig. 4a), which implies that the stubble and the enhanced soil quality in general also reduced soil erosion.

In the almond orchard, the ability of reduced tillage to control runoff was similar, independent of the rainfall erosivity (between 55 and 70% reduction for the lowest and highest erosivity classes), while the reduction in erosion was highest (between 75% and 87%) for the most erosive events (class III). With the RTG management, where the average reduction in erosion for the less erosive events (class I) was about 40%, the reduction in class III was almost double (70%) (Fig. 4c). Previous work has also found greater reduction of soil losses during the most erosive events in other tree crops managed with ground covers (Marques et al., 2008; Napoli et al., 2017; Bagagiolo et al., 2018).

These results are also consistent with the higher sensitivity to the rainfall erosivity under conventional management than with SLM practices, as indicated by the less significant correlations of erosion and sediment concentration with rainfall erosivity under reduced (RT and RTG) tillage, in comparison with CT. This suggests that these management practices are particularly useful techniques in the context of adaptation to climate change, characterized by an increase in the irregularity and intensity of rainfall (IPCC, 2013; Ozturk et al., 2015; Eekhout et al., 2018). Other researchers also found that conservation tillage increased the resilience of soils to high-intensity rainfall events (Beniston et al., 2015). It is interesting to note that in our study only four events represented about 60% of the total erosion that occurred during the six years of study, in both crops; precisely, these were events of greater intensity (class III), as is characteristic of semiarid zones (Ruiz-Colmenero et al., 2011; Merten et al., 2015).

In general, the correlation coefficients between climatic characteristics and the erosive response had higher significance in the wheat than in the almond field (Table 3). This is consistent with the fact that fragile and nutrient-poor soils (is the case of the wheat field) are more sensitive to the climatic conditions (Beverley et al., 2018), which reinforces the importance of soil regeneration as a way to increase their resilience and adaptation to climate change (Batáry et al., 2015; Maharjan et al., 2018).

In both crops, the effect of the sustainable management practices on

Table 3
Spearman correlations between climatic variables and runoff and erosion response in the wheat and almond field.

Wheat

	SC	Erosion	Runoff	OC	N	P	ER_{clay}	ER_{silt}	ER_{sand}	MWD_e	MWDd	Aggregation Ratio
Rainfall	0.139^{**}	0.267^{***}	0.34^{***}			0.215**	0.41^{***}		-0.32^{**}			
I_{30}	0.48^{***}	0.56^{***}	0.46^{***}			0.353***	0.33^{**}					
I_{60}	0.5^{***}	0.63^{***}	0.53^{***}			0.356***	0.22*		−0.26*			
RE	0.45***	0.52***	0.455***			0.344***	0.301**		−0.223*			
SC		0.67^{***}	0.24^{***}	-0.24^{***}	-0.35^{***}					-0.42^{***}		
Erosion			0.8^{***}	-0.32^{***}	-0.33^{***}					-0.27^{**}		
Runoff				-0.23^{***}	-0.14^{**}							
OC					0.54^{***}	0.396***		−0.27*				
N						0.198**					0.241*	
P												
ER_{clay}									-0.67^{***}		−0.483***	0.506***
ER_{silt}									-0.4^{***}		−0.463***	0.297*
ER_{sand}											0.894***	−0.711***
MWD_e												0.378**
MWDd												−0.801***
Aggregation Ratio												

Almond

	SC	Erosion	Runoff	OC	N	P	ER_{clay}	ER_{silt}	ER_{sand}	MWD_e	MWDd	Aggregation Ratio
Rainfall		0.22^{***}	0.25^{***}	0.47^{***}	0.34^{***}	0.261**	0.31*	0.37^{**}	-0.39^{**}	-0.74^{***}	−0.35**	
I_{30}		0.26^{***}	0.22^{***}	0.37^{***}	0.27^{***}	0.437***		0.42^{**}	-0.37^{**}	-0.62^{***}	−0.394**	
I_{60}	0.2^{***}	0.37^{***}	0.27^{***}	0.34^{***}	0.2^{**}	0.355***		0.4^{**}	-0.35^{**}	-0.61^{***}	−0.347**	
RE	0.143^{**}	0.302^{***}	0.231^{***}	0.437^{***}	0.321^{***}	0.44***		0.466^{***}	-0.42^{**}	-0.702^{***}	−0.429**	
SC	1	0.66^{***}	-0.18^{**}			0.368***						
Erosion			0.57^{***}			0.259**		0.46^{***}	-0.43^{**}	−0.24*	−0.385**	
Runoff							0.44^{***}	0.54^{***}	-0.55^{***}	-0.44^{***}	−0.535***	
OC					0.87^{***}	0.634***				-0.56^{***}		
N						0.687***				-0.53^{***}		−0.452*
P										−0.395*		−0.467*
ER_{clay}								0.76^{***}	0.83^{***}		−0.787***	0.729***
ER_{silt}									-0.99^{***}	-0.46^{**}	−0.979***	0.507***
ER_{sand}										0.44^{**}	0.98***	−0.546***
MWD_e											0.468**	0.315
MWDd												−0.545***
Aggregation Ratio												

SC: sediment concentration. OC: organic carbon in sediments; N: nitrogen in sediments; P: available phosphorous; ER_{clay}: enrichment of clay in sediments; ER_{silt}: enrichment of silt in sediments; ER_{sand}: enrichment of sand in sediments; MWDe: effective mean weight diameter; MWDd: dispersed mean weight diameter; I30: maximum rainfall intensity in 30 min; I60: maximum rainfall intensity in 60 min; RE:rainfall erosivity index; ***: $p < 0.01$. **: $p < 0.05$. *: $p < 0.10$.

the runoff and erosion was evident before the second year of their implementation. Sastre et al. (2017) reported the benefits of permanent cover crops, one year after their establishment, for the control of erosion in olive groves. Such short-term beneficial effects underline the interest in using these techniques in areas where erosion is a potential risk in the acceleration of soil degradation.

4.2. Effect of reduced tillage (RT) and green manure (RTG) on organic carbon and nutrient mobilization

In this study we did not consider the loss of OC and nutrients (N and P) by runoff in solution, so all the mobilized OC, N, and P measured was associated with the solid phase. Nevertheless, prior studies performed close to this site showed that the OC lost was mostly linked to the solid phase (Martínez-Mena et al., 2008). Other authors found the same trend for P mobilization (Beniston et al., 2015).

In comparison with CT, the concentrations of OC and nutrients in the mobilized sediment were higher under the reduced tillage treatment in the wheat crop and were slightly higher, although not significantly so, in the almond orchard (Table 1). This is consistent with the increases in the soil OC, N, and P concentrations with the implemented soil managements as mentioned before. Specifically, reducing tillage frequency - with the subsequent development of vegetation and the incorporation into the soil of plant residues - increased the soil OC and P contents in the wheat field by 45%. In the almond field, soil OC increased between 23 and 30%, while soil N increased between 35% and 40%, depending on the soil management (RT or RTG), compared to CT. Previous work showed similar increments in soil OC and nutrients with RT management, under a variety of crop types (Ramos et al., 2011; García-Franco et al., 2015; Pardini et al., 2017; Almagro et al., 2017).

The enrichment of OC in the sediment was also higher for RT than for CT under the wheat crop, while the opposite occurred in the almond orchard, especially in the case of RTG, where ER_{OC} and ER_N were lower in the RT treatments (Fig. 5). This aspect was linked to the enrichment of sand and the depletion of silt observed for the reduced tillage treatments in the almond orchard, and thus to the lower abundance of OC and N linked to these fractions. Reductions in the enrichment ratios of several nutrients, related to the increment in the sediment size in the course of a rainfall event, have been identified elsewhere (Shi and Schulin, 2018). Related to this, higher nutrient enrichment in sediments, associated with the preferential loss of the finer particles in the erosion–runoff processes, has been reported previously (Ordoñez-Fernández et al., 2007). Furthermore, green manure application has been reported to result in greater physical protection of carbon (García-Franco et al., 2015; Almagro et al., 2017), compared to conventional management, which can explain why there was less mobilization of OC under RTG than under CT.

Despite the general increases in the concentrations of OC, N, and P in soil under RT, in both crops, their total losses were lower. This was a direct consequence of the reduction in runoff and erosion, as well as of the size of the material transported, achieved with this management (Gómez et al., 2009; Napoli et al., 2017). The total OC, N, and P losses in the wheat field were reduced by 56%, 45%, and 64%, respectively, while in the almond field the OC, N, and P losses were reduced by 90% under RT and by 85% under RTG. Other authors found smaller reductions in the losses of OC and N with RT than we found here: about 33% in wheat (Atreya et al., 2006) and 50–67% under permanent and mowed cover crops in vineyards (Ruiz-Colmenero et al., 2011, 2013) or under cover crops in olives (Márquez-García et al., 2013). Values similar to ours were found for OC and N under olive trees with cover crops (Repullo-Ruibérriz de Torres et al., 2018), and also for P in a wheat crop (Atreya et al., 2006). Altogether, these results stress that management practices that control soil loss have a greater impact on the reduction of C and nutrient losses via erosion than those that might change sediment C and nutrient concentrations (Owens et al., 2002).

In the wheat field, no significant relationships were observed between the particle size of the transported sediment and the rainfall erosivity, while significant negative relationships between the erosion rates and the OC, N and P concentrations in the sediments were found (Table 3). This suggests that in the wheat field the most erosive events mobilize soil particles from the deeper layers that are less rich in OC and nutrients (N and P).

In the almond field the most erosive events transported the smallest particles (Table 2), which are strongly linked to OC and nutrients (N and P) (García-Franco et al., 2015; Shi and Schulin, 2018). In fact, a strong and negative correlation between the different nutrient concentrations and the particle sizes of the exported sediments was found in this field, indicating that these elements were exported primarily in sediment-bound form, as small particles generally have a greater specific binding capacity for all kinds of sorbents than large particles (Sharpley, 1980; Quinton and Catt, 2007). Other authors also found positive correlations between OC concentration in sediments and the rainfall intensity in soils with characteristics similar to those of the almond field (Martínez-Mena et al., 2008; Velardo et al., 2009; Sastre et al., 2017).

In the same way that the SLM practices evaluated here were more effective in reducing erosion in more intense events, they also showed greater decreases in the total OC, N, and P losses in the most intense events. These results should help to increase the awareness among farmers and stakeholders of the importance of preventing soil erosion by the implementation of improved soil management practices; economic assessments incorporating the costs associated with losses of soil organic matter and nutrients (indirect costs) would help this. Montanaro et al. (2017) reported that the losses of C and nutrients (e.g. N, P, K) from bare soils by erosion were 35-fold greater than those from protected (by vegetation) soil. This would lead to the impoverishment of the top-soil and therefore to additional costs for farmers; namely, the fertilization needed to replace the nutrients lost by erosion and minimize the erosion-induced loss of productivity (Pimentel et al., 1995).

Under the wheat crop, the mobilized OC in the CT and RT treatments accounted for approximately 1% of the total eroded soil, while the mobilized N and P represented about 0.13% and 0.003%, respectively, the values being slightly higher in the CT. Under conventional and reduced tillage (RT and RTG) management of almonds, the mobilized OC represented about 4%, N $\sim$ 0.4%, and P $\sim$ 0.02%, respectively, of the total soil eroded, the values being slightly higher in the CT. The average percentages obtained in the present work are within the range observed by other authors (Napoli et al., 2017). The percentages increased as the rain event intensity increased, mainly in the almond field, where positive correlations between the OC and nutrient concentrations and the rainfall intensity were obtained (Table 3).

5. Conclusions

The sustainable land management (SLM) practices evaluated increased organic carbon (OC) and nutrients (N and P) contents in the soil, and reduced runoff, erosion, and mobilization of OC, N and P in sediments independently of the lithology and the type of crop. In general, the practices implemented were more effective in controlling erosion than runoff. Reductions in runoff of 30% and 65% and decreases in erosion of 65 and 85% were found in wheats and almond orchards, respectively.

The effectiveness of tillage reduction on erosion control and carbon and nutrients mobilization was greatest during the most intense rainfall events, which produce the highest erosion rates in Mediterranean areas. This underlines the usefulness of implementing SLM practices under semiarid conditions regarding climate change mitigation and adaptation, given the projected increase in high-intensity rainfall events in many Mediterranean semiarid areas.

The beneficial effect of the SLM practices on soil erosion was observed in the first 18 months after their implementation and continued throughout the six years of the study. Such short-term beneficial effects support the use of these techniques in areas where erosion is a potential risk in the acceleration of soil degradation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.catena.2019.104352.

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