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# Comparative Analysis of Runoff and Sediment Yield with a Rainfall Simulator After Experimental Fire

E. MARCOS
R. TÁRREGA
E. LUIS-CALABUIG
Area of Ecology
Faculty of Biology
University of León
Léon, Spain

*Changes produced in runoff and sediment levels before and after fire and during the revegetation process were examined using a rainfall simulator. The area was burned in an experimental fire, reaching temperatures from 35° to 563°C. Then it was revegetated using different species combinations. Fifteen permanent plots were established in the burnt area (4 treatments and a control replicated three times). Simulated rainfall of 15 mm per 5 min was applied in each treatment. No significant differences were found in sediment yield and runoff between treatments, but greatest runoff was observed to occur immediately after the fire. A significant relationship was found between runoff and woody cover, and a decrease in runoff can be observed as cover increases. The relationship between sediment yields and runoff rates was also positive. The low rates observed during rainfall simulation are due to the effect of natural vegetation rather than revegetation treatments. The high organic matter content also had an influence on the low rates of runoff and sediment.*

**Keywords** burning, heathlands, revegetation, soil loss

Heathland communities are among the main types of vegetation in the province of León (NW Spain), covering 33% of its surface (Ministerio de Agricultura 1984). *Erica australis* L. shrubs are the most representative amongst these communities (Luis et al. 1989). Most of these heathlands are the result of human action, first replacing forest by grazing and then abandoning them, which allowed heathlands to invade progressively. For this reason, communities with a high fire risk are formed. A mean of about 600 fires occur annually in León province producing a mean annual burnt surface of 2800 ha (Source: Dirección General del Medio Natural, Ministry of the Environment). The main result of fires is the disappearance of plant cover, so the soil is exposed to erosive agents.

The effects of fire on soil depend on the temperature reached in the fire, its duration and the postfire rainfall. There are three processes of chemical change in soil associated with fire: the combustion of organic matter, ash addition, and changes in nutrient availability (Diaz-Fierros et al. 1990). Generally, a small increase in soil fertility is observed (Raison 1979), although a long-term net loss of nutrients from the ecosystem, mainly by leaching, generally occurs. Forest fires disturb soil properties related to erodibility, since they remove plant cover and also induce

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Address correspondence to Dr. E. Marcos, Area of Ecology, Faculty of Biology, University of León, 24071 León, Spain. E-mail: degemp@unileon.es

changes in the organic matter content, structure, particle size, and other characteristics (Vallejo 1997).

Studies on the effects of burning on erosion in the Mediterranean Basin were initiated two decades ago (Sala and Rubio 1994). In Italy, Giovannini and Lucchesi (1993) reported mean annual erosion of 144 kg $ha^{-1}$ in plots subjected to light fire but 1472 kg $ha^{-1}$ in those subjected to severe fire and only 30 kg $ha^{-1}$ in control plots. In Spain, Sala, Soler, and Pradas (1994) found that the erosion rates in burned plots were 127.33 g $m^{-2}$ $a^{-1}$ and 16.63 g $m^{-2}$ $a^{-1}$ in the controls. Soto and colleagues (1994) reported values of 169 and 226 g $m^{-2}$ $a^{-1}$ in burnt areas and 50 g $m^{-2}$ $a^{-1}$ in the control area. Calvo and Cerdá-Bolinches (1994), using a rainfall simulator, found values of 19.72 g $m^{-2}$ $a^{-1}$ one day after the fire and 3.11 g $m^{-2}$ $a^{-1}$ one year later. These differences are due to various methods of assessing erosion and runoff, variation in rainfall intensities, slope, conditions, and small-plot versus watershed-scale studies.

Numerous studies have made use of artificial rainfall to study surface soil erosion and other processes both in the field (Da Silva 1990; Commandeur 1992; Greene and Sawtell 1992; Loch and Foley 1992; Swistock, Sharpe, and Dewalle 1992; Chow and Rees 1994; Robichaud and Waldrop 1994; Sardo, Vella, and Zimbone 1994; Eldridge and Kinnell 1997; Greene et al. 1998) and in the laboratory (Edwards and Burney 1992; Burgoa et al. 1993; Havis and Alberts 1993; Soto 1993). The major advantage of rainfall simulator research is that it allows comparison of the same rainfall characteristics between treatments and replications, as well as the possibility of using small plots (1 $m^2$). It also allows rain of differing erosive powers to be simulated under controlled conditions and on soils of different uses and typologies.

