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Hydrological and erosive effects of over-grazing at patch scale in humid mediterranean rangelands (Serranía de Ronda, South of Spain)

Efectos hidrológicos y erosivos del sobre-pastoreo a escala detalle en el monte mediterráneo húmedo (Serranía de Ronda, sur de España)

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Abstract

The study focussed on the role played by over-grazing in the hydrological and erosive response of Mediterranean rangelands under humid climatic conditions. Two factors were considered to investigate such effect at patch spatial scale: hillslope exposure and soil surface component. A set of micro-plots (1.5 m^2) were installed in the experimental area for recording runoff and soil loss during two-year period. The results indicated that exposure was a significant factor controlling runoff generation and soil loss since it influenced soil surface component: i) soil completely bare in south facing hillslopes and ii) soil covered by annual plants and moss in the north facing ones. The consequence was that southern micro-plots showed hydrological and erosive response similar to those observed in more arid Mediterranean climatic conditions due to the impact of over-grazing in vegetation cover and soils, while the northern hillslopes seem to withstand better the grazing pressure.

Keywords: Runoff, soil loss, hillslope exposure, soil surface component, over-grazing, Mediterranean rangeland.

Resumen

El estudio analiza la influencia del sobrepastoreo en el funcionamiento hidro-erosivo del monte mediterráneo en condiciones climáticas húmedas. La actividad pastoril en la zona de estudio es de tipo caprino (todo el año) y vacuno (de octubre a mayo); el área experimental se encuentra en la zona de tránsito diario del ganado. Se consideraron dos factores en este estudio a escala de detalle: exposición y características superficiales del suelo. Se instalaron micro-parcelas (1,5 m^2) para recabar información de la escorrentía y pérdida de suelo durante dos años. Los resultados indicaron que la exposición era más determinante porque influía en las características superficiales de los suelos, favoreciendo el crecimiento de plantas anuales y musgo en exposición norte a pesar del paso continuo de ganado, mientras en la sur el suelo quedaba completamente desnudo. En consecuencia, las micro-parcelas de exposición sur se comportaron de modo similar a lo que se ha observado en condiciones climáticas mediterráneas más áridas debido al impacto del sobrepastoreo en la cubierta vegetal y los suelos, mientras que en las de exposición norte parece que se soporta aún la presión ganadera.

Palabras clave: escorrentía, pérdida de suelo, exposición, características superficiales del suelo, sobre-pastoreo, monte mediterráneo.

1. Introduction

The Mediterranean region is characterized by different and changeable land uses (cultivated and grazed lands, abandoned areas, rangelands, etc.) during the last centuries affecting directly runoff and soil erosion (Kosmas *et al.*, 1997). In the case of grazing, this human activity introduces deeply modifications in the hydrological and erosive response of hillslopes in Mediterranean rangelands (Cerdà, 1998). Modifications are especially transcendent in the vegetation cover and soil properties (Thornes, 1990; Boix *et al*., 1995) resulting in a reduction of potential areas of water infiltration (Cammeraat and Imeson, 1999) and increment of soil degradation processes leading to desertification (López-Bermúdez and Albaladejo, 1990). In fact, over-grazing may disturb the environment susceptibility to erosion and its resilience for recovering from the impact of a disturbance process as, for instance, highly intense soil erosion (Coppus *et al*., 2003).

Rangelands on metamorphic rocks are a major component of the Mediterranean landscape in southern Spain. From the Strait of Gibraltar to Cabo de Gata, in Almería, a decreasing trend in rainfall occurs: more than 1,500 mm year^{-1} in the former, to less than 250 mm year^{-1} in the latter. The consequence is the reduction in vegetation cover and changes in composition of Mediterranean rangelands in such geographical area (Ruiz-Sinoga and Martínez-Murillo, 2009a). In general, the higher the frequency and volume of rainfall the greater vegetation cover. However, even in the rainiest regions, some human activities (e.g., grazing) can affect this general pattern, resulting in less vegetation cover than expected (Boix *et al*., 1995; Kosmas *et al*., 2000; Ruiz-Sinoga *et al*., 2011). Consequently, a pattern of patchy vegetation is evident in Mediterranean regions, even in humid climatic conditions. The resulting bare soil areas are a key factor in runoff generation (Arnau-Rosalén *et al*., 2008; Ruiz *et al*., 2010; Ruiz-Sinoga *et al*., 2010a), even in the more humid areas, where biotic factors (vegetation cover, annual plants, moss, and organic matter) are commonly the most important in controlling this hydrological process (Lavee *et al*., 1998).

In more semi-arid Mediterranean rangelands on metamorphic rocks, Puigdefábregas *et al*. (1999) studied the effects of vegetation patterns and rock fragments on the hydrological and erosive functioning in the short and long terms. In general, the size and disposition of rock fragments and the growth of annual plants influence the mechanisms of runoff generation during natural rainfall events and in rainfall simulations (Cerdà, 1998; Cerdà, 2001; Calvo *et al*., 2005; Martínez-Murillo and Ruiz-Sinoga, 2007; Ruiz-Sinoga *et al*., 2010b). When vegetation cover decreases (e.g. because of grazing or fire), the soil hydrological response in humid Mediterranean environments may be very similar to that observed under more arid climatic conditions (Martínez-Murillo *et al*., 2011) due to the appearance of crusts and embedded rock fragments in the soil surface which limit water infiltration and enhancing runoff and soil erosion (Katra *et al*., 2007; Ruiz-Sinoga *et al*., 2010c).

A typical example of grazed Mediterranean rangeland is the dehesa which becomes hydrologically complex due to this human activity (Bergkamp, 1998) because of the runoff generation mechanism vary through the year (Schnabel, 1997). Indeed, infiltration excess can control runoff generation where plant growths are prevented by over-grazing (Boix *et al*., 1995). The hydrological response of the soil surface components can also be modified by the exposure (Calvo-Cases *et al*., 2003; Arnau-Rosalén *et al*., 2008). This is a key factor controlling soil surface conditions as exposure affects the water balance, and hence features including the presence of annual plants and moss cover, which can modify the hydrological response of soils (Ruiz-Sinoga and Martínez-Murillo, 2009b; Ruiz-Sinoga *et al*., 2010c). Therefore, in Mediterranean rangeland environments, exposure has a direct effect on the hillslope hydrology (Boix-Fayos, 1999; Boix *et al*., 1998).

The aim of the study is to investigate the effect of over-grazing in the hydrological and erosive response of soils from two-contrasted hillslopes in a rangeland under humid Mediterranean climate. The objectives are: i) to characterize the runoff generation and soil loss processes; ii) to determine the exposure and soil surface component influence; and iii) to assess the effect of over-grazing in reducing the hydrological and erosive differences between humid Mediterranean sites and the more arid ones.

2. Methodology

2.1. *Experimental area*

Figure 1 shows the location of the experimental area and a general view of the hillslopes at

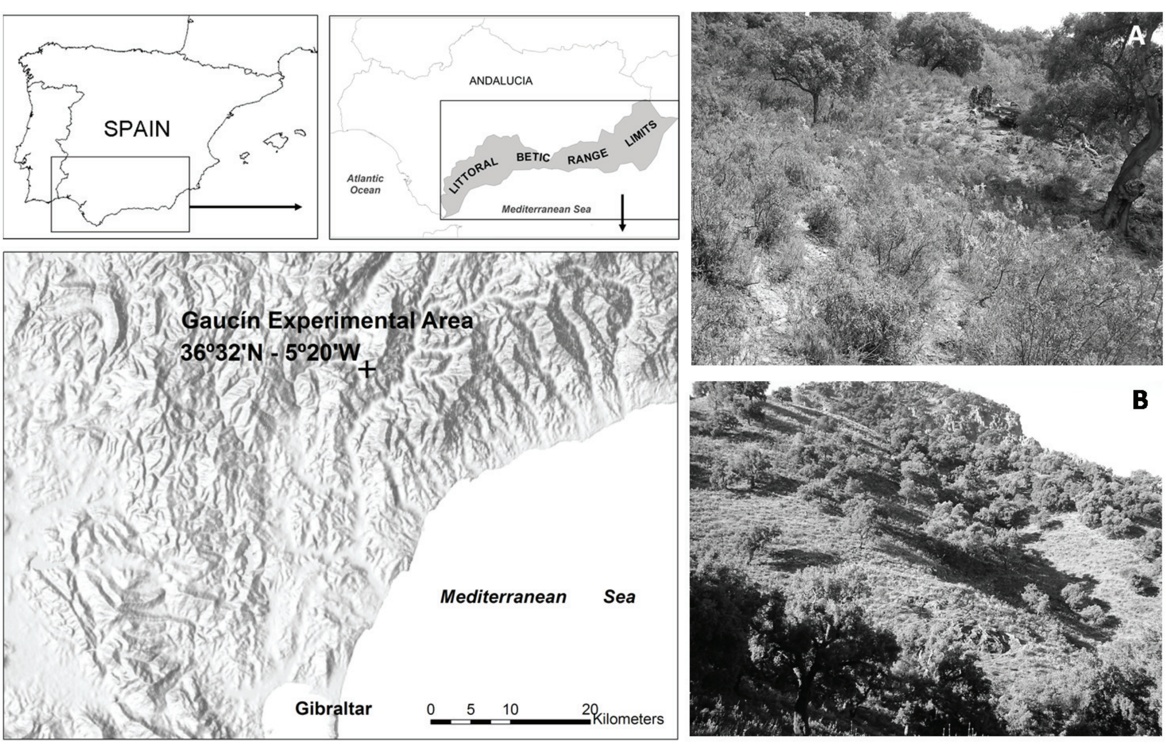

Fig.1. Location and general views of the experimental area where the study was conducted. A: south facing exposure; B: north facing exposure.

Fig. 1. Localización y vista general del área experimental. A: ladera de exposición sur; B: ladera de exposición norte.

which the study was conducted. The experimental area is located in the so-called Serranía de Ronda (Province of Málaga, South of Spain). The geographical area is characterised by humid Mediterranean climate (annual precipitation: 1,010 mm y^{-1}; annual temperature: 14.7ºC), mountainous topography (680 m.a.sl.; steep hillslopes, >25%), metamorphic rock substratum (phyllites and shales), and land use of Mediterranean rangeland, in some areas affected by grazing. Although the climatic conditions let maintain a vegetation cover equal to 90-100%, the grazing activity has decreased the vegetation cover to 60% approximately where it is concentrated. Grazing relates to goats (the whole year) and cows (from October to May).

The experimental area is composed by two-contrasted over-grazed hillslopes (N20º and N220º) with mean slope gradients greater than 20%, patchy vegetation pattern (vegetation cover ranged from 40 to 60% and 50 to 70% in north and southfacing hillslopes, respectively). Goats and cows graze in the experimental area every day. Grazing pressure is especially high during the rainy season (from October to May) when vegetation cover of shrubs increases and annual plants grow in the bare soil areas due to the water supply, especially in the north exposures. From the geomorphic point of view, the water erosion is the main process acting in both hillslopes, being more intense in the south facing one due to the major percentage of bare soil (as a consequence of grazing). In this hillslope, bare soil are usually characterised by the presence of crusts and embedded rock fragments in the soil surface. The northfacing hillslope presents not less bare areas as they are almost covered by moss and annual plants. Likewise, in both hillslopes, different erosive morphologies produced by the cattle and goats can be also observed: footpaths and small terracettes.

2.2. *Measurements of hydro-meteorological variables*

Figure 2 depicts the experimental design installed in the experimental area according to the objectives of the study. Rainfall was recorded by a meteorological station installed at the experimental area; the rain gauges had

