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Effects of soil management techniques on soil water erosion in apricot orchards

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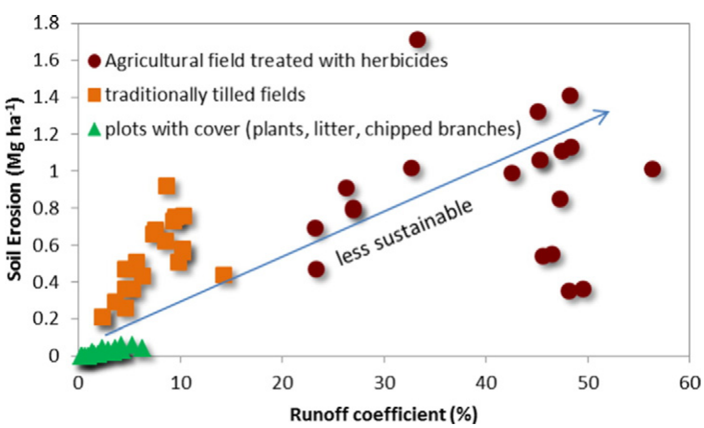
HIGHLIGHTS

- Prevailing management (tillage and herbicide treatment) keeps soil bare and prone to erosion
- Assessment of runoff and erosion for three management types (tillage, herbicide and covered)
- Herbicide treatment causes 1.8 and 45.5 times more erosion than tillage and covered respectively
- 60 rainfall simulation experiments showed tenfold lower erosion rates with covered soil
- Soil erosion was extremely high in herbicide treated orchards, even higher than in tilled orchards

GRAPHICAL ABSTRACT



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ABSTRACT

Soil erosion is extreme in Mediterranean orchards due to management impact, high rainfall intensities, steep slopes and erodible parent material. Vall d'Albaida is a traditional fruit production area which, due to the Mediterranean climate and marly soils, produces sweet fruits. However, these highly productive soils are left bare under the prevailing land management and marly soils are vulnerable to soil water erosion when left bare. In this paper we study the impact of different agricultural land management strategies on soil properties (bulk density, soil organic matter, soil moisture), soil water erosion and runoff, by means of simulated rainfall experiments and soil analyses. Three representative land managements (tillage/herbicide/covered with vegetation) were selected, where 20 paired plots (60 plots) were established to determine soil losses and runoff. The simulated rainfall was carried out at 55 mm h^{-1} in the summer of 2013 (<8% soil moisture) for one hour on 0.25 m^2 circular plots. The results showed that vegetation cover, soil moisture and organic matter were significantly higher in covered plots than in tilled and herbicide treated plots. However, runoff coefficient, total runoff,

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sediment yield and soil erosion were significantly higher in herbicide treated plots compared to the others. Runoff sediment concentration was significantly higher in tilled plots. The lowest values were identified in covered plots. Overall, tillage, but especially herbicide treatment, decreased vegetation cover, soil moisture, soil organic matter, and increased bulk density, runoff coefficient, total runoff, sediment yield and soil erosion. Soil erosion was extremely high in herbicide plots with 0.91 Mg ha^{-1} h^{-1} of soil lost; in the tilled fields erosion rates were lower with 0.51 Mg ha^{-1} h^{-1}. Covered soil showed an erosion rate of 0.02 Mg ha^{-1} h^{-1}. These results showed that agricultural management influenced water and sediment dynamics and that tillage and herbicide treatment should be avoided.

1. Introduction

Acceleration of soil erosion rates is the main cause of land degradation and, as a consequence, leads to loss of soil fertility and decrease in agricultural production and farmers income, which results in unsustainable agriculture (Colazo and Buschiazzo, 2015; Novara et al., 2015; Yan and Cai, 2015). Acceleration of soil erosion rates is the result of increased runoff on soil surfaces that are vulnerable to soil detachment (Van Oost et al., 2009). If a soil has characteristics (Stanchi et al., 2015) that prohibit infiltration of water (e.g. crusting, slacking, lack of macro pores) the runoff coefficient will be higher (Liu et al., 2014). However, if the soil has a rough surface (Gao et al., 2015), runoff will be delayed by ponding water, allowing water to infiltrate and reducing the soil erosion on such sites. But in the case where the soil is covered by vegetation infiltration rates are generally higher as a result of better soil structure, and the soil is protected against sediment detachment, which reduces the vulnerability to soil erosion (Seutloali and Beckedahl, 2015).

Agriculture is the main cause of soil losses and runoff (Cerdà et al., 2009a, 2009b; Novara et al., 2011; Laudicina et al., 2015) and orchards under rainfed agriculture have some of the highest soil erosion losses due to the lack of land levelling, terraces, intense tillage, compaction due to heavy machinery and herbicide application (Bisantino et al., 2015; Prosdocimi et al., 2016). Tillage has been part of the Mediterranean agricultural practices for millennia. Farmers have used this as a tool to avoid the competition for water with the crops, to enhance the infiltration by creating a rough and permeable surface. In addition the tillage breaks the capillary routes for the water to evaporate after a rain event. In Vall d'Albaida the tradition of an intense ploughing was used also to produce “dust” that protect the plant against insects (farmers personal communication). Because of the long tradition of Mediterranean farmers to keep their fields clean of weeds, farmers continue to do this, even when from a sustainability or productivity point of view this is no longer necessary and this is now a key point in the education for a better soil management (Keesstra et al., 2016a, 2016b). In Vall d'Albaida the ploughing use to take place 3 to 4 times per year, but many farmers over-tillage because this tradition of produce “dust” and avoid any weed. In Fig. 1B can be seen how farmers plough already bare orchards.

High erosion rates have been observed in avocado (Atucha et al., 2013) and olive orchards (Gómez et al., 2003; Vanwalleghem et al., 2010), new citrus plantations (Cerdà et al., 2009b; Li et al., 2015) and vineyards (Novara et al., 2013; Tarolli et al., 2015). Almond (Faulkner, 1995), persimmon (Cerdà et al., 2015), and apricot (Abrisqueta et al., 2007) orchards have also shown high erosion rates, but little research has been carried out comparing agriculture land management in fruit orchards. Also no research has been reported in other orchards such as apples, cherries or pears even though the worldwide land area devoted to fruit production is growing due to demand for fresh fruits and juices (Jackson et al., 2011). Until recently, most of the research in soil erosion has been done in areas occupied by cereals. These annual crops show high erosion rates due to intense tillage and a lack of vegetative cover (Cerdà et al., 2009a, 2009b; Stevens et al., 2009; Rodríguez-Blanco et al., 2013; Ligonja and Shrestha, 2015). High erosion rates result in the loss of soil, and with that the loss of services soils provide for society (Brevik, 2009; Keesstra et al., 2012; Berendse et al., 2015; Brevik et al., 2015; van Leeuwen et al., 2015).