One of the methods most commonly used against soil erosion is the revegetation of burned areas. At present numerous studies are being carried out on restoration of areas affected by fire and under serious risk of erosion. Their aim is to accelerate the growth of vegetation in the first few months after the fire to protect the soil, avoid erosion and its degradation (Pinaya and Díaz-Fierros 1996; Badía, Cristobal and Duraw 1996; Fernández-Abascal et al. 1996; Bautista, Gras, and Bellot 1996; Vallejo 1997); the importance of vegetation cover as protecting agent is pointed up (Andreu et al. 1994; Soto et al. 1994).

Although studies on the effects of fire on soil chemical properties have been carried out in León province (Marcos et al. 1995), there were no data on erosion levels after fire. So a study was carried out to determine soil loss after an experimental fire reaching known temperatures. Furthermore, the effect of revegetation, using species natural to the area, without any improvement as possible additional protection for the soil, was considered in order to determine whether it is necessary to revegetate after a fire in these areas. Therefore, the main aim of this study was to determine the changes produced in the runoff rates and sediment yield after an experimental fire and during the revegetation process by using a rainfall simulator.

## Materials and Methods

### *Study Site*

The study was carried out in a typical shrub area of *Erica australis* L. subsp. *aragonensis* (Willk.) P. Cout., in the province of León (NW Spain, 42°41′N, 1°25′W). The study plots were located in a homogeneous, dense heathland, 1–1.5 m high. The dominant species in the area before the fire was *Erica australis* L. subsp. *aragonensis* (Willk.) P. Cout., with a mean biomass of 1 kg $m^{-2}$ and a cover of 63.3% (Fernández-Abascal, Tarréga, and Luis 1995). Other abundant species were *Arctostaphylos uva-ursi* (L.) Sprengel (36.6% cover) and *Calluna vulgaris* (L.) Hull (34.5%). Mean cover of herbaceous species was about 5%.

It has a 10% slope, N-NE orientation and the elevation is 1063 m above sea level. The climate is subhumid Mediterranean with a mean annual temperature of 10.2°C and a mean annual rainfall of 839.8 mm, with 732 mm annual evapotranspiration (EVT). Maximum rainfall is in January (103 mm) and the minimum in July 29.2 mm, EVT 139.4 mm). The soil is a humic Cambisol (FAO 1985), formed on Tertiary materials consisting of siliceous conglomerates (Mapa Geológico de España 1982).

### *Fire Traits*

An experimental fire was carried out in an 18 × 10 m plot in July, 1993. Immediately prior to burning, samples of the woody fuels, forest floor, and mineral soil were collected to determine moisture content (on a weight basis). During the fire, the Forestry Service (Centro de Investigaciones Forestales de Lourizán, Ministry of the Environment) measured environmental data such as air temperature, relative humidity, wind speed, and wind direction. Average fuel loading in the area was 1.8 kg $m^{-2}$ (Fernández-Abascal et al. 1995).

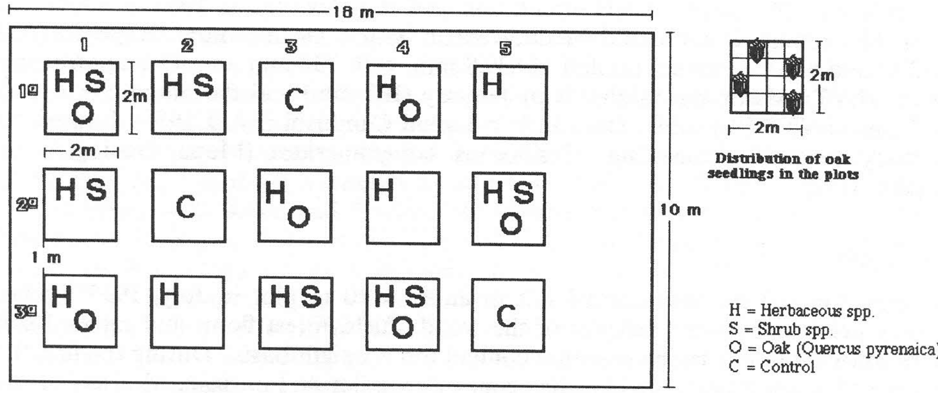
A thermocouple system was used to measure temperatures in the soil. These were placed at different vegetation heights (litter, 35, 65, 100, and 150 cm), and buried in the soil (at depths of 0, 1, 2, and 3 cm), then linked by buried electrical cables to a data-logger. Data from each sensor were recorded every 15 seconds. During the fire, some posts on the edge of the plot were placed two meters apart in order to determine the spread rate and flame height.