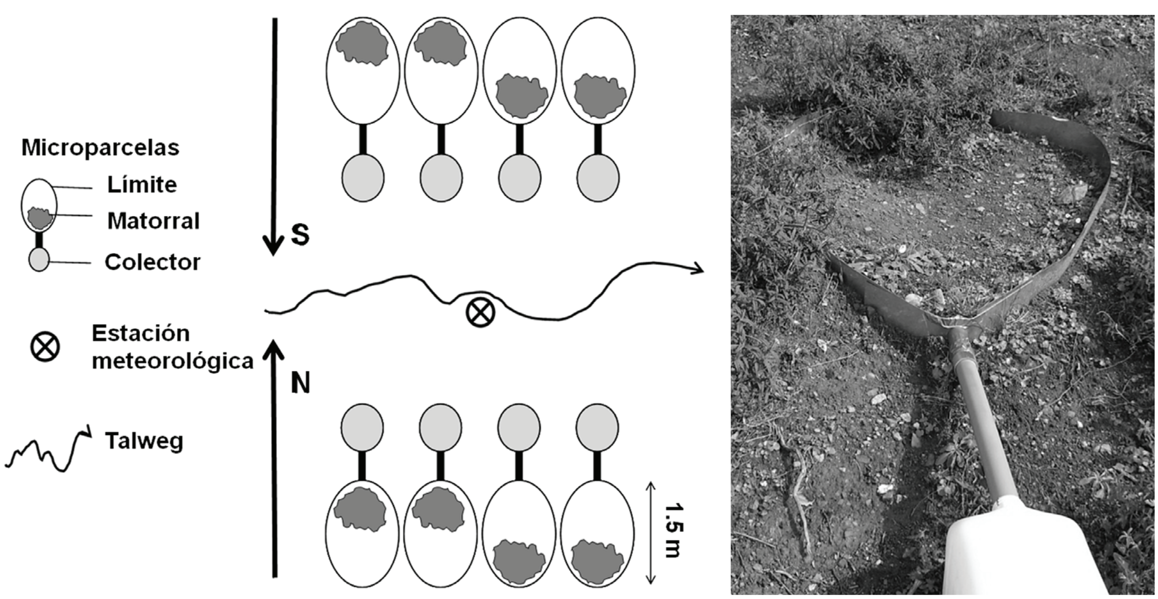

Fig. 2. Sketch of the experimental design and devices installed in the experimental area, and photographic detail of one micro-plot from the south facing hillslope.

Fig. 2. Esquema del diseño experimental e instrumentación instalada en el área de trabajo, y detalle fotográfico de una de las micro-parcelas de la ladera con exposición sur.

a precision of 0.3 mm. The maximum rainfall intensity for 10 minutes (I10) was calculated for every rainfall event. The soil water content was measured manually over the depth range 0–15 cm using a time domain reflectometer (TDR) probe of 15 cm length (Tektronix 1502C). These measurements were performed under similar eco-geomorphologic conditions to those included within the plots when runoff was collected. The measurement period was from 2008 February to 2010 January.

Table 1. Eco-geomorphologic characteristics and soil surface components of micro-plots. Abbreviations: SCN, North plot with shrub; BSN, North plot with bare soil; SCS, South plot with shrub; BSS, South plot with bare soil; S, slope gradient; VP, vegetation position (B: bottom; T: top); VS, vegetal specie; VC, vegetation cover; D, distance of vegetation to collector; RF, rock fragment cover; SSC, soil surface condition (1: crusts and 20 to 70% rock fragment cover embedded in soil surface; 2: moss and annual plants).

Tabla 1. Características ego-geomorfológicas de las micro-parcelas. Abreviaturas: SCN, parcela norte con matorral; BSN, parcel sur con suelo desnudo; SCS, parcela sur con matorral; BSS, parcela sur con suelo desnudo; S, pendiente; VP, posición del matorral (B: baja; T: alta); VS, especie vegetal; VC, cubierta vegetal; D, distancia al colector; RF, cubierta de fragmentos rocosos; SSC, condición superficial del suelo (1: encostrado y con cubierta de fragmentos rocosos del 20 al 70% embebida en la superficie del suelo; 2: musgo y plantas anuales).

Exposure	North			
Plot	SCN1	BSN-1	BSN-2	SCN-2
S (m m^{-1})	0.15	0.20	0.20	0.15
VP	B	T	T	B
VS	*Cistus monspeliensis*			
VC (%)	30	30	40	40
D (cm)	5	80	90	10
RF (%)	10	20	15	20
SSC	1	1	1	1
Exposure	South			
Plot	SCS-1	BSS-1	SCS-2	BSS-2
S (m m^{-1})	0.25	0.25	0.25	0.25
VP	B	T	B	T
VS	*Cistus monspeliensis, Phlomis purpurea*			
VC (%)	60	40	60	40
D (cm)	10	80	10	120
RF (%)	5	10	5	15
SSC	2	2	2	1

Likewise, Figure 2 also shows the experimental design for the set of closed plots (length: 1.5 m; area: 1.3 m^2) at each hillslope (four plots per hillslope). For each hillslope position, two plots had one shrub in the upper part and the other two plots each had one shrub in the lower part. The plots were located in representative areas of each hillslope. The shrub species in the plots were those found most commonly in the larger surrounding area of the field site for both north and south facing slopes. Runoff was collected in 25-liter tanks and the volume was measured after every rainfall event during the same period above mentioned; total runoff, runoff rate and runoff coefficient were calculated. A runoff sample was taken to calculate the sediment concentration and soil loss rate by means of the completely evaporation of water in a laboratory electric heater. These hydrological and erosive variables were used as indicators to evaluate the soil response of both hillslopes to natural rainfall events at patch spatial scale. Goats and cows were able to get into the micro-plots for grazing. In fact, before some important rainfall events, animals disturbed the micro-plots limits and, thus, the corresponding data were not considered for the study.

2.3. *Analysis of soil surface components and soil properties*

The type of soil surface components (vegetation, rock fragments, crusts, litter, etc.) was measured by aerial photo-interpretation using a geographic information system (ArcGIS 9D2 software) and applying a similar inventory to that used by other authors (Arnau-Rosalén *et al*., 2008; Ruiz-Sinoga and Martí nez-Murillo, 2009c; Ruiz-Sinoga *et al*., 2010b, 2011). Likewise, several soil properties related to the hydrological and erosive response of soils were analysed. Several soil samples from the top of soil (0-5 cm depth) were taken near and in similar eco-geomorphologic conditions to those included within the closed plots totalling five samples from soil beneath shrub and bare soil, and in every hillslope, respectively (total: 20 soil samples). The analysed soil properties and the applied method were: gravel content by 2 mm sieved, texture by Robinson's method (1922), bulk density by the cylinder method, organic matter content by espectrofotometry (AFNOR, 1987), and aggregate stability fraction by the wet sieving method (Kemper and Rosenau, 1986).

2.4. *Statistical analysis*

Different statistical tests were performed to investigate soil properties and related alterations along the study area. Student's t-test was applied to assess significant differences ($p > 0.05$) between the mean values of soil properties with regard to the location and depth. Similarly, the relationships between the hydrological and erosive variables were assessed by means of Pearson's correlations ($p > 0.05$). Also, the two-way ANOVA test ($p < 0.05$) was conducted to establish whether the factors, exposure and vegetation cover position within the plot, significantly influenced the measured variables. Both ANOVA tests were applied when the analyzed variables exhibited homoscedasticity according to Levene's test ($p \geq 0.05$). The absence of variance homogeneity in the measured variables indicated the need for application of a non-parametric test. In this case, the Mann-Whitney U-test was applied to data. As the soil water content data was in percentage, the arc sin or angular transformation was applied to them for their statistical uses. These procedures were performed with the Windows-based PAWS® software, version 18.

Table 2. Soil properties of north and south hillslopes. Abbreviations: SC, shrub; BS, bare soil; G, gravel content; S, sand content; St, silt content; C, clay content; BD, bulk density; OM, organic matter content; ASF, aggregate stability fraction.
Tabla 2. Propiedades de los suelos en las laderas norte y sur. Abreviaturas: SC, matorral; BS, suelo desnudo; G, contenido de gravas; S, contenido de arenas; St, contenido de limos; C, contenido de arcillas; BD, densidad aparente; OM; contenido de material orgánico; ASF, fracción de agregados estables.

Hillslope	North		South	
Soil property	SC	BS	SC	BS
G (%)	26.6	49.8	46.4	69.4
S (%)	29.0	15.4	31.2	23.3
St (%)	43.2	60.4	46.8	55.7
C (%)	27.8	24.2	22.0	21.0
BD (g cm^{-3})	0.90	1.11	1.01	1.30
OM (%)	10.0	7.9	9.5	5.8
ASF (%)	92.0	84.1	92.6	56.8

3. Results

3.1. *Micro-plots and soil properties*

Table 1 shows the eco-geomorphologic characteristics of the plots. The slope gradient was steep or very steep. Due to the existence of more humid conditions in the north facing hillslope, the vegetation cover was higher than in the south facing one. In the former, the presence of Phlomis purpurea may indicate the presence of frequent subsurface flows. Likewise, those conditions were also result in abundant moss covering the bare soil areas in the north facing hillslope (the soil surface not covered by shrub was considered as bare soil). Otherwise, the soil not covered by shrub in the south facing hillslope was completely or almost completely bare (in some cases, annual plants grew covering less than 20% of the surface) and characterised by crusts and a rock fragment cover higher than 20% embedded in the topsoil. These areas showed the greatest water erosion evidences and over-grazing effects.

Table 2 summarizes the results of the soil properties analysis. North facing hillslope was characterised by lower gravel content and bulk density, more loamy texture, and higher organic matter content and aggregate stability fraction than in the south facing one. Likewise, the soil beneath shrubs from both hillslopes presented a similar trend to that described above for the north exposure in comparison to the bare soil. Results indicated better eco-geomorphologic conditions and a potential sink hydrological response for shrub areas, while bare soil areas seemed to be more degraded from the water erosion point of view.

3.2. *Rainfall events and soil water content*

Table 3 summarizes the rainfall data registered in the experimental area during the study period. More than two thousand millimetres were measured in almost four hundred rainy days in two years. Most of rainfall events ranged from 0 to 5 mm depth (50.0%) and from 10 to 25 mm depth (24.5%); the rest of rainfall depth frequencies were 14.1% from 5 to 10 mm, 6.5% from 25 to 50 mm, and 4.3 from 50 to 100 mm. Only one day registered more than 100 mm (144.0 mm, 31/Oct/2008). The rainfall intensities tended to be not very high except during occasional events: 76.2 mm (23/Dec/2010); 45.6 mm (18/Dec/2009); and 42.3 mm (20/Oct/2009).

Figure 3 shows the variability of rainfall depth in the period of study. Typical temporal distribution for Mediterranean climate was observed, with events concentration mainly from September to May. Only three months with no rainfall were registered given that the experimental area was located in a geographical area characterised by humid Mediterranean climatic conditions. Regarding to maximum rainfall intensities, highest values were obtained during the autumn and winter events (>20 mm h^{-1}), while lowest were recorded in spring (<20 mm h^{-1}). Likewise, the relationship between rainfall depth and rainfall intensity showed two trends: the greater rainfall depth, the lower intensities, and viceversa.

Regarding to the soil water content measured during the same period of study, in general, the highest value were observed in the north facing hillslope and in the soil beneath the shrubs. In the north exposure, the soil water content beneath the shrub was equal to 21.0% (standard deviation, sd= ±11.8%) and in bare soil equal to 17.9% (sd= ±10.6%). In the case of the south facing hillslope, shrubs presented a mean soil water content of 12.4% (sd = ±11.6%) and the bare soil of 8.0% (sd= ±7.7%). A two-way ANOVA test was performed to determine the effect of both considered factors ('Exposure' and 'Vegetation

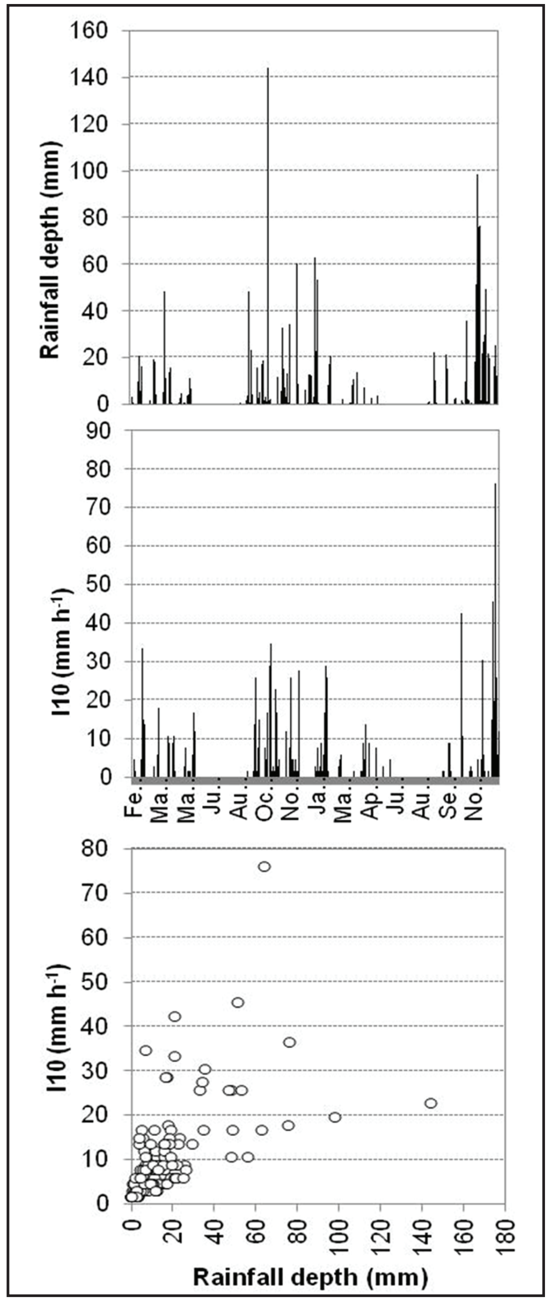

Fig. 3. Variability of rainfall depths (top) and rainfall intensity I10 (middle) registered in the experimental area. Relationships between rainfall depth and I10 (bottom).

Fig. 3. Variabilidad de la precipitación (arriba) e intensidad de precipitación I10 (mitad) registrada en el área experimental. Relación entre la precipitación y la intensidad de precipitación en 10 minutos I10 (abajo).

cover'). As the Levene's test was significant, the two-way ANOVA was carried out. The result indicated the soil water content was significantly different with regard to the factor 'Exposure', but not in the case of the factor 'Vegetation cover' or the interaction of both factors. The significant influence of 'Vegetation cover' in the soil water content was expected considering the apparent difference between the mean values; however, the high standard deviation in all of the cases implicated the absence of significance obtained in the performance of the two-way ANOVA test.

According to Figures 3 and 4, the soil water content was characterised by a temporal pattern similar to that observed for rainfall. In general, soils from north exposure presented higher water content in the topsoil than those in south exposure. The difference between both exposures was especially higher during the rainy season. Following the end of the rainy season in early June, the soil water content decayed rapidly below 5%, becoming all soils very dry in surface, independently of exposure. In contrast, soils in the north facing hillslope were over field capacity and even closed to saturation during periods of continuous rainfalls. In fact, areas with slope gradient close to 0 were characterised by ponded and saturated soil surfaces experiencing difficult drainage.

3.3. *Runoff and soil loss*

Table 4 shows an overview of statistics of the hydrological and erosion data of the entire micro-plots. In general, considering only the factor 'Exposure', plots in the northern exposures emitted almost 20 litres (l) less of runoff than plots in the southern ones (174.8 l and 190.3 l, respectively). The mean runoff rates for both exposures were very similar: North = 0.82 l m^{-2}, and South = 0.97 l m^{-2}. These values of runoff rendered in very low runoff coefficients in both exposures (North = 0.8%, and South = 1.4%); rainfall events with less than 5 mm and low rainfall intensities resulting in almost no runoff. Comparing all the hydrological data from plots with the shrub in the bottom and in the top of the plot (or bare soil), the differences were much larger. The former generated a total of 95.9 l, while the latter 265.0 l (250% more of runoff). In fact, the mean runoff rate in bare soil was more than the double of that registered in shrub micro-plots (1.31 l m^{-2} and 0.60 l m^{-2}, respectively). Mean runoff rate of shrub micro-plots from the north exposure was equal to 0.28 l m^{-2}, while in the south micro-plots was of 0.66 l m^{-2}. However, the total runoff from the bare soil micro-plots in both exposures was almost equal: North = 132.6 l, South = 132.5 l.

Figure 5 shows the increment in total runoff and sediment exported from the plots during the study period with regard to the rainfall depth increases. With one exception, runoff and, especially, sediment were registered in almost all the rainfall events in the south plots. Two periods of abundant rainfalls produced the largest increments for both hydrological and erosive variables, occurring mainly from October to December, despite high runoff volumes were also recorded during winter months in the last year.

Student's test indicated significant differences due to the factor 'Exposure' between mean values of runoff coefficients (Table 5).

Table 3. Summary of rainfall event data registered during the study period. Abbreviations: T, total rainfall depth; N, number of rainy days; D, depth of rainfall event; T, duration of rainfall event; I60, rainfall intensity calculated for a period of 60 minutes; I10, rainfall intensity calculated for a period of 10 minutes.
Tabla 3. Resumen de los datos de precipitación registrados durante el periodo de estudio. Abreviaturas: T, precipitación total; N, número de días con lluvia; D, precipitación del evento; I60, intensidad de precipitación en 60 minutos; I10, intensidad de precipitación en 10 minutos.

T (mm)	2,232.1		
N	392		
	Mean	SD (±)	Max.
D (mm)	12.0	18.9	144.3
T (h)	0.92	3.5	19.0
I60 (mm h^{-1})	2.9	1.6	10.0
I10 (mm h^{-1})	8.1	9.7	76.2

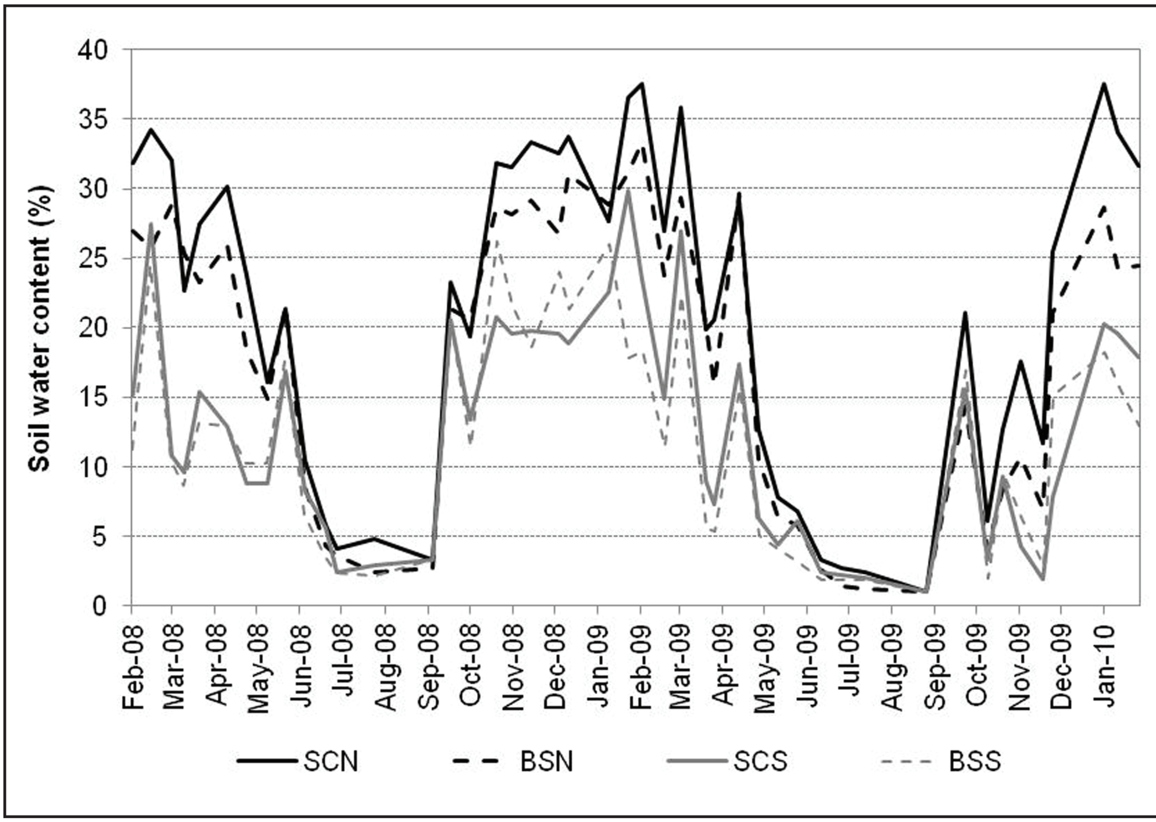

Fig. 4. Variability of soil water content in the plots micro-environments from both hillslopes.
Fig. 4. Variabilidad de la humedad del suelo en los micro-ambientes de las parcelas en ambas laderas.

In the case of the erosion variables (total sediments, sediment concentration and soil loss rate), all of them were significantly different in relation to the same factor. Regarding to the factor 'Vegetal position within the plot', all hydrological variables (total runoff, runoff rate and runoff coefficient) presented significant changes according to shrub position (top or bottom of the plot). However, none of the erosion variable showed significant differences according to this factor.

Although differences could be observed respect to the mean values, the two-way ANOVA did not achieved remarkable results as it was expected. The test indicated that there were no significant changes in the total runoff due to the factors 'Exposure' or 'Vegetation position within the plots' if the entire database were taken into account. Neither significant changes in the total runoff were obtained considering the effect of both factors, separately. In the case of the runoff rate, the Levene`s test was no significant, so the two-way ANOVA could not be performed. Thus, the U Mann-Whitney test was applied and the result indicated that only the runoff rate was significantly different according to the vegetal position within the plot, independently of the exposure effect ($p < 0.005$). The two-way ANOVA showed there were significant differences runoff coefficient between north plots with the shrub in the bottom and the similar micro-plots in the south exposure ($p < 0.05$).

The Pearson's correlation was performed to investigate the relationship between runoff, rainfall and soil water content data. Results indicated that significant relationships exist between total runoff/rainfall depth and total runoff/I10 ($r^2 = 0.47$, $p < 0.01$; $r^2 = 0.39$, $p <$

0.01, respectively). The runoff rate was significantly correlated to the rainfall depth (r^2 = 0.28, p < 0.01), and the runoff coefficient to soil water content (r^2=-0.19, p < 0.05).

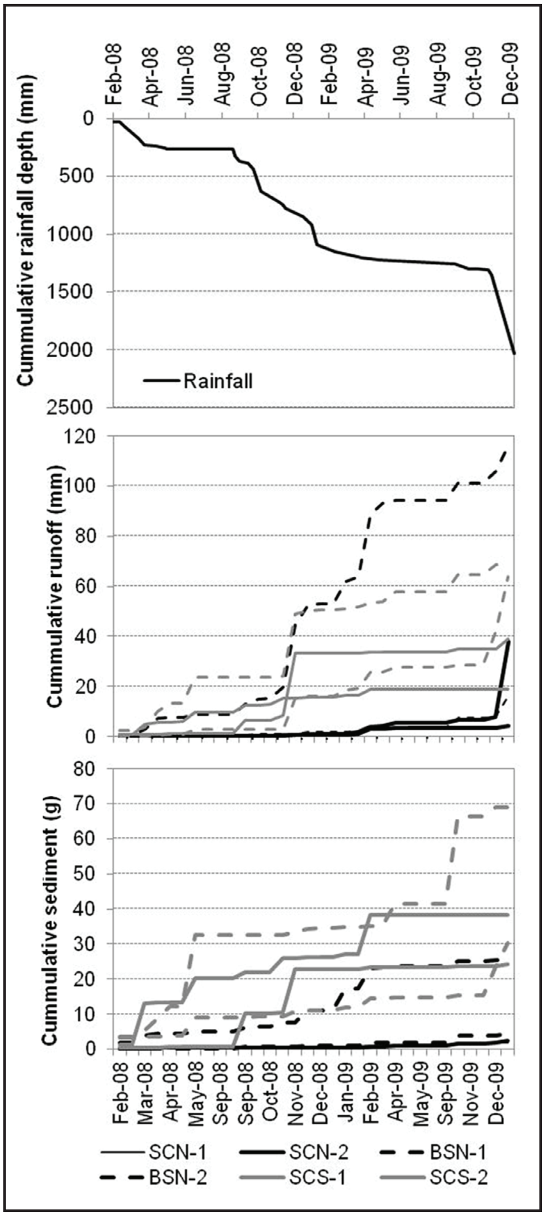

Fig. 5. Cummulative rainfall depth, runoff volume, and sediment registered in the experimental area from the micro-plots of both north and south facing hillslope during the study period.
Fig. 5. Precipitación, escorrentía y sedimentos acumulados en las micro-parcelas de exposición norte y sur durante el periodo de estudio.

Figure 6 depicts the relationships between different hydro-meteorological variables. Although the data tended to be scattered, some trends shall be drawn. The threshold of rainfall depth for generating runoff was always lower in bare soil plots than in the shrub ones, being especially evident in the north micro-plots. It was observed that many rainfall events with more than 50 mm and/or 20 mm h^{-1} of depth and I10, respectively, did not register runoff. However, and especially in the north micro-plots, some rainfall events with less than 20 mm h^{-1} also produced runoff rates greater than 1 l m^{-2}. Regression analysis indicated notable increments in runoff (up to one order of magnitude) with small increments in I10 in all of the plots. According to these regression lines, shrubs seem to be more efficient in reducing runoff in the south micro-plots.

4. Discussion

Over-grazing produced a decrease of vegetation cover in the experimental site in relation to that observed in nearby natural areas not grazed. That result is a patchy vegetation pattern in both north and south facing hillslope where the micro-plots were installed. This type of vegetation pattern is very frequent in more arid climatic conditions in Mediterranean rangelands (Lavee *et al*., 1998; Cammeraat, 2004; Arnau-Rosalén *et al*., 2008; Ruiz-Sinoga *et al*., 2011). As a consequence, soils remained bare in the case of the south facing hillslopes and not covered by shrubs in the north facing ones. On one hand, bare soils in south facing micro-plots were characterised by crusts and embedded rock fragments in the soil surface which limited water infiltration in similar ways to those observed by other authors in laboratory and field conditions (e.g. Poesen and Lavee, 1994; Poesen *et al*., 1994; Katra *et al*., 2007; Ruiz-Sinoga and Martínez-Murillo, 2009b). Indeed, some properties from bare soils showed more degraded conditions (lower clay and organic matter content, and aggregate stability) and thus water erosion and soil degradation features following the model proposed by Lavee *et al.* (1998). On the other, soils not covered by shrubs in north facing micro-plots were cover instead by annual plants and moss, which imply less evaporation and higher soil water content during longer periods. This resulted in less marked differences regarding to eco-geomorphologic conditions in relation to soils covered by shrubs, with similar soil properties that are being favoured by water infiltration in both micro-environments. Similar hydrological response was observed by Ruiz-Sinoga and Martínez-Murillo (2009b) and Ruiz-Sinoga *et al.* (2010c) in Mediterranean rangelands in southern Spain. Some remarks can be drawn from our results at this stage:

First, eco-geomorphologic differences in the micro-plots implicated different soil moisture responses to rainfall during the study period. Soil moisture was always higher in north facing hillslope and beneath shrubs (and, also, independently of exposure); favourable conditions for water infiltration in north facing soils and, in general, in soils beneath shrubs explained the higher soil water contents. In fact, ponded areas were common to be observed in the north facing hillslope after abundant and prolonged rainfalls in areas with minor slope gradient. Although soil moisture data did not exactly correspond to data measured during rainfall events or just after they finished, it can be used for the hydrological interpretation of the micro-plot responses, in addition to the field observations. Micro-plots from both exposures achieved similar total runoff volumes at the end of the study period. However, the soil water content measured during the rainy seasons was always smaller in bare soil than in shrubs, and in south micro-plots than in the north ones. Crusted surfaces of bare soils in south micro-plots may be limiting water infiltration an enhancing runoff generation by Hortonian mechanisms (infiltration excess); while eco-geomorphologic conditions of soils in north

Table 4. General statistic of the hydrological and erosive data recorded. Abbreviations: R, total runoff; Sd, standard deviation; Rr, runoff rate; Rc, runoff coefficient; S, total sediments; SC, sediment concentration; SL, soil loss.
Tabla 4. Eventos y resultados estadísticos generales de los datos hidrológicos y registrados. Abreviaturas: R, escorrentía total; Sd, desviación estándar; Rr, tasa de escorrentía; Rc, coeficiente de escorrentía; S, sedimentos totales; SC, concentración de sedimentos; SL, pérdida de suelo.

Plot		R (l)	Rr (l m^2)	Rc (%)	S (g)	SC (g l^{-1})	SL (g m^{-2})
SCN-1	Total*/Mean	4.18/0.13	0.09	0.1	2/0.2	0.33	0.14
	Sd	0.37	0.27	0.2	0.2	0.62	0.28
SCN-2	Total*/Mean	38.1/1.19	0.47	0.3	2.4/0.2	0.35	1.85
	Sd	5.3	1.77	0.5	0.2	0.56	5.91
BSN-1	Total*/Mean	16.4/0.51	0.22	0.2	4.4/0.4	0.25	0.19
	Sd	1.63	0.55	0.6	0.6	0.26	0.33
BSN-2	Total*/Mean	116.1/3.63	2.49	2.8	25.8/1.3	0.81	1.05
	Sd	6.31	4.75	1.8	1.8	1.37	1.78
SCS-1	Total*/Mean	38.8/1.21	0.87	0.7	24.2/2.2	0.45	0.14
	Sd	4.49	3.44	2.1	4.4	0.55	0.18
SCS-2	Total*/Mean	19.0/0.59	0.46	1.0	38.4/2.7	2.29	4.21
	Sd	1.17	0.90	2.5	4.2	3.12	7.41
BSS-1	Total*/Mean	63.7/1.99	1.04	1.1	30.3/2.0	0.83	1.96
	Sd	4.83	2.26	2.2	2.7	1.12	4.38
BSS-2	Total*/Mean	68.8/2.15	1.50	2.6	69.0/4.3	1.78	5.72
	Sd	4.87	3.68	6.3	7.5	3.75	16.11
North exposure		198.3/1.4	0.82	0.8	37.4/0.63	0.48	0.85
South exposure		190.3/1.5	0.97	1.4	161.8/2.89	1.40	3.31
Scrub		100.1/0.8	0.47	0.5	66.9/1.39	0.93	1.74
Bare soil		265.0/2.1	1.31	1.7	129.5/2.06	0.97	2.35
North scrub		42.2/0.7	0.28	0.2	4.4/0.19	0.3	0.96
South scrub		57.9/0.9	0.66	0.9	62.5/2.50	1.5	2.55
North bare soil		132.6/2.1	1.36	1.5	30.1/0.94	0.6	0.76
South bare soil		132.5/2.1	1.27	1.9	99.3/3.20	1.3	3.84

micro-plots (annual plants and moss) were more prone to infiltrate water, thus favouring soil saturation and registering similar runoff volumes to those of south micro-plots, especially, after long rainy periods recorded. Both trends and runoff mechanisms were also recognized in similar Mediterranean rangeland environments (Martínez-Murillo and Ruiz-Sinoga, 2007; Ruiz-Sinoga and Martínez-Murillo, 2009c), even with soils on limestone (Calvo *et al*., 2003; Boix-Fayos *et al*., 2007). These may explain the absence of significant differences between runoff from north and south micro-plots, especially, in those under shrubs in the upper plot positions and in bare soils in the lower zones. Nevertheless, differences arise when the response of the micro-plots was analyzed at the event scale: south micro-plots, especially those with bare soil in the lower position, registered more frequently runoff rates higher than 1 l m^{-2} with rainfall intensities lower than 20 mm h^{-1}; despite such differences were not so clear and significant as it was originally expected.

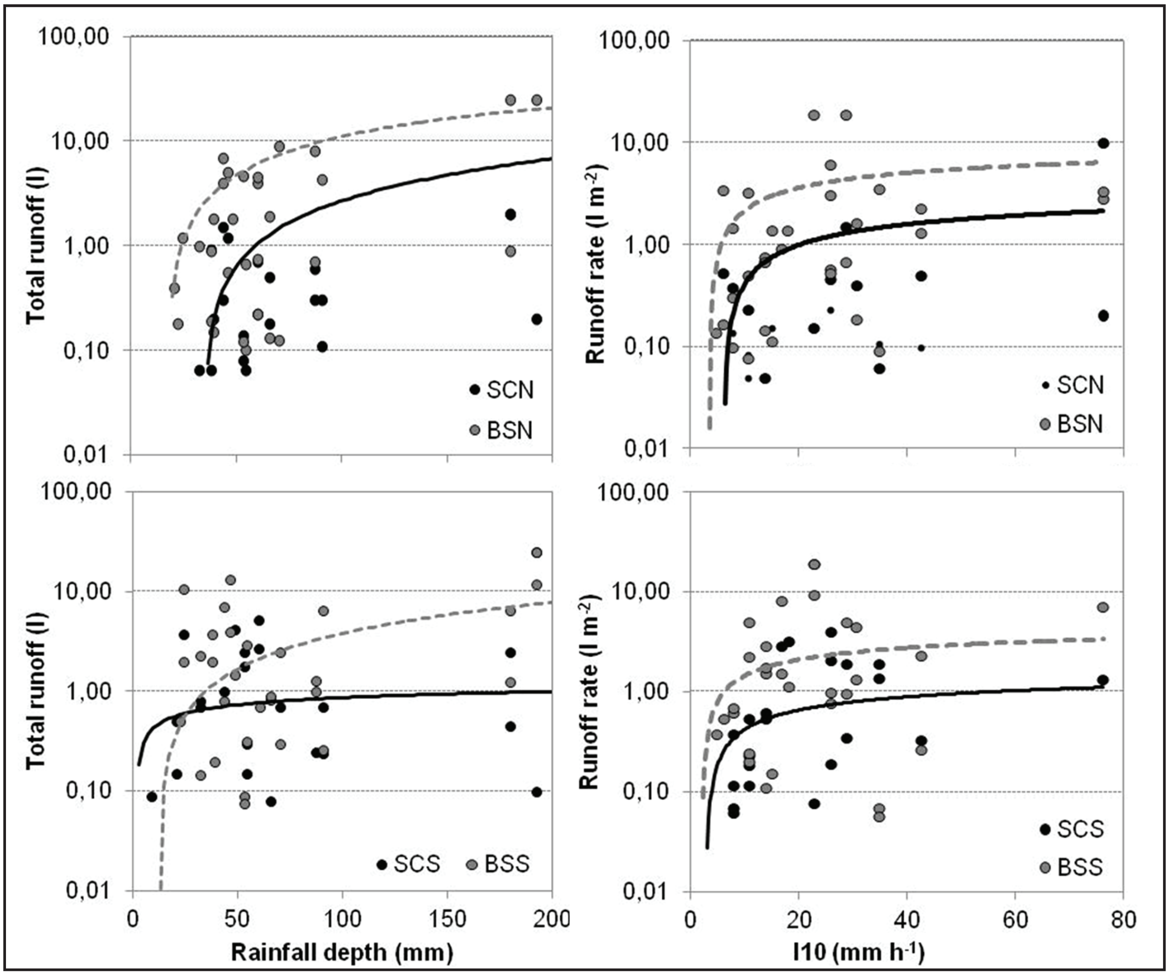

Fig. 6. Scatter-plots and general trend of the relationships between rainfall depth, rainfall intensity, total runoff and runoff rate in the micro-plots from north and south facing hillslope. Abbreviations: I10, maximum rainfall intensity for 10-minutes period.

Fig. 6. Gráfico de nube de puntos y tendencia general de las relaciones establecidas entre precipitación total, intensidad de precipitación, escorrentía total y tasa de escorrentía registradas en las micro-parcelas con exposición norte y sur. Abreviaturas: I10, intensidad de precipitación maxima en 10 minutos.

Second, soil loss appeared to be directly correlated to eco-geomorphologic features, as it was previously expected. The presence of completely bare soils in the south facing micro-plots explained the larger and more frequent emission of soil sediments in comparison to the north facing ones. Except for one north micro-plot, the south ones recorded an order of magnitude larger sediment loss. Crusts and embedded rock fragments in the soil surface enhanced runoff generation and soil particle transport at the studied patch scale in the south facing hillslope. No temporal trends were recognized as there were no significant differences in the emission of sediments along the study period (i.e. more sediment transport during autumn rainfall events). In contrast, the soil not covered by shrubs in the north facing micro-plots was covered by annual plants (in winter) and moss resulting in the absence or lower emission of sediments. Only one micro-plot in the north facing hillslope presented similar soil loss rates to those observed in the south facing ones (i.e. autumn 2008). The cause was the disturbance occurred within the plot due to grazing: cows stepped on the micro-plot, breaking the moss cover and leaving the soil completely bare. Moss cover recovered after rainy season, and annual plants recolonised the site at the same time; as a consequence soil loss reduced (Figure 4).

Table 5. Results of the F-test and significance levels obtained for the means of the considered hydrological and erosion variables. Abbreviations: F, F-test; Sig., level of significance ($p < 0.05$).
Tabla 5. Resultados del F-test y nivel de significancia obtenidos a partir de las medias de las variables hidrológicas y erosivas consideradas. Abreviaturas: F, F-test; Sig., nivel de significancia ($p < 0.05$).

Factor		F	Sig.
Exposure	R	-	-
	Rr	-	-
	Rc	5.42	0.021
	S	27.9	0.000
	SC	12.0	0.001
	SL	8.7	0.004
Vegetal position	R	13.6	0.000
	Rr	13.0	0.000
	Rc	21.6	0.000
	S	-	-
	SC	-	-
	SL	-	-

5. Conclusions

The exposure factor reduces the impact of over-grazing on the hydrological and erosive response of soils in Mediterranean humid rangelands. Soil moisture in north facing hillslopes remains higher, thus enhancing the presence of moss cover and the growth of annual plants, the two main soil surface component in that exposure in the study area. In contrast, bare soil as in the south facing hillslopes was characterised by crusting and embedded rock fragments. Therefore, the hydrological and erosive response in those south facing areas were more similar to those observed in more arid sites; i.e. first, regarding to the mechanisms of runoff generation related to limited water infiltration capacity; and second, in relation to soil loss rates registered during rainfall events. Oppositely, the north facing ones showed mechanisms typically found under natural eco-geomorphologic conditions, related to soil saturation (despite of the over-grazing have also produced a significant reduction in vegetation cover). Soil erosion in those areas is almost negligible. The south facing hillslopes face critical grazed pressure that has pushed them to an abnormal situation for their eco-geomophologic potential conditions; the impact of climate change towards a more arid climate may trigger positive feedback processes leading to desertification. In contrast, north facing hillslopes seem to better support over-grazing, under current climatic conditions.

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