Apricot (*Prunus armeniaca*) production in Spain was 119.400 Mg in 2013, which is 3% of the total world production (FAO, 2015). In Spain, 25 to 50% of the total apricot production is exported to European

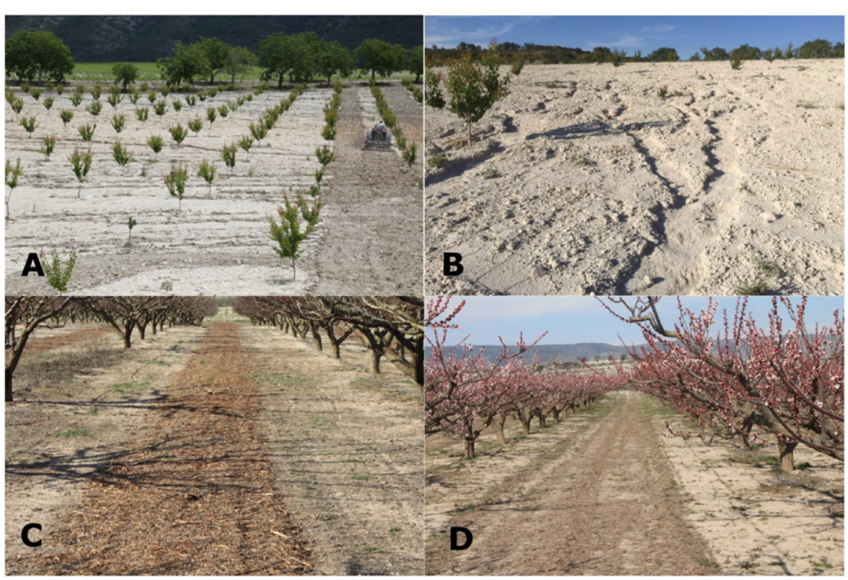

Fig. 1. Views of apricot orchards in the province of Valencia. Pictures A and B show evidence of high erosion rates after a thunderstorm that dropped 40 mm of rain in 30 min on 2-year old apricot orchards. Pictures C and D show chipped branches spread over the soil between the trees in mature apricot orchards in winter.

markets making Spain and France the largest exporters of apricots in the world (Siddiq et al., 2012). The Spanish production of apricots is centred in the provinces of Murcia and Valencia. The orchards are modern plantations managed to produce apricots of high quality for the international market. Most of the apricot production is based on farms that keep the soil bare using intense tillage and herbicides, and that use pesticides to control the plagues (Fig. 1). Some farmers manage their orchards without herbicides (organic farming) and tillage, allowing vegetative cover that is sown three times per year to cover the soil between trees, although this is very rare (1% of the apricot production) because most farmers believe apricots cannot be produced without the use of chemicals (source: RECARE project stakeholders participation: http://www.recare-project.eu/, personal interviews with the farmers).

This paper aims to assess water and soil losses in apricot orchards under the three main management strategies used in La Vall d'Albaida: tillage, no-tillage with herbicides, and no-tillage with sowing of vegetative cover and chipped branches. We assessed the main factors that determine soil losses and runoff: vegetation cover, organic matter, soil moisture and bulk density.

2. Materials and methods

2.1. Study site

The experimental area was selected in the northern Albaida river basin, south of Valencia province in Eastern Spain, in the municipality of Aielo de Malferit (38°52 N, 0°35'W) where apricot production under rainfed conditions is traditional. Parent materials in the area's apricot fields are Cretaceous limestone and Tertiary deposits of marls. The soils are typical for this area, a Typic Xerorthent (Soil survey Staff, 2010; Cerdà and Doerr, 2007), with a soil organic matter (SOM) content of about 1%, basic (pH 8) and with a loamy texture, developed on Miocene Marls. The climate is Mediterranean with 3–5 months of summer drought, with mean annual rainfall at the study site of 620 mm. On average there are 48 days of rain per year. Rainfall shows a maximum peak of rain intensity and volume during the autumn. The mean annual temperature is 13.9 °C while the hottest month (August) has an average temperature of 24 °C. The field sites were selected close to each other, to assure that all differences measured are only the result of the management treatments and not because of differences in slope, aspect or parent material. The selected fields were neighbouring fields on the same hillslope with the same slope and in the same physiographic characteristics. Fig. 1 shows an overview of the landscape and the orchards.

2.2. Field experiments and laboratory analyses

A 30-year old apricot orchard was selected to measure soil losses on no-till bare management (herbicide treatments, called “herbicide”), on tilled fields (tillage treatment, called “tillage”), and on fields where the soil was covered by vegetation (sowing treatment, called “covered”). In the herbicides plots, herbicides were applied every time the farmer saw some seedlings, all vegetative cover was prevented, and pruning residuals were burnt after removal from the field. The tillage plots were tilled three or four times per year depending on the amount of rain and weed cover, and the pruning residuals were removed from the field and burned. Tillage has an average depth of 20 cm. The tilled and herbicide plots had both been under these treatments for 30 years. The covered fields were characterised by vegetative cover and chipped pruning residuals and had been so managed for 20 years. Over that time the covered field have regenerated to a state in which the average vegetative cover in the covered field are 87% during the winter and 56% in summer due to the Mediterranean drought and passes of machinery. In these fields representative plots were selected to perform rainfall simulations between the tree lines (10 m between the lines of trees) of the apricots at 5 m distance from earch other. In each line of apricot trees four plots were selected. In total this covered a surface of 1000 m^2 in each management type. In total sixty rainfall simulation experiments were carried out at 55 mm h^{-1} rainfall intensity for one hour on circular paired plots of 0.25 m^2. The intensity chosen for this experiment represents a high intensity, low frequency storm as occurs in the Mediterranean climate prevailing in this area with a return period of 10 years (Castillo and Beltran, 1977; Pereira et al., 2015). The experimental trial took place in July 2013, when soil moisture was the lowest of the year. In the tillage plots the ploughing was done one week prior to the experiments, and as no rainfall occurred prior to the measurements, no crusts had formed. In the covered plots, the sites with representative

Table 1
Vegetation cover (%), soil moisture (%) at 0–1 cm depth. Soil organic matter content at 0–1 cm depth. And bulk density at 0–5 cm depth for 60 samples collected at the Herbicide, Tillage and Covered plots in the Vall d'Albaida research sites on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Vegetation (%)			Soil moisture (%)			Organic Matter (%)			Bulk density (g cm^{-3})		
n = 60	Herbicide	Tillage	Covered	Herbicides	Tillage	Covered	Herbicides	Tillage	Covered	Herbicides	Tillage	Covered
1	3	0	49	3.25	2.65	3.48	0.98	0.98	1.50	1.32	1.23	1.10
2	2	0	21	2.26	2.48	6.25	1.02	0.97	0.98	1.45	1.26	1.21
3	1	0	75	2.45	3.47	3.48	0.98	0.98	2.32	1.23	1.24	1.03
4	3	1	37	2.69	3.52	4.65	0.89	1.02	1.23	1.65	1.19	1.08
5	2	0	56	3.54	3.14	5.96	1.03	1.32	1.06	1.25	1.35	1.15
6	5	1	45	3.42	3.68	5.78	1.06	1.59	1.45	1.42	1.26	1.12
7	2	0	33	3.61	3.57	5.02	1.25	1.23	1.33	1.32	1.24	1.18
8	0	2	15	2.98	3.42	5.15	1.24	1.25	1.20	1.65	1.35	1.35
9	2	1	69	2.78	3.56	2.35	1.32	1.00	2.01	1.32	1.38	1.10
10	6	0	33	5.10	3.02	4.35	1.21	1.02	1.80	1.41	1.24	1.06
11	5	0	28	2.78	3.14	5.65	1.06	1.36	1.06	1.52	1.21	1.15
12	0	1	78	3.64	3.26	3.25	1.04	1.02	3.02	1.48	1.23	1.02
13	3	2	62	3.25	3.75	4.85	0.98	1.02	1.68	1.47	1.38	1.03
14	1	2	45	4.26	3.68	5.24	0.97	0.89	1.55	1.64	1.25	1.24
15	2	1	97	5.15	3.95	3.65	0.96	0.87	2.78	1.54	1.24	0.99
16	0	0	84	2.35	4.65	3.47	0.98	0.89	2.64	1.61	1.26	0.98
17	2	4	81	3.87	5.86	1.69	0.87	0.96	2.06	1.36	1.27	1.02
18	5	2	54	4.02	3.25	5.98	0.89	0.98	1.75	1.44	1.29	1.09
19	0	0	61	4.65	2.45	3.54	0.98	0.95	1.56	1.33	1.33	1.06
20	2	1	65	4.01	2.96	4.98	1.03	0.96	2.03	1.60	1.24	1.10
Average	2.30b	0.90b	54.40a	3.50b	3.47b	4.44a	1.04b	1.06b	1.75a	1.45a	1.27b	1.10c
Max	6	4	97	5.15	5.86	6.25	1.32	1.59	3.02	1.65	1.38	1.35
Min	0	0	15	2.26	2.45	1.69	0.87	0.87	0.98	1.23	1.19	0.98
Std	1.81	1.07	22.48	0.86	0.76	1.27	0.12	0.19	0.59	0.13	0.06	0.09

plant and litter cover were chosen. These measurements were representative of interill or pedon scale soil erosion processes and inform on the detachment of material under different agricultural management practices. Detailed information on the characteristics of the rainfall in the region and the rainfall simulator can be found in Cerdà (1997) and Cerdà and Jurgensen (2011). Overland flow from the plot area was measured at 1-min intervals and every five minutes a one-minute runoff sample was collected for laboratory analysis in order to determine sediment concentration and calculate the erosion rates. The runoff rates and sediment concentration measurements were used to calculate the sediment yield, total runoff, runoff coefficient (percentage of discharged rainfall), and erosion rates. Vegetative cover was determined with 100 pins measurement in each 0.25 m^2 plot, and soil moisture was measured by drying 100 cm^3 ring samples, collected from the surface to 5 cm of depth before the rainfall experiments, at a temperature of 105 °C for 24 h. Sediment concentration in the runoff was calculated after the desiccation of the samples in the laboratory. Soil bulk density was measure by means of the ring method (Cerdà, 1999) and soil organic matter after Walkley and Black (1934). The experiments were carried out during the Mediterranean summer drought. There was no rain in the 32 days prior to the experiments.

2.3. Statistical analysis

Prior to statistical comparisons, data normality was tested using the Shapiro–Wilk test. Data normality was considered at a $p < 0.05$. Among all the variables, only bulk density (BD) followed the Gaussian distribution. Soil moisture (SM) followed normality after a logarithmic transformation. The other variables (vegetation cover, soil organic matter, runoff coefficient, sediment concentration, total runoff, sediment yield and soil erosion) in the study did not follow normality, even after square-root and Box–Cox transformation. Thus, a one-way ANOVA was used to identify significant differences among plots in BD and SM (using logarithm transformed data). If significant differences were found the Tukey HSD post-hoc test was applied. The non-parametric Kruskal–Wallis ANOVA test (KW) was used to identify differences among plots for variables that did not follow normality after transformations. If significant differences were found, non-parametric multiple comparisons were applied to identify differences within management practices. In all cases, significant differences were considered at $p < 0.05$. A Principal Component Analysis (PCA) was carried out (using the square root transformed data, since the data distributions were closest to normality), based on the correlation matrix, in order to identify correlations among the variables. Statistical analyses were carried out using Statistica 10.0 for windows.

3. Results

3.1. Vegetative cover and soil properties

Significant differences in vegetative cover were identified between the different plots ($KW = 43.31$, $p < 0.001$). Vegetative cover was significantly higher in covered plots (54.4%) than in the tilled (0.90%) and herbicide treated plots (2.3%) (Table 1). The covered plots showed vegetation cover that ranged from 15 to 97% as some areas were bare. The herbicide and tillage plots showed almost completely bare soils, as the maximum vegetation cover recorded was 6 and 4% respectively (Table 1).

Significant differences among treatments were also identified in soil moisture ($F = 4.41$, $p < 0.05$). Soil moisture was significantly higher in the covered plots (4.44%) than in the tillage (3.47%) and herbicide plots (3.50%) (Table 1). In the 0–1 cm depth layer, soil moisture was very low (<7% in all plots) and homogenous for all management strategies. The herbicide plots ranged between 2.26 and 5.15%, the tillage plots between 2.45 and 5.86% and the covered plots between 1.69 and 6.25% (Table 1).

Soil organic matter showed significant differences between plots ($KW = 27.49$, $p < 0.001$). On average, the SOM content was significantly higher in the covered (1.75%) plots than in the tilled (1.06%) and herbicide treated plots (1.04%) (Table 1). The variability in measurements was very similar between the herbicide treated plots and the tillage plots (std of 0.12 and 0.19). However, the highest variability was identified in the covered plots (std = 0.59).

Significant differences were observed in soil BD between plots ($F = 61.40$, $p < 0.001$). It was the highest in herbicide treated plots (1.45 g cm^{-3}) and the lowest in the covered plots (1.10 g cm^{-3}) (Table 1). Soil BD values ranged from 1.23 to 1.65 g cm^{-3} in the herbicide treated plots, from 1.19 to 1.38 g cm^{-3} in the tillage plots, and from 0.98 to 1.35 g cm^{-3} in the covered plots.

When the soil characteristics are compared with the vegetation cover in the plots (Fig. 2), it is clear that the different treatments form groups when plotted. In the vegetated plots the BD becomes lower when the vegetation cover is higher (Fig. 2A). In the herbicide and tilled plots there is no or very little vegetation, but in the tilled plots the BD is lower than in the herbicide plots (Fig. 2A). Similar relations can be observed when the SOM content is compared to the vegetation cover (Fig. 2B), although here the difference between tilled and herbicide treated plots in not clear. When the relation between BD and OM is plotted (Fig. 2C) we can observe three groups: the covered plots with low

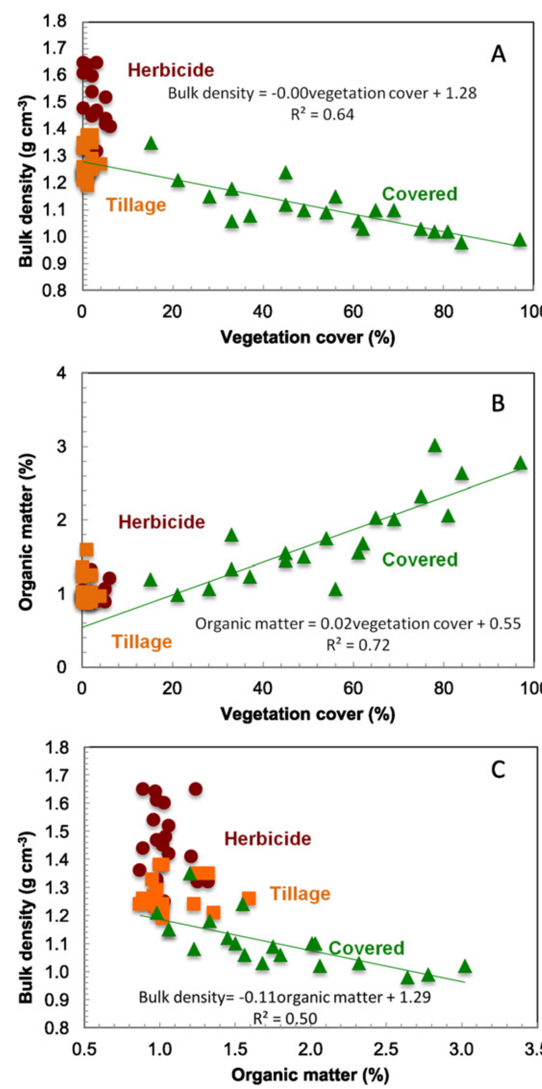

Fig. 2. Relationship between vegetative cover and soil bulk density (A) and organic matter (B) and Bulk density and organic matter (C) in apricot orchards at the Vall d'Albaida research site, Eastern Spain.

Table 2
Runoff coefficient (%), Sediment concentration ($g\ l^{-1}$) and Total runoff (l) for the 60 plots researched at the three experimental site on Herbicide (n = 20), Tillage (n = 20), and Covered plots (n = 20) in the Vall d'Albaida research sites on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Runoff coefficient (%)			Sediment concentration ($g\ l^{-1}$)			Total runoff (l)		
n = 60	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered
1	49.52	5.32	2.32	5.32	18.54	1.20	6.81	0.73	0.32
2	45.25	6.30	5.32	5.32	16.32	2.01	6.22	0.87	0.73
3	23.32	4.58	1.02	4.25	14.25	0.98	3.21	0.63	0.14
4	45.60	5.69	1.36	5.36	13.36	1.35	6.27	0.78	0.19
5	48.25	7.58	2.32	3.65	14.25	1.26	6.63	1.04	0.32
6	46.50	10.20	2.98	2.15	13.25	1.32	6.39	1.40	0.41
7	48.20	10.36	4.35	5.32	16.32	3.00	6.63	1.42	0.60
8	47.50	9.36	6.32	4.25	16.32	2.50	6.53	1.29	0.87
9	56.32	8.54	1.25	3.25	16.32	1.30	7.74	1.17	0.17
10	45.14	7.36	2.32	5.36	10.25	1.65	6.21	1.01	0.32
11	26.98	9.54	4.25	4.25	14.25	2.54	3.71	1.31	0.58
12	45.32	8.65	0.36	9.32	19.32	1.36	6.23	1.19	0.05
13	23.25	4.58	1.58	5.98	12.25	1.24	3.20	0.63	0.22
14	47.25	2.36	3.65	3.26	12.36	2.01	6.50	0.32	0.50
15	48.32	3.65	0.25	4.25	14.25	0.81	6.64	0.50	0.03
16	26.32	4.58	0.35	6.32	10.32	0.98	3.62	0.63	0.05
17	26.98	2.36	0.68	2.15	16.25	1.30	3.71	0.32	0.09
18	42.50	9.85	4.25	1.32	9.35	1.34	5.84	1.35	0.58
19	33.33	10.25	1.98	4.25	9.89	0.89	4.58	1.41	0.27
20	32.69	14.25	3.45	5.65	5.65	1.25	4.49	1.96	0.47
Average	40.43a	7.27b	2.52c	4.55b	13.65a	1.51c	5.56a	1.00b	0.35c
Max	56.32	14.25	6.32	9.32	19.32	3.00	7.74	1.96	0.87
Min	23.25	2.36	0.25	1.32	5.65	0.81	3.20	0.32	0.03
Std	10.29	3.13	1.75	1.76	3.37	0.59	1.41	0.43	0.24

BD and high OM; the herbicide plots with high BD and low OM; and the tilled plots with low BD and low OM.

3.2. Soil losses and runoff

Table 2 shows the average runoff coefficient (%), sediment concentration ($g\ l^{-1}$) and total runoff (l) for each type of plot. Significant differences were observed in runoff coefficient between each of the plots (KW = 48.72, $p < 0.001$). On average, the runoff coefficient was significantly higher on the herbicide treated plots (40.43%) than for the tillage plots (7.27%) and the covered plots (2.52%). The values ranged from 23.25 to 56.32% in the herbicide plots, from 2.36 to 14.25% in the tillage plots and from 0.25 to 6.32% in the covered plots.

The sediment concentration showed different behaviour. Significant differences were identified in sediment concentration among all the studied management strategies (KW = 50.10, $p < 0.001$). It was the highest in the tillage plots (13.65 $g\ l^{-1}$), followed by the herbicide plots (4.55 $g\ l^{-1}$), and was the lowest in the covered plots (1.51 $g\ l^{-1}$). The values ranged from 1.32 $g\ l^{-1}$ to 9.32 $g\ l^{-1}$ in the herbicide treated plots, from 5.65 $g\ l^{-1}$ to 19.32 $g\ l^{-1}$ in the tillage plots and from 0.81 $g\ l^{-1}$ to 3.00 $g\ l^{-1}$ in the covered plots. The variability in the

Table 3
Sediment yield (g), Soil erosion ($g\ ha^{-1}\ h^{-1}$), and Soil erosion ($Mg\ ha^{-1}\ h^{-1}$) for the 60 plots researched at the three experimental sites on Herbicide (n = 20), Tillage (n = 20), and Covered (n = 20) plots in the Vall d'Albaida research site on apricot production. Different letters represent significant differences at a $p < 0.05$.

Plots	Sediment yield (g)			Soil erosion ($g\ m^{-2}\ h^{-1}$)			Soil erosion ($Mg\ ha^{-1}\ h^{-1}$)		
n = 60	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered	Herbicide	Tillage	Covered
1	8.99	8.96	0.40	35.95	35.84	1.58	0.36	0.36	0.02
2	26.44	10.71	1.47	105.77	42.83	5.88	1.06	0.43	0.06
3	11.70	8.97	0.11	46.81	35.90	0.45	0.47	0.36	0.00
4	13.48	12.77	0.47	53.92	51.07	1.87	0.54	0.51	0.02
5	35.29	17.01	0.41	141.18	68.04	1.66	1.41	0.68	0.02
6	13.75	14.38	0.68	54.99	57.50	2.70	0.55	0.58	0.03
7	8.75	19.03	0.81	34.99	76.13	3.23	0.35	0.76	0.03
8	27.76	18.34	1.09	111.03	73.36	4.38	1.11	0.73	0.04
9	25.17	15.56	0.23	100.67	62.24	0.91	1.01	0.62	0.01
10	33.02	16.52	0.96	132.08	66.06	3.83	1.32	0.66	0.04
11	19.74	18.69	1.48	78.94	74.77	5.94	0.79	0.75	0.06
12	26.48	22.98	0.07	105.94	91.91	0.27	1.06	0.92	0.00
13	17.14	11.68	0.26	68.54	46.70	1.04	0.69	0.47	0.01
14	21.18	5.30	1.01	84.72	21.18	4.04	0.85	0.21	0.04
15	28.24	7.15	0.03	112.95	28.61	0.13	1.13	0.29	0.00
16	22.87	6.50	0.05	91.49	26.00	0.19	0.91	0.26	0.00
17	19.88	5.27	0.12	79.54	21.09	0.49	0.80	0.21	0.00
18	24.84	12.66	0.78	99.34	50.65	3.13	0.99	0.51	0.03
19	42.71	13.94	0.24	170.85	55.75	0.97	1.71	0.56	0.01
20	25.40	11.07	0.59	101.58	44.28	2.37	1.02	0.44	0.02
Average	22.64a	12.87b	0.56c	90.56a	51.50b	2.25c	0.91a	0.51b	0.02c
Max	42.71	22.98	1.48	170.85	91.91	5.94	1.71	0.92	0.06
Min	8.75	5.27	0.03	34.99	21.09	0.13	0.35	0.21	0.00
Std	8.85	4.99	0.46	35.38	19.96	1.83	0.35	0.20	0.02

measurements was the highest in the tillage plots and lowest in the covered plots (Table 2).

The average total runoff was significantly different among plots (KW = 48.72, p < 0.001). The highest runoff was identified in the herbicide treated plots (5.56 l) and the lowest in the covered plots (0.35 l) with intermediate values in the tillage plots (1.00 l). Total runoff values ranged from 3.20 to 7.74 l in the herbicide treated plots, 0.32 to 1.96 l in the tillage plots, and 0.03 to 0.87 in the covered plots. The variability in the measurements was the highest in the herbicide treated plots, the lowest in the covered plots, and intermediate in the tillage plots (Table 2).

Significant differences were observed in sediment yield between plots (KW = 45.14, p < 0.001). On average, sediment yield was significantly higher in herbicide treated plots (22.64 g) than tillage (12.87 g) and covered plots (0.56 g). Covered plots sediment yield was also significantly lower than in the tillage plots. Sediment yield values ranged from 8.75 to 42.71 g in herbicide treated plots, from 5.27 to 22.98 g in tillage plots, and 0.03 to 1.48 g in covered plots. The sample variability was the highest in herbicide treated plots and lowest in covered plots (Table 3).

Soil erosion as calculated in g m^{-2} h^{-1} and Mg ha^{-1} h^{-1} (Table 3) were significantly different between plots (KW = 45.14, p < 0.001, g m^{-2} h^{-1}). In both unit measurements, the highest values were identified in the herbicide treated plots (90.56 g m^{-2} h^{-1} and 0.91 Mg ha^{-1} h^{-1}) and the lowest in the covered plots (2.25 g m^{-2} h^{-1} and 0.02 Mg ha^{-1} h^{-1}), with tillage plots having intermediate values (51.50 g m^{-2} h^{-1} and 0.51 Mg ha^{-1} h^{-1}). The values ranged from 34.99 to 170.85 g m^{-2} h^{-1} and 0.35 to 1.71 Mg ha^{-1} h^{-1} in the herbicide treated plots, from 21.09 to 91.91 g m^{-2} h^{-1} and 0.21 to 0.92 Mg ha^{-1} in the tillage plots and from 0.13 to 5.94 g m^{-2} h^{-1} and from 0.00 to 0.06 Mg ha^{-1} h^{-1} in the covered plots. The variability in the measurements was the highest in the herbicide treated plots and the lowest in the covered plots (Table 3).

When the data was combined (Fig. 3) we observed that in the vegetated plots the runoff was very low regardless of the vegetation cover and the OM (Fig. 3A and B). In the tilled plots the runoff was also low, however there was more scatter. Because there was no vegetative cover, there was also no relation between the two parameters (Fig. 3A); however OM causes some scatter in the data (Fig. 3B). In the herbicide plots the runoff seemed to be scattered regardless of the OM and vegetation cover (Fig. 3A and B). In Fig. 3C where the runoff coefficient was plotted against the sediment concentration three groups can be clearly identified; the covered plots had low sediment concentration and a low runoff coefficient; the tilled plot showed low runoff coefficients but high sediment concentrations; and the herbicide treated plots showed a low sediment concentration but very high runoff coefficient.

3.3. Multivariate analysis

The first two factors explained a total of 81.85% of the total variance. The multivariate analysis identified 3 main groups, the first composed of vegetation cover, soil moisture and SOM, the second of bulk density, total runoff, runoff coefficient, sediment yield and soil erosion, and the third of sediment concentration (Fig. 4). These results show that the variables in the first group were negatively correlated with the variables in group 2. The variable in group 3 (sediment content) also had a negative correlation with the variables of group 1 and had a low positive correlation with the variables of group 2. Fig. 5 shows that the variables studied strongly depended on the type of management. The soil properties and runoff are more similar in the herbicide treated and tilled plots than in the covered areas.

The total sediment generated averaged 22.64 g per plot in the herbicide treatment, while the tillage treatment was 12.87 g and the covered plots 0.56 g. The plots under herbicide treatment ranged from 8.75 to 42.71 g, tillage from 5.27 to 22.98 g, and covered from 0.03 to

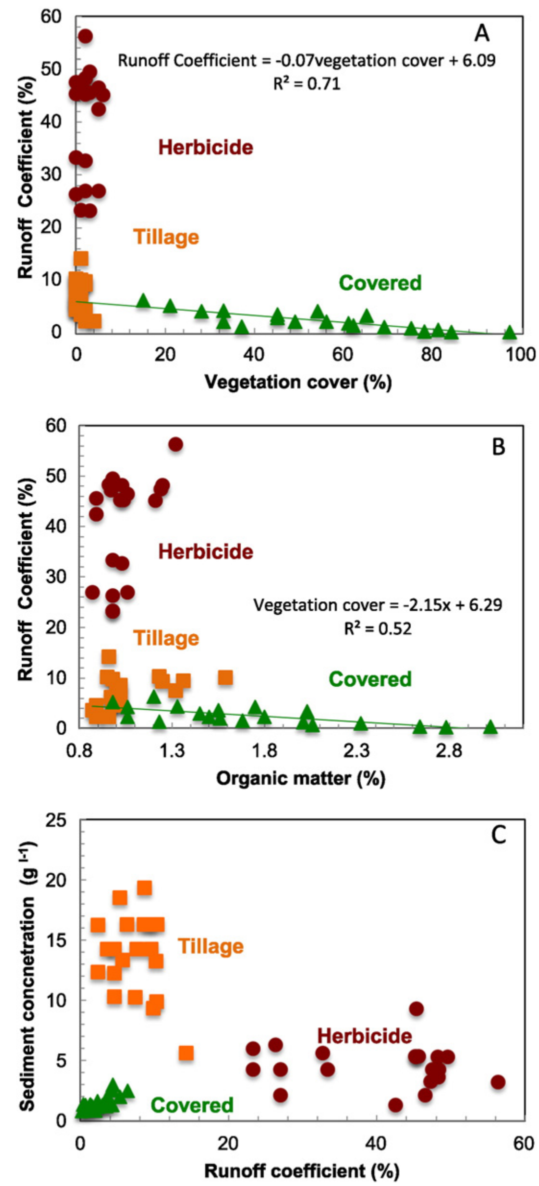

Fig. 3. Relationship between the organic matter (A) and vegetation cover (B) with the runoff coefficient, and the runoff coefficient with the sediment concentration (C).

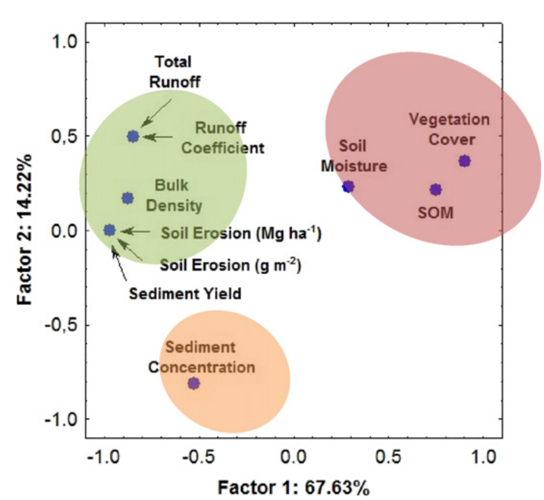

Fig. 4. Relation between factor 1 and factor 2 variables. Different colours show the groups identified.

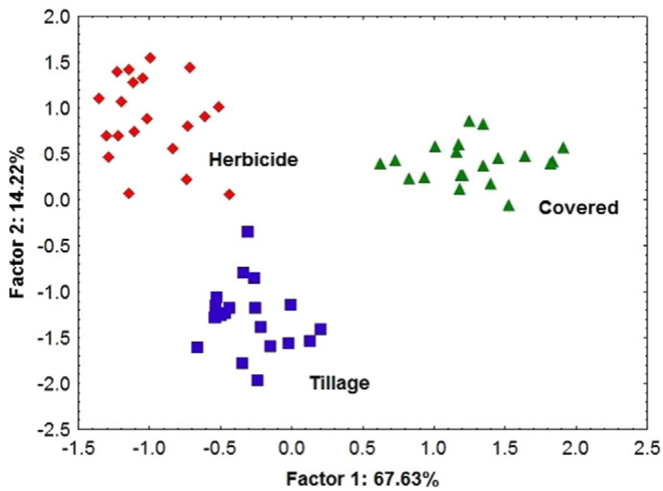

Fig. 5. Relationships between factor 1 and factor 2 cases. Different colours show the groups identified.

1.48 g. Soil erosion showed a similar pattern: covered plots lost 2.25 g m^{-2} h^{-1}/0.02 Mg ha^{-1} h^{-1}, meanwhile the tillage plots lost 51.50 g m^{-2} h^{-1}/0.51 Mg ha^{-1} h^{-1} and the herbicide plots 90.56 g m^{-2} h^{-1}/0.91 Mg ha^{-1} h^{-1}.

4. Discussion

Rainfed agriculture in the Mediterranean belt produces fruits for international markets in orchards that often have extensive areas of bare soils due to intense tillage or the massive use of herbicides. Soil and water conservation strategies are rarely applied. Sustainable land management strategies are very infrequent and there is a need to research which management strategies are sustainable. Soil erosion is one of the consequences of the bare soils, and soil erosion contributes to soil degradation, but also results in damages due to floods and the sedimentation of lakes, reservoirs and rivers, and the loss of soil fertility and farmers' income (de Graaff et al., 2010; Adimassu et al., 2012; Yuan et al., 2015). This study demonstrates that the use of herbicides (leading to bare soils the whole year round) and the conventional tillage system applied in Spain on rainfed orchards (three to four tillage events yearly) results in negligible vegetative cover, high soil bulk density, and extremely high runoff sediment concentrations that result in high erosion rates. The measurements carried out here simulated high magnitude low frequency rainfall events and showed that apricot orchards can lose as much as 0.5 Mg ha^{-1} of soil in one hour, when measured at the plot scale, which make these land management practices unsustainable. Tillage has been seen as a major cause of soil erosion since agriculture was developed (Brevik and Hartemink, 2010), both in terms of water erosion (Novara et al., 2011; Casalí et al., 2015) as well as wind erosion (Gao et al., 2015). Tillage is also seen as a key factor for agricultural production (Singh et al., 2014) as it modifies soil properties such as organic carbon (Hassan et al., 2014; Parras-Alcántara and Lozano-García, 2014;), the habitat for biota (Balota et al., 2014; Costantini et al., 2015) and chemical properties (Laudicina et al., 2015; Zornoza et al., 2015). Tillage is usually seen as the primary cause of soil erosion in rainfed agriculture (Lieskovský and Kenderessy, 2014), and the cause of the acceleration of sediment fluxes on all the continents (Dupin et al., 2009; Van Oost et al., 2009; Zhang et al., 2009).

In the Vall d'Albaida research area tillage caused high erosion rates. Over the last two decades tillage management for weed control has been replaced by herbicides at many orchards. Although herbicides were recommended to be used only during the spring, many farmers use high doses of herbicides throughout the growing season to avoid any weeds and keep the orchards “clean”. This is likely culturally inherited, as under tillage the soil is bare the whole year round and farmers now use herbicides with this same goal. This is why the soil surfaces in the orchards managed with herbicides are almost bare and soil erosion rates are twice as high as the rates measured in the tilled orchards, as herbicides also contribute to compaction of the surface layer of the soil due to wheel traffic during application (Bayhan et al., 2002). The misuse and abuse of herbicides has been observed in other orchards, such as olive (Gómez et al., 2004; Gómez et al., 2009) and citrus (Cerdà et al., 2009a, 2009b). In a study by Francia Martínez et al. (2006) in an olive orchard, soil loss at the hillslope scale (24 m long plots) under natural condition rainfall was studied for sites under tillage, herbicides and a combination with vegetation and herbicides. This experiment showed the same trend in sustainability as found in the current study. Also a study under natural rainfall in a vineyard showed no-tilled herbicide treated hillslopes experienced more soil loss than a tilled hillslope (Raclot et al., 2009). These results are contrary to the findings of pioneering researchers who found that a sustainable use of herbicides reduced soil losses and runoff in comparison to tillage (Locke and Bryson, 1997; Shipitalo and Edwards, 1998; Sanchez et al., 2002). This study was done on a plot scale, which is representative for the interrill erosion and sheet erosion component of the sediment yield of a total field, hillslope or even catchment. This information cannot be unscaled by simply multiplying the numbers found; however, it gives good insights and quantifies changes in water and sediment dynamics at the small scale due to differences in soil properties resulting from the management treatments studied. The insights generated for the plot scale show the differences in soil properties that develop due to the management strategies employed. The impact of the soil and surface properties that influence the processes of infiltration and soil detachment can be best studied in detail at the plot scale as no other factors can disturb the measurements.

Fig. 2 shows the importance of vegetative cover in the recovery of organic matter in the soils. Herbicides and tillage do not allow vegetation to grow which causes an extremely low organic matter content of approximately 1%. However, when vegetative growth was re-established for a period of 20 years the organic matter in the top soil (0–1 cm of depth) increased significantly (1.75%). The correlation between vegetative cover (in the covered plots) and soil organic matter shown in Fig. 2a demonstrates their positive relationship. This increase in organic matter results in a decrease in bulk density, which is due to the fact that organic matter has a low particle density as well as the effect of roots, insects and burrowing animals drawn by the vegetative food source creating macropores and aggregate formation. More vegetation means more organic matter and more organic matter results in a lower bulk density (Fig. 2c) (Brevik and Fenton, 2012; Srinivasarao et al., 2014; Parras-Alcántara et al., 2015).

When looking at the whole hillslope other processes such as rill and gully erosion (Poesen et al., 2003) and the impact of roads and man-made structures (Parsons et al., 2006) enter the picture. These features can increase total erosion and facilitate sediment transport downstream; however, large volumes of water and sediment can also be retained in (temporal) storage sites along the hillslope (Baartman et al., 2013). The connectivity issue is of great importance to understand the impact of the land management on the detachment of soil particles that is studied here, but also the transport and sedimentation. There is a need to understand how the land management affect the connectivity of water, sediments, nutrients and seeds along the fields, trams of slopes, slopes, watershed and basin (Marchamalo et al., 2015; Parsons et al., 2015).

This research demonstrates that tillage results in non-sustainable management in Mediterranean orchards from the point of view of soil and water conservation. However, the misuse of herbicides produces even higher soil erosion rates, and the sustainability is not improved. The erosion rates in this study was twice as high in the plots treated with herbicides than in the tilled plots (Fig. 3). Moreover, runoff was 5.6 times higher in the herbicide treated than in the tilled orchards. The use of vegetative cover and chipped pruning residuals was the best management practice studied to reduce soil losses and runoff. The experiments carried out in the Vall d'Albaida traditional apricot production region demonstrated that soil losses from the covered soils (0.02 Mg ha^{-1} h^{-1}) were lower than the herbicide plots (0.9 Mg ha^{-1} h^{-1}) and tillage plots (0.5 Mg ha^{-1} h^{-1}). This has been recently found in other experiments in the same region with the use of straw mulch as a cover (Cerdà et al., 2015; Prosdocimi et al., 2016).

The literature shows that vegetation can control soil erosion (Beadle, 1948; Ola et al., 2015), in other regions and on forest and agriculture soils (Borrelli et al., 2015; Nanko et al., 2015; Ochoa-Cueva et al., 2015). The reason for the decrease in soil erosion rates as a consequence of vegetation recovery is because the vegetation reduces or avoids the rainfall erosivity (Cerdà, 1998; Keesstra, 2007; Ni et al., 2015; Taguas et al., 2015), improves soil properties and reduces runoff and soil losses. Keesstra et al. (2009) found that vegetation recovery reduced sediment losses in Slovenia. Similar findings were reported by Palacio et al. (2014) at pachy-pedon scales in Patagonia. Land use and land cover changes are the reason for the changes this study found in runoff and soil erosion, as Gessesse et al. (2014) found in Ethiopia and Cao et al. (2015) found in China as a consequence of the conservation programmes of their governments. Cerdà (2000) reported similar findings when measuring aggregate stability in Bolivia under different land uses and management. Over long time scales vegetative cover not only shields the soil surface from the force of rain, it improves the quality of soil and thus reduces soil erosion as infiltration increases and surface runoff is reduced (Brevik, 2009).

At the research sites in Vall d'Albaida, tillage was the only management strategy used by farmers until the 1990's when the use of herbicides was introduced and runoff and soil losses increased. The influence of the demand for organic products and the change in management adopted by some pioneering farmers led to vegetative cover between the trees in some orchards and to chipping after pruning and spreading the chips on the soil's surface, rather than burning them. This allowed the soils to recover, increasing soil organic matter and reducing soil bulk density. The vegetative cover is not only reducing soil erosion due to the direct effects of the cover, it is also a long-term soil changes. Vegetation and the associated ecosystem including biota create a higher soil quality with more macro-pores, better soil structure and higher soil fertility (Reicosky and Forcella, 1998). The effectiveness of the vegetative cover management was confirmed with the PCA. The variables of group 1 (vegetative cover, soil moisture and SOM) showed high values in covered plots, while the variables of group 2 (bulk density, total runoff, runoff coefficient, sediment yield and soil erosion) and 3 (sediment concentration) were low. In the other management types, the values of group 1 were low and from groups 2 and 3 were high. Overall, group 1 showed high values in covered management, group 2 in herbicide treatments, and group 3 in tillage plots. The PCA identified that the variables studied were importantly different according to the type of management. From a soil erosion and water conservation perspective, the management types studied can be classified as covered > tillage > herbicide.

In addition, the changes in soil erosional and hydrological response introduced by the soil cover from vegetative growth and the use of mulch (litter) plus the chipped pruning residuals, which is a regular practice in farms with covered fields, is clearly shown by the results of this study: a reduction in surface runoff and sediment concentration. Fig. 3a and 3b show the relationships between soil organic matter and vegetation cover and soil runoff coefficient, showing that as soil organic matter or vegetative cover increase, the runoff coefficient decreases.

Fig. 3c shows that there is a clear correlation between land management and the erosional and hydrological response of soils under rainfed apricot production. There are three clear responses to the rainfall: the vegetation covered soils had low runoff and sediment concentration and as a consequence low erosion rates. The soils under tillage had high sediment concentrations due to the high erodibility of tilled soils, but had lower runoff rates in comparison to the herbicide treatment. Finally, the soils with herbicide treatment showed very high runoff discharges due to their high bulk density (crusting) and the low organic matter content, but the runoff sediment concentration was not as high as under tillage. However, the total soil loss from the plots treated with herbicides was the highest of all studied management strategies due to the very high runoff discharge.

5. Conclusions

The soil and water losses in rainfed apricot orchards in Eastern Spain are not sustainable when traditionally tilled. The use of herbicides aggravates the situation, increasing the erosion rates to as much as two times the rates in traditionally tilled plots in one hour of intense rain. However, in orchards where the soil is covered with vegetation and chipped pruning residuals there is an increase in vegetative cover and soil quality. There, erosion rates are reduced by as much as an order of magnitude. Those findings show that from a soil erosion and water conservation perspective, the management types studied here can be classified as covered > tillage > herbicide. Following the practice of keeping the soil covered with vegetation would contribute to better land use management in apricot orchards in the Eastern Iberian Peninsula, and this is a general rule for the Mediterranean Type Ecosystems such as we found in the literature.

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