### *Revegetation Treatments*

In March, 1994, revegetation of the area was started using different species combinations, all of them natural to the area. Fifteen permanent plots measuring 4 $m^2$ were established in the burned area (four treatments and a control replicated three times). These plots were distributed according to the scheme in Figure 1. Treatments were randomly assigned to plots. Seed quantity was estimated by weight in order to have 20,000 seeds, equally divided amongst the species assigned to each treatment, per square meter in each plot sown.

- Treatment 1: Herbs: *Lotus corniculatus* L. (40 g); *Agrostis capillaris* L. (2.4 g) and *Festuca rubra* L. (34 g).
- Treatment 2: Herbs and shrubs: *Lotus corniculatus* L. (20 g); *Agrostis capillaris* L. (1.2 g); *Festuca rubra* L. (16 g); *Cytisus scoparius* (L.) Link (10 g); *Calluna vulgaris* (L.) Hull (7 g) and *Erica australis* L. subsp. *aragonensis* (Willk.) P. Cout. (24 g).
- Treatment 3: Herbs and trees: *Lotus corniculatus* L. (20 g); *Agrostis capillaris* L. (1.2 g); *Festuca rubra* L. (16 g) and *Quercus pyrenaica* Willd. (four oak seedlings).
- Treatment 4: Herbs, shrubs and trees: *Lotus corniculatus* L. (20 g); *Agrostis capillaris* L. (1.2 g); *Festuca rubra* L. (16 g); *Cytisus scoparius* (L.) Link (10 g); *Calluna vulgaris* (L.) Hull (7 g); *Erica australis* L. subsp. *aragonensis* (Willk.) P. Cout. (24 g) and *Quercus pyrenaica* Willd. (four oak seedlings).
- Treatment 5: Control

Herb seeds used to revegetate were commercial varieties, with a high germination index, while shrub and tree seeds were purchased from the Forest Nursery, Nature Conservation Institute. The shrub species were subjected to heat treatment at 100°C for 11 minutes before sowing to stimulate germination. Species germination capacity was analyzed in the laboratory, simultaneously with sowing in the field; *Erica australis* and *Calluna vulgaris* did not germinate but *Cytisus scoparius* and the herbaceous species had a germination of over 50% (Fernández-Abascal et al. 1996). In the case of shrub and herb species, sowing was by scattering the seed. Tree species seedlings were obtained from germination of seeds in the laboratory.




| Plot H | Plot H + S | Plot H + O | Plot H + S + O |
|---|---|---|---|
| Lotus. 40 g | Lotus. 20 g | Lotus. 20 g | Lotus. 20 g |
| Agrostis. 2,4 g | Agrostis. 1,2 g | Agrostis. 1,2 g | Agrostis. 1,2 g |
| Festuca. 34 g | Festuca. 16 g | Festuca. 16 g | Festuca. 16 g |
| | Cytisus. 10 g | Quercus 4 U | Cytisus. 10 g |
| | Calluna. 7 g | | Calluna. 7 g |
| | Erica. 24 g | | Erica. 24 g |
| | | | Quercus 4 U |

FIGURE 1 Distribution of plots in the experimental burned area, with weight (g) of seeds of each species sowed in each plot.

To assess plot revegetation, inventories of the vegetation were carried out before each simulated rainfall. The abundance values of each of the species present (species sown and not sown) were visually estimated as percentage cover, as well as percentage of bare soil.

### *Rainfall Simulation Experiments*

In order to assess sediment yield and runoff rates, simulated rainfall was applied both before and after burning and one and a half years after carrying out revegetation (September, 1995), always on the same plots. To do this 1 m$^2$ plots were isolated by a 20 cm sheet of metal placed vertically in the ground to a depth of 5 cm. The rainfall simulator used was made at León University and is a modification of the model suggested by Wilcox et al. (1986). The rain-making system consists of a 1/4 G 12 SQ type spraying nozzle, made by the Spraying Systems Company, on an adjustable telescopic leg. Pressure is regulated with a compression stop valve and monitored with two low pressure steam gauges, one situated in the lower part of the rainfall simulator and the other over the nozzle. Flow and pressure are guaranteed by a pump connected to a double circuit water entry and exit which sucks up the water from a 30 liter capacity reservoir. In order to determine the characteristics of the artificial rainfall, drop size distribution and median volume drop diameter were determined using the flour pellet method (Hudson 1985).

A rainfall intensity of 180 mm h$^{-1}$ was selected for this study. It was applied to each plot for five minutes, at a constant pressure of 0.5 bar and from a fall height of 2 m. Light-weight plastic was placed around the square in order to avoid wind disturbance.

Surface runoff was collected and delivered to a single exit point situated at the lowest part of the plot and manually collected in 1000 mL bottles. The time taken to fill each one was recorded. All runoff samples were weighed and oven-dried to determine runoff rates and sediment yield.

### *Soil Properties*

Chemical and physical properties of soils at the study site were determined using soil samples taken from two depths: 0–2 cm and 2–5 cm. Properties were measured on air-dried samples as follows:

Organic carbon was measured using the Walkley–Black (1934) wet combustion technique. Amounts of organic carbon were high (>5%). Soil pH, determined potentiometrically in a 1:2.5 ratio in $H_2O$, was acid (4.7). Available P (Olsen et al. 1954) was very low (0.16 mg $kg^{-1}$) and the CEC. (Peech et al. 1947) was 28 $cmol_c$ $kg^{-1}$. Particle size analysis of the fraction <2.0 mm was carried out according to Gattorta (1953) using dispersed samples and the pipette method. This analysis revealed that the 0–2 cm layer consisted of 4.4% clay, 8.45% silt, and 85.62% sand. Aggregate stability was measured using a modified wet-sieving technique as recorded by Malquori and Cecconi (1962). This involved two immersions of 2-1 mm fraction of the soil in water for 5 and 60 minutes. The results were expressed as a Structural Stability Index (69.94, which is considered good). Gravimetric moisture content of the two layers was determined using disturbed samples.

### *Data Analysis*

To determine whether significant differences exist between the treatments in sediment yield and runoff rates, the results were analyzed using analysis of variance and statistical significance determined at the $P < 0.05$ level. Then linear regression analysis was carried out to discover the relationship between the previously mentioned parameters and herb cover, woody cover (considering sown and nonsown species together) and bare soil.

## Results and Discussion

### *Experimental Fire*

Environmental data and moisture content of the soil and fuel (Table 1) indicate a low moisture content in the mineral soil (10.3%) as well as the litter (13.9%) but a higher moisture content in the fuel, which was over 100% (of dry weight) in many cases. The experimental fire had the same characteristics as a typical fire in this area and in this type of vegetation (Table 2). Flame height (10 m) was rather high and so was the rate of spread (2 m $min^{-1}$). Maximum average temperature within the litter

TABLE 1 Fuel moisture and weather conditions at the time of ignition

| | |
|---|---|
| Ambient characteristics | |
| Relative humidity | 38.8% |
| Wind speed | 0.5 m $s^{-1}$ |
| Wind direction | E |
| Ambient temperature | 33°C |
| Woody fuel moisture (<0.5 mm) | |
| *Erica australis* (dry) | 4.64% |
| *Erica australis* (green) | 104.24% |
| *Arctostaphylos uva-ursi* (green) | 146.23% |
| Other species (green) | 120.94% |
| Litter moisture | 13.90% |
| Soil moisture | 10.30% |

TABLE 2 Fire behavior

| | |
|---|---|
| Firing technique | Strip headfire |
| Flame height | 10m |
| Rate of spread | 2.0 m $min^{-1}$ |
| Preburn litter depth | 13mm |
| Postburn litter depth | 2mm |
| Max. average temperature | |
| at litter | 563°C |
| at mineral soil surface | 72°C |
| at 2 cm below mineral interface | 33°C |

was 563°C and lasted for only one minute, but temperatures higher than 300°C lasted for four minutes. Surface mineral soil temperature never exceeded 80°C and temperature at below mineral soil interface was under 33°C. The low temperatures and short duration of the fire (5–10 minutes), as well as the existence of black ash after it, indicate a low-severity fire in which the fuel has been charred but not completely burned (except at some points in the area where white ash can be seen). Approximately 85% of the litter layer was consumed in the fire and the mineral soil was evenly exposed at certain points. After this type of fire in which charred fallen leaves and a large amount of litter remain, the structure and hydric properties of the soil are not significantly changed (Da Silva 1990).

### *Rainfall Simulation*

Distribution values of drop size dimension, expressed as volume %, and the median drop size (D 50), expressed as accumulated volume %, are shown in Figure 2. It can be seen that the 0.63 mm drops gave the highest percentage for this pressure. No drops larger than 2 mm were found. D50 for pressure used is 0.71 mm. The drop size produced by this rainfall simulator is smaller than that produced by natural rainfall at the same intensity. For example, Laws and Parsons (1943) reported that average drop diameter in natural rainfall at an intensity of 100 mm $h^{-1}$ was 2.8 mm. It is also smaller than that produced by other simulators at lower intensities and similar fall heights (Wilcox et al. 1986; Da Silva 1990; Rejman 1992). Raindrop terminal velocity was 6.97 m $s^{-1}$ and mean kinetic energy at the pressure used was 15.75 j $m^{-2}$ $mm^{-1}$, which is approximately equivalent to 50% natural rainfall at the same intensity.

Rainfall intensity obtained in this rainfall simulator was very high when compared with other intensities obtained using the same type of nozzle. For example, with a pressure of 0.5 bar Da Silva (1990) obtained a rainfall intensity of 121 mm $h^{-1}$ and Wilcox and others (1986) obtained an intensity of 98 mm $h^{-1}$ with 0.48 bar. These differences could be due to variations in the manufacture and the regulation of water flow by the valve. Although a rainfall intensity of 180 mm $h^{-1}$ or above is a rare event in the area, due to the small drop size produced by the rainfall simulator, the rainfall energy is low but very similar to that produced by lower rainfall intensities (Marcos 1997).

### *Natural Recovery and Revegetation in Relation to Runoff and Sediment Yield*

Plant cover percentage one and a half years after sowing for woody and herbaceous species reached practically 50% of unburned cover, both in the treatments and control (Table 3). No significant differences ($P < 0.05$) were found for woody cover, herb cover, and bare soil on carrying out ANOVA between treatments. The contribution in cover values of the sown species was not above 5% for all treatments,

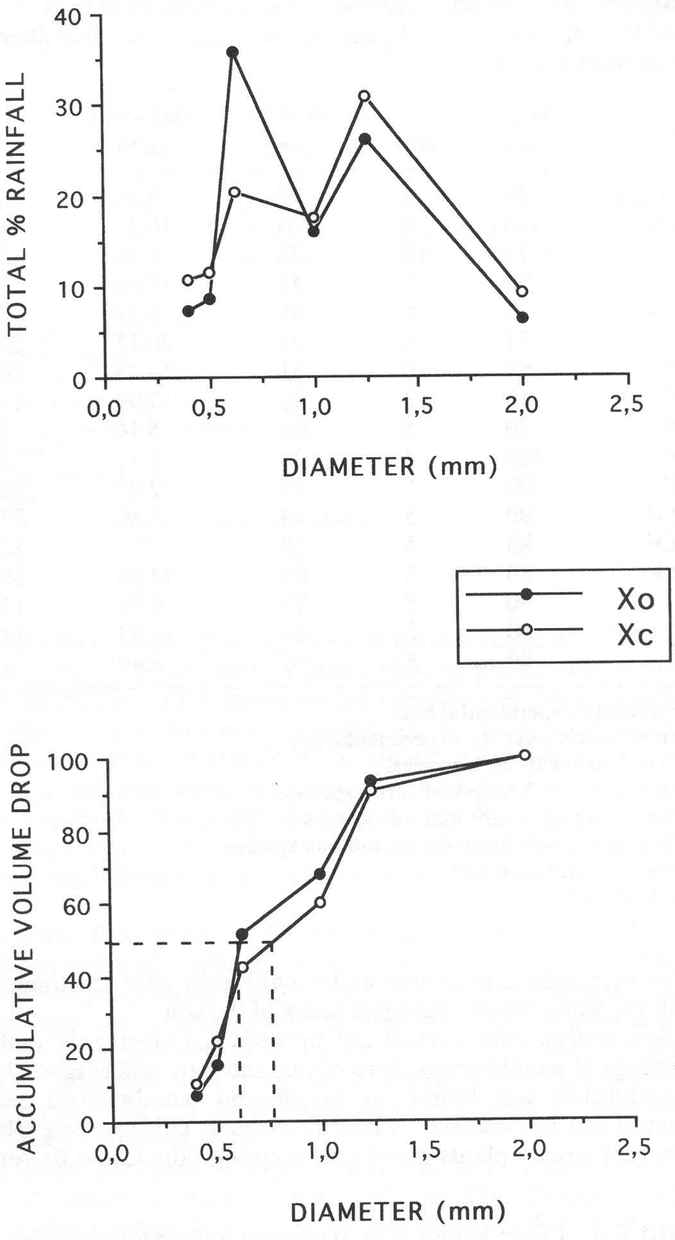



**FIGURE 2** Drop size distribution and median volume diameter (D50). (Xo = Drop size distribution in the combined outside quadrats; Xc = Drop size distribution in the center quadrat, according to Hudson, 1985).

while unsown species reached values of 70% in some cases (Table 4), due to sprouting ones such as *Erica australis* subsp. *aragonensis* and *Halimium alyssoides*. This also explains the high percentage of bare soil present in these plots.

When comparing some soil properties before and after the fire and for each treatment, it can be observed that pH and sand, silt, and clay contents are very similar in all cases, not detecting any change after the fire or after revegetation (Table 5). In the case of organic carbon, a strong increase is observed after the fire

**TABLE 3** