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Soil structural stability and erosion rates influenced by agricultural management practices in a semi-arid Mediterranean agro-ecosystem

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Abstract

Unsuitable agricultural practices can cause loss in soil quality and erodibility to thus increase or trigger desertification under Mediterranean conditions. A field experiment was performed at the El Teularet-Sierra de Enguera Experimental Station (eastern Spain) to assess the influence during a 5-yr period of different agricultural practices on physical and chemical indicators of soil quality (total and water-soluble carbohydrates, glomalin-related soil proteins (GRSP), total organic carbon, aggregate stability (AS), vegetation cover and soil erosion). The management practices included residual herbicide use, ploughing, ploughing + oats, addition of oat straw mulch and a control (land abandonment). Adjacent soil under natural vegetation was used as a reference for local, high-quality soil and as a control for comparison with the agricultural soils under different management practices. Oat straw mulching led to higher levels of water-soluble carbohydrates, GRSP and AS and lower soil erosion rates, resulting in values similar to those in the soil under native vegetation. The lowest levels of carbohydrates and GRSP were for the plots that were treated with herbicide or were ploughed. The maintenance of and increases in stable aggregates promoted by the different agricultural management practices over the years were attributed to increases in labile organic fractions such as carbohydrates and to the GRSP content. The results demonstrate that land abandonment (control plot) or the use of a cover (plants or straw) contributes to increases in soil quality and reduces the risk of erosion. The research also shows that sustainable agricultural management allows soil to recover and that the use of straw mulching is the most effective management strategy.

Keywords: Aggregate stability, sustainable agriculture management, carbohydrates, glomalin-related soil proteins, eastern Spain, soil erosion

Introduction

Agriculture has been practised in the semi-arid Mediterranean for ca. 10 000 yr. Ploughing, burning and grazing have resulted in soil erosion, compaction and organic matter depletion owing to unsuitable agricultural practices (Caravaca *et al*., 2002; Cerdà *et al*., 2010; García Ruiz, 2010). Land degradation has occurred on Mediterranean agricultural land for millennia (Lynrintzis & Papanastasis, 1995; Castro *et al*., 2000; Gómez Gutiérrez *et al*., 2010). Soil erosion is the most widely known land degradation process and is caused by post-fire surface wash and overgrazing. Soil erosion is especially intense in rain-fed orchards such as olive groves in Andalucia (Gómez *et al*., 2003), in newly irrigated citrus orchards (Cerdà *et al*., 2009) and in vineyards (Casalí *et al*., 2009). The erosion problem is well known for Mediterranean-type ecosystems and has been intensively researched (Cerdà *et al*., 2010). During the last decade, the research focus has been on the impact of agriculture to explain the intense degradation of Mediterranean soils (Cerdà *et al*., 2007) and on land abandonment (Seeger & Ries, 2010). The main conclusion from the last 30 yr of research on soil erosion and degradation in Mediterranean lands is that unsuitable land management is the problem; however, land management can also provide solutions if new methods are

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applied (Cerdà *et al.*, 2010). Staff at the Soil Erosion and Degradation Research Station in the rain-fed agricultural land of Massís del Caroig in eastern Spain have studied the soil degradation processes resulting from agriculture, and they collaborate with farmers and policy makers to find solutions to land degradation in olive groves, fruit and almond orchards and vineyards. Such collaboration can play a role in selecting the most sustainable management systems such as those proposed in this paper for agricultural land under Mediterranean conditions.

Desertification (land degradation in arid and semi-arid lands) is triggered by the loss of natural vegetation. Vegetation recovery in the Mediterranean is subject to severe climatic conditions, which are characterized by low and uneven precipitation and frequent droughts. These conditions have a damaging effect on soil quality and a negative effect on plant growth. Thus, degraded soils require strategies to reduce soil loss and to minimize the impact of degradation on soil quality. The use of catch crops, the implementation of no-tillage or reduced tillage systems, the addition of chipped pruned branches and the use of straw mulches are some of the land management techniques currently being applied on experimental farms to reduce the high erosion rates on rain-fed agricultural land in eastern Spain (García-Orenes *et al.*, 2009). The effects of these strategies contribute to the reduction of soil erosion (Garcia-Orenes *et al.*, 2010), but there is doubt as to whether the soil properties recover and how long this recovery process will last.

This paper reports the effects of applying on farms the most sustainable agriculture management practices under Mediterranean climatic conditions. Soil management practices affect not only the erosion processes but also soil properties. Over years or seasons, the stability of soil aggregates increases or decreases owing to climatic conditions, agricultural practices and the decomposition of fresh organic matter (Abiven *et al.*, 2009). Changes in soil aggregation in response to agricultural management practices require investigation because of the critical role that soil structure plays in infiltration and biological processes.

The stabilization of soil aggregates depends on a number of biological factors, including microbial extracellular polysaccharides, fungal hyphae, soil microbial biomass, plant roots, carbon and nitrogen inputs from fresh organic matter, aromatic humic substances (Lax & Garcia Orenes, 1993; Roldan *et al.*, 1994a,b; Amézketa, 1999) and glomalin-related soil proteins (GRSP) derived from arbuscular mycorrhizae (Benedi *et al.*, 2009; Spohn & Giani, 2010). In this study, it was hypothesized that agricultural management practices can modify soil aggregate stability through changes in soil biology, as expressed in water-soluble carbohydrates and GRSP, and that such structural changes correlate with changes in the factors involved in soil aggregation and soil erosion.

The objective of this study was to determine the effects on soil erosion rates, soil structural stability and aggregation under different management practices for semi-arid rain-fed orchards; the aim was to propose alternatives to traditional agriculture appropriate to semi-arid rain-fed orchards in eastern Spain. The broad objective was to establish the criteria for selecting more sustainable management systems for agricultural land under Mediterranean conditions. The paper reports changes in some key soil properties related to soil structure and soil erosion during a 5-yr period.

Materials and methods

Study area

The experiment was at the El Teularet Experimental Station (García-Orenes *et al.*, 2009; Garcia-Orenes *et al.*, 2010) in the Enguera Range (38°50′N; 0°42′W) in the southern part of the Province of Valencia (eastern Spain). The land has been rain-fed and cultivated for olives, almonds and wheat over the last century, and the soil has been ploughed intensively for centuries. The soil is a Typic Xerorthent (Soil Survey Staff, 2010), developed from Cretaceous marls. The climate is typically Mediterranean, with 3–5 months of summer drought, usually from June to September. The mean annual rainfall in the study area is 479 mm with an average annual temperature of 14.2 °C over the last 10 yr.

Experimental design and layout

An experimental paired-plot layout was established (a homogeneous terrace with a 5% slope and without vegetation) in the autumn of 2003, and the area was ploughed to create uniform surface soil conditions before the start of the experiment. Before the experiment began, the soil was sampled at different points across the terrace, and no significant differences were found in the soil properties before the different treatments were established. Ploughing over centuries has contributed to a reduction in the spatial variability of the soil properties as shown in Table 1. Different management treatments were initiated in February 2004, with three replicate plots per treatment (6×10 m^2) (Table 2), and the measurements and sampling were conducted from 2005 until 2009 (samples were taken in July from 2005 to 2009). An adjacent area with the same type of soil under natural vegetation was used as a standard for local, high-quality soil, and this area was used as a reference for natural cover. The different treatments were selected based on the practices most commonly used by farmers in the study area: ploughing and application of herbicides and organic farming methods using oat straw or tillage with oats. A control was selected using a plot with land that had been abandoned after farming, a common occurrence in recent decades in the agricultural areas of the Mediterranean.

Table 1 Analytical characteristics of the soil (0–5 cm depth) used in the experiment (n = 20), before the experiment

Texture (%)[a]	39, 38, 23
pH (extract 1:5, w/v)	8.3 ± 0.02
Electrical conductivity EC (1:5, μS/cm)	185 ± 4
$CaCO_3$ (%)	60 ± 3
Total organic carbon (g/kg)	12.5 ± 0.1
Soluble C (μg/g)	74 ± 1
Microbial carbon biomass (C_{mic}) (μg/g)	270 ± 2
Total N (g/kg)	0.78 ± 0.03
Available P (mg/kg)	2.00 ± 0
Extractable K (mg/kg)	303 ± 12
Basal respiration rate (μg CO_2/g/h)	5.7 ± 0.3

Mean ± Standard deviation. [a]Sand: 2–0.02 mm, Silt: 0.02–0.002 mm, Clay: < 0.002 mm.

Table 2 Description of the different soil agricultural management practices

Treatments	Description
Residual herbicide (RH; Oxyfluorfen)	3 applications/year (240 g/L); 1.5 kg/ha
Ploughing (P)	4 times/year; (ploughing depth 20 cm)
Oats + Ploughing (OP)	Ploughing: 4 times/year; (ploughing depth: 20 cm) Sown 100% oats (ground and added to soil in spring)
Control (C)	Abandoned field with natural plant recolonisation (*Brachypodium retusum* (Pers.) Beauv., *Cistus albidus* L., *etc.)*
Oats straw (OS)	Amount: 0.25 kg/m^2/yr, straw mulch weed chopped add on surface of the soil.
Natural cover (NC)	Adjacent non-cultivated area (*Quercus coccifera* L., *Pistacia lentiscus* L., *Juniperus oxycedrus L.* and *Brachypodium retusum* (Pers.) Beauv.*)*

Soil sampling and analyses

For 5 yr, soil samples were collected in July immediately after the rainy season when the soil properties were expected to be stable. Each sample consisted of six bulked sub-samples per replicate (100 cm^3 cores), randomly collected at 0–5 cm depth. Field-moist soil samples were sieved at 2 mm and stored at 2 °C for subsequent chemical analyses. Soil sample aliquots were sieved between 0.25 and 4 mm to determine aggregate stability.

The microbial biomass carbon (C_{mic}) was determined by the fumigation–extraction method (Vance *et al*., 1987). The basal soil respiration was measured using a multiple sensor respirometer (Micro-Oxymax, Columbus, OH, USA). Total carbohydrates (TCH) extracted with anthrone and water-soluble carbohydrates (SCH) extracted with water were determined using the method of Brink *et al*. (1960) and were measured spectrophotometrically at 630 nm. Glomalin-related soil protein was extracted from the soil samples sieved between 0.25 and 4 mm with 20 mM sodium citrate (pH 7.0) at a rate of 250 mg of aggregates in 2 mL of buffer and autoclaved at 121 °C for 30 min (Wright & Anderson, 2000). The supernatant was removed, and two additional sequential 1-h extractions were performed. All of the supernatants from a sample were combined, the volume was measured, an aliquot was centrifuged at 10 000 ***g*** for 15 min to remove soil particles, and the Bradford-reactive total protein was measured. Soil organic carbon was determined using the potassium dichromate oxidation method (Nelson & Sommers, 1982), and the organic matter (OM) values were calculated using the Wasksman coefficient (1.72). Aggregate stability (AS) was measured according to Roldan *et al*. (1994b), based on Benito *et al*. (1986). This method examines the proportion of aggregates that remain stable after a soil sample is subjected to an artificial rainfall of known energy (270 J/m^2).

Five rainfall simulation experiments were performed in the field, coinciding with every sampling date under dry conditions for each treatment to determine soil and water losses. In total, 150 experiments (5 experiments × 6 treatments × 5 yr) were conducted during the summer drought period when soil moisture was low (< 10%). Deionized water was applied from a height of 2 m onto a 1-m^2 sub-plot, and the run-off was collected from a bordered circular 0.25-m^2 area in the centre of the sub-plot. The rainfall simulation lasted 1 h at a rate of 55 mm/h, simulating the rainfall from a thunderstorm, which in the study areas would occur on average once every 5 yr. Overland flow from the circular collection area was measured at 1-min intervals. Every tenth 1-min run-off sample was collected for laboratory analysis to determine sediment concentration. The run-off rates and sediment concentration were used to calculate the sediment yield, total run-off, run-off coefficient, infiltration and erosion rates (Cerdà, 1999). Vegetation cover was measured in the field as the percentage of the soil covered by plants. Cerdà (1996) and Cerdà *et al*. (1997) give more detailed information on rainfall characteristics and the rainfall simulator.

The effects of the agricultural practices were tested using a one-way analysis of variance, and comparisons between the means were made using the least significant difference (LSD) test calculated at P < 0.05. The data were tested for normality using the Kolmogorov–Smirnov test. Pearson's correlation coefficients (r) were calculated to assess the relationships between the parameters. The statistical procedures were performed using SPSS 18.0 for Windows.

Results

The greatest soil organic matter content (4.5%) was in the uncultivated plot under natural vegetation (NC) (Figure 1), and no significant variations in this were found during the 5-yr period of the experiment. The plot contains a traditional maquis with 98% vegetation cover with dense *Quercus coccifera* L., *Pistacia lentiscus* L., *Juniperus oxycedrus* L. and grass (*Brachypodium retusum* (Pers.) Beauv.) and has been considered as a reference system, not as a treatment. For the experimental treatments, an increase in soil organic matter was determined after the addition of oat straw (OS), and the same values found in the NC plot were achieved 5 yr after the OS treatment was established. The remaining treatments (RH, P, OP, C) had similar organic carbon contents (ca. 2%), with no significant variations during the experimental period (Table 3). Figures 2 and 3 show the change in total (TCH) and soluble (SCH) carbohydrate, respectively. The greatest values for these parameters were detected in the natural cover plot at the start of the experiment; these were four times higher than in the other soil treatments. Some variation in the values of these parameters was observed for these plots during the experiment, but both were at a maximum by the end of the experimental period. The SCH and TCH levels increased in the soil with the oat straw application, with some annual variations, and reached almost the same value as the NC soil after 3 yrs. No significant variations in these parameters were found for the rest of the treatments throughout the study period, and the values were lower than those obtained for the reference soil (NC) and OS treatments. For GRSP, the greatest production was also found for the reference soil (NC) in the first sampling; again, the addition of oat straw to the soil boosted the production of this protein as can be observed in Figure 4. After 3 yr of treatment, the oat straw contributed to a GRSP content that was higher than that of the NC plot (Figure 4) at the end of the experiment.

The highest value of AS was under the NC and OP treatments (Figure 5), 1 yr after the start of the experiment. These values remained high during the 5-yr experiment. The other treatments did not show significant change in this parameter during the 5-yr research period, and the values for those treatments were constantly lower than for the NC plot. The oat straw application treatment and the natural cover soil had the highest percentage of vegetation cover (Figure 6). An important increase in the vegetation cover of the control treatment was observed, reaching 68% after 5 yr. The vegetation cover was negligible after the herbicide application and nonexistent on the ploughed treatment.

The herbicide application gave the highest erosion rates, followed by ploughing; no soil losses were found in the plots either with the addition of oat straw or with natural cover (Figure 7). Comparison of the results for 2005 and 2009 indicates the impact of the treatments on soil erosion. The herbicide treatment resulted in the largest soil losses (1.40 Mg/ha/h), while the tillage (0.75 Mg/ha/h), ploughing + oats (0.19 Mg/ha/h) and control plots (0.08 Mg/ha/h) have intermediate values. Five years later, the soil losses were similar; the largest values were for the herbicide treatment (0.97 Mg/ha/h), while the tillage (0.60 Mg/ha/h), tillage + oats (0.16 Mg/ha/h) and the control plot (0.01 Mg/ha/h) had slightly lower values than in 2005.

Discussion

Results from the agricultural soil illustrate contrasting responses to the rainfall and soil property changes as a result of the different treatments. The soil used as a reference had natural cover (NC), and the results indicate that this soil was of good quality as shown by the high OM content, aggregate stability and vegetation cover. These properties also indicate a lack of soil loss on the natural cover plots. No significant differences were found during the 5-yr study period. Similar results are reported from previous work at this study site by Garcia-Orenes *et al.* (2010) who showed that the microbial biomass carbon, soil basal respiration and enzymatic activities were stable and at high levels under the NC treatment. These data demonstrate that the NC plots can be

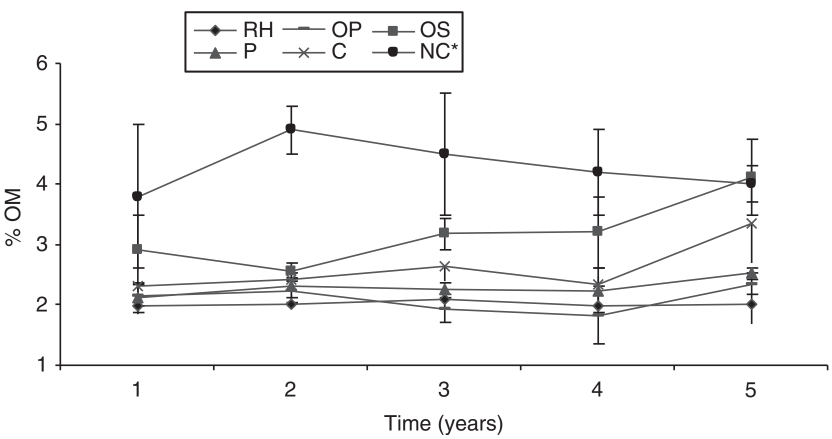

Figure 1 Change in the soil organic matter (OM) content in samples taken from the surface of the top soil layer (0–5 cm) during the 5 yrs of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

Table 3 Significant differences in the evolution of the parameters studied during the experiment for every treatment. Samplings were taken in July

	Year 1	Year 2	Year 3	Year 4	Year 5	*F*-value
OM						
RH	a	a	a	a	a	0.236
P	a	a	a	a	a	1.218
OP	a	a	a	a	a	1.912
C	a	a	a	a	a	4.079
OS	a	ab	ab	ab	b	4.245*
SCH						
RH	a	ab	a	bc	c	8047**
P	ab	ab	b	a	ab	2070*
OP	c	b	b	a	c	17370***
C	ab	ab	b	a	ab	4440*
OS	a	a	a	a	a	1322
AS						
RH	a	a	a	a	a	6.118
P	ab	bc	c	a	ab	13.886***
OP	a	a	a	a	a	1.112
C	a	a	a	a	a	0.479
OS	a	a	a	a	a	2.043

	Year 1	Year 2	Year 3	Year 4	Year 5	*F*-value
TCH						
RH	a	a	a	a	a	2773
P	a	ab	ab	ab	b	3502*
OP	a	a	a	a	a	1142
C	a	ab	ab	c	c	4243*
OS	a	ab	b	b	ab	6786**
GRPS						
RH	ab	a	b	ab	a	6369*
P	a	a	a	a	a	1422
OP	a	a	a	a	a	0.195
C	a	a	a	a	a	1809
OS	a	a	a	a	a	2456
VC						
RH	a	a	a	a	a	0.278
P	a	a	a	a	a	1000
OP	a	a	a	a	a	2324
C	a	a	b	bc	c	67361*
OS	a	a	a	a	a	0.791

Different letters within the same row indicate significant differences ($P < 0.05$) among samplings after one-way ANOVA, ns, not significant. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

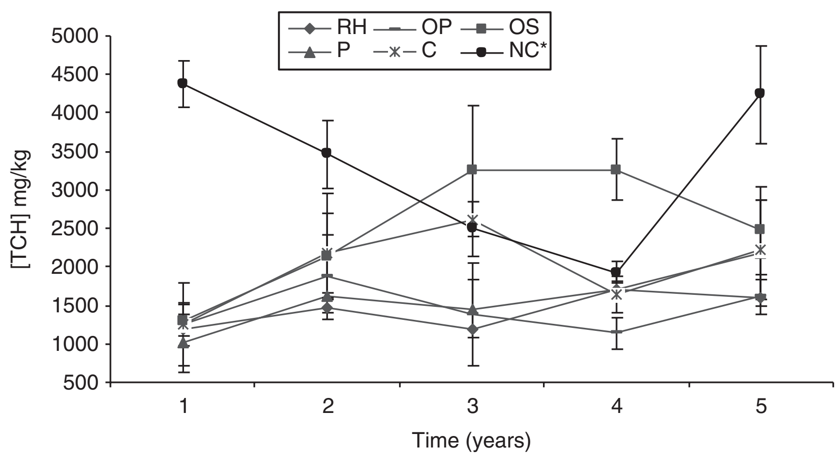

Figure 2 Change in the total carbohydrates (TCH) content in soil samples taken from the surface of the top soil layer (0–5 cm) during the 5 yr of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

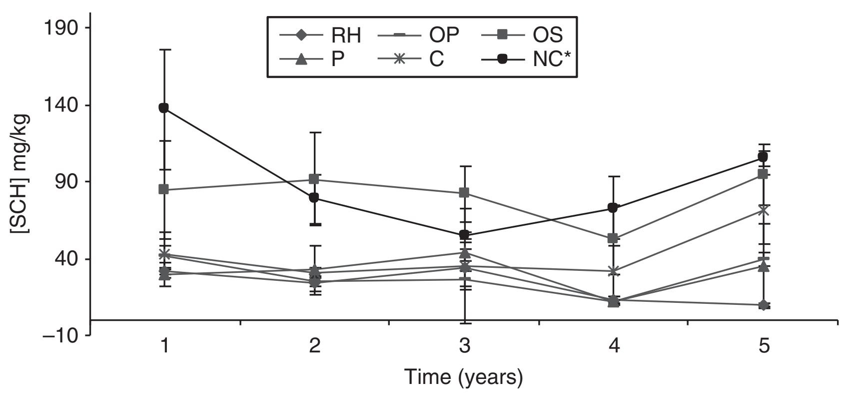

Figure 3 Change in soluble carbohydrate content l (SCH) in soil, mean and standard error, in samples taken from the surface of the top soil layer (0–5 cm) during the 5 yrs of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

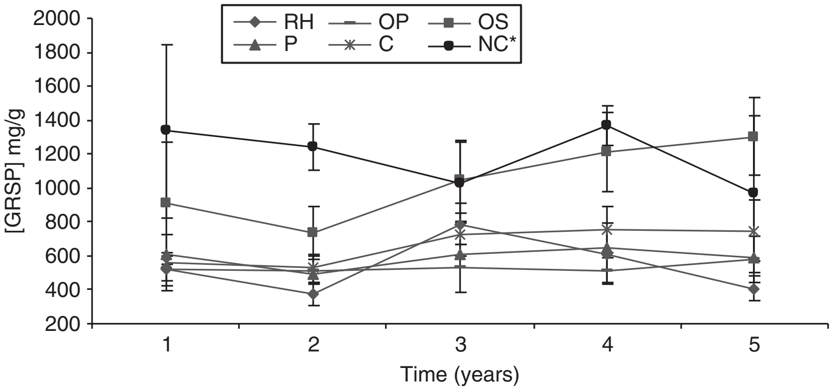

Figure 4 Change in glomalin-related soil protein (GRSP) mean and standard error, in samples taken from the surface of the top soil layer (0–5 cm) during the 5 yr of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

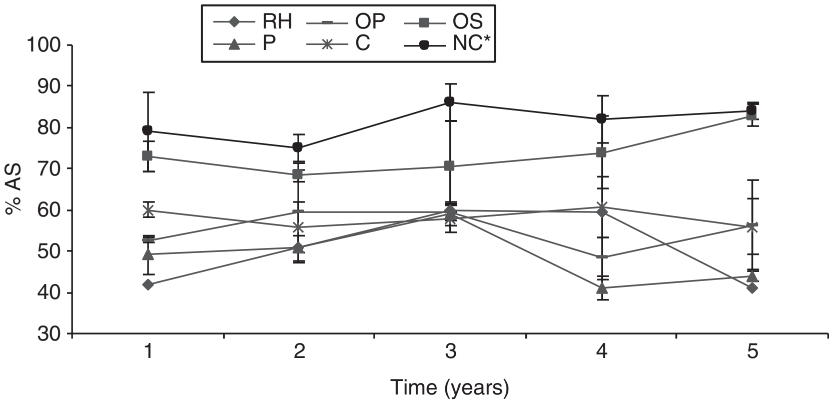

Figure 5 Change in the percentage of aggregate stability (AS) mean and standard error, in samples taken from the surface of the top soil layer (0–5 cm) during the 5 yr of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

used as a reference or control for comparison to the other plots under different treatments.

The other plots had lower values for OM, vegetation cover and aggregate stability compared with the NC plot in 2004 when the experiment was launched. These values are attributable to previous agricultural management that contributed to soil structure degradation through ploughing and the loss of organic matter. For the treated plots, the application of oat straw (OS plot) to the soil was quite effective in improving the soil structure and the AS values, which were similar to those of the NC plots after 5 yr. Aggregation is facilitated by soil organic matter, biota, ionic bonding, clays, carbonates (Bronick & Lal, 2005) and polysaccharides from bacteria, fungi or root mucilage, described as a labile soil organic fraction that acts as an important binding agent for aggregation (Oades, 1984; Puget *et al*., 1999; Jolivet *et al*., 2006). The increase in stable aggregates with the oat straw treatment in comparison with the control (C) can be explained by a significant increase in organic matter and soluble C fractions. The observed seasonal variations in AS values and Carbon fractions can be attributed to the strong influence of soil humidity cycles. Some studies show differences in carbohydrate content owing to land use management, for example, Jolivet *et al*. (2006) report that cultivation of former forest soils reduces carbohydrate content. In our study, all of the treatments showed carbohydrate levels significantly below those of the natural cover plot that was used as a reference, except for the soil with oat straw addition. This agricultural management practice can reduce the decrease in carbohydrates, providing an important aggregating agent for soil under conventional agriculture. Additionally, this treatment contributes significantly to the production of GRSP in the soil. Several studies have established that this protein contributes to soil aggregation (Bedini *et al*., 2009; Kohler *et al*., 2009; Haner *et al*., 2004; Wright & Upadhyaya, 1998). The values for GRSP after 5 yr of oat addition (1200 mg/g) are very similar to those obtained by Kohler *et al*. (2009) for this protein in a degraded soil from a semi-arid Mediterranean area inoculated with *Glomus mosseae* and *Glomus intraradices* (1190 and 1000 mg/g, respectively). These two mycorrhizal fungi species produce the glycoprotein GRSP in soil rhizospheres. Thus, we can propose that oat straw addition is very effective in promoting this protein because it induces the proliferation of soil microbial populations (Garcia-Orenes *et al*., 2010).

Significant relationships were found between some of the variables with positive correlations between the following: AS and OM (r = 0.558, P < 0.01), AS and TCH (r = 0.463; P < 0.01), AS and SCH (r = 0.619, P < 0.01) and AS and GRSP (r = 0.418; P < 0.01). These results support the hypothesis that the studied factors (OM, TCH, SCH and GRSP) are important for soil aggregation in semi-arid conditions.

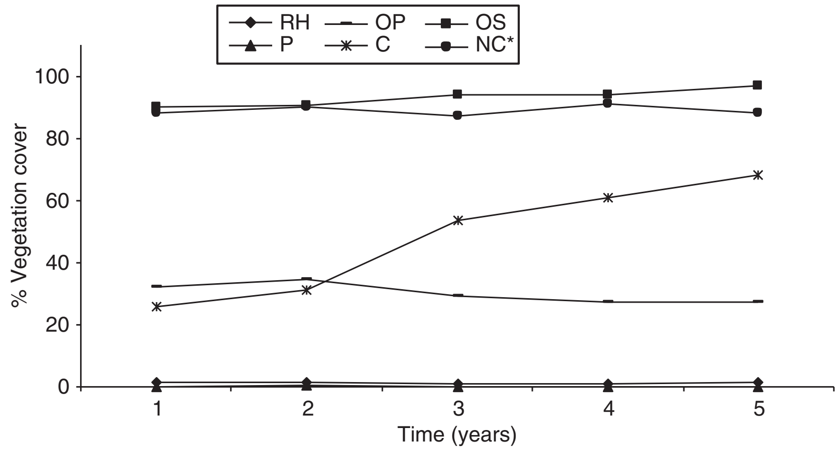

Figure 6 Change in the percentage of vegetation cover (VC) mean and standard error during the 5 yr of land management study treatments: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Samplings were taken in July.

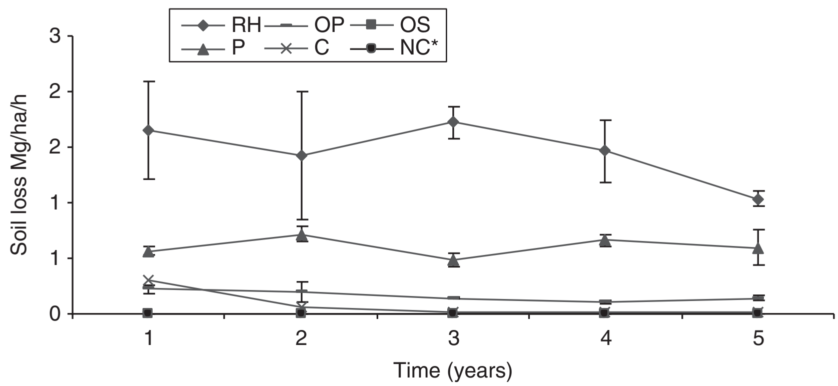

Figure 7 Change in soil loss (SL) during the 5 yr of land management study treatments from the rainfall simulation: RS, residual herbicide; P, Ploughing; OP, Oat ploughing; C, Control; OS, Oat straw and NC*, which is considered to be a reference system and not a treatment. Error bars denote the standard error. Samplings were taken in July.

Table 4 Significant differences between different treatments applied for every parameter studied

	OM	TCH	SCH	GRSP	AS	VC	SL
RH	a	a	a	a	ab	b	a
P	a	ab	a	ab	a	a	b
OP	ab	ab	a	ab	bc	c	c
C	b	b	b	b	c	c	c
OS	c	c	c	c	d	d	c
F-value	0.019***	0.205***	0.001***	0.035***	0.025***	0.02***	0.085***

Different letters within the same row indicate significant differences ($P < 0.05$) among samplings after one-way ANOVA, ns, not significant *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

The higher values obtained for the studied parameters and the maintenance of these values during the experiment in the treatments with oat straw addition indicate that the improvement in soil properties was related to the increase in either soil vegetation cover or the straw cover. The soil behaviour under this treatment was very similar to that in the plot with natural cover at the end of the experiment as both reached the highest percentage of vegetation cover (ca. 100%). As a consequence of the vegetation and straw cover, soil water losses were negligible during the rainfall simulation experiments. The soil losses in the control plot, as already mentioned, were negligible after 3 yr because this soil developed a 60% vegetation cover, which is sufficient to control sediment losses (Ruiz Sinoga *et al.*, 2010); even with 40% plant cover in the OP treatment, a considerable decrease in soil losses was found. The impact of vegetation recovery in reducing soil losses during land abandonment has been reported in eastern and northern Spain (García-Ruiz *et al.*, 1995; Cerdà *et al.*, 1997). The importance of vegetation, straw or litter cover is explained by the fact that plant cover reduces the kinetic energy of raindrops. Thus, particle detachment by splash is negligible, as are soil losses. Several studies have found results similar to these: the lowest soil losses were found for straw mulch plots and fallow plot treatments (e.g. Schwing, 1978; Messer, 1980; Grill *et al.*, 1989; Maigre & Murisier, 1992; Klik *et al.*, 1998). Soil losses had a significant negative correlation with vegetation cover ($r = -0.462$; $P < 0.01$), and vegetation was positively correlated with aggregate stability ($r = 0.592$; $P < 0.01$). These data indicate that two main factors protect the soil against erosion: vegetation cover, which can reduce raindrop energy, and aggregate stability, which is related strongly to soil organic matter content, TCH, SCH and GRSP as confirmed in this study. The interaction between vegetation and aggregate stability indicates that when vegetation is present, the AS is attributable to the protection that cover provides and to the contribution of organic material and the soil biota (Cerdà, 2000). Moreover, aggregate stability is a good indicator of the quality of the soil system and is affected by the type of vegetation in Mediterranean rangelands (Cerdà, 1998).

Spanish agricultural land suffers soil degradation due not only to soil erosion but also to aggregate breakdown, low organic matter content and lack of a protective vegetation cover. The results demonstrate that soil erosion control is possible through the use of catch crops, weeds or straw mulches in < 5 yr; straw mulch is very efficient when applied, as soil losses are reduced within 1 yr. AS improvement will contribute to less erodible soil.

This research contributes not only to the understanding of the impact of land management and the use of agricultural land in Spain, but also to the understanding of the impacts from land abandonment. Throughout the twentieth century, mountainous terrain in Spain has been abandoned with a loss to agriculture. In some cases, this abandonment has resulted in vegetation recovery, soil erosion control and improvement in soil properties, similar to the experimental results from this study. Therefore, the non-management of soils after cropping is a viable option.

Agricultural management has an important influence on the properties of the studied soil, such as organic matter, total and soluble carbohydrates and extractable soil glomalin content (Adesodun *et al*., 2001; Bedini *et al*., 2007; Garcia-Orenes *et al*., 2010). These soil properties are related strongly to the formation of stable soil aggregates and change as a consequence of soil erosion control. The application of straw mulch to the soil was the most effective soil management treatment to cause increases in OM, TCH, SCH and GRSP as reflected in the improvement in aggregate stability with values similar to those in the non-treated soil with natural cover that was used as a high-quality reference soil.

Greater aggregate stability and vegetation cover are the two main factors for protecting soil against erosion under Mediterranean conditions when vegetation regeneration occurs on former agricultural soils. When straw is applied, the recovery is even faster. This research demonstrates that land abandonment, which has affected the northern Mediterranean region over the last 50 yrs, contributes to increases in soil quality and reduces erosion risks. This study has also shown that sustainable agricultural management avoids soil degradation and that the use of straw is the most effective strategy to combat land degradation.

Conclusion

The agricultural management of Mediterranean land affects soil properties and determines soil and water losses. The use of tillage and herbicides prevents soil development and triggers high erosion rates. Management practices that favour the development of plant cover (ploughing and growth of oats) and the use of catch crops and straw mulch contribute to an increase in total and water-soluble carbohydrates, GRSP, total organic carbon, and aggregate stability; the result is a reduction or elimination in soil and water losses under Mediterranean environmental conditions.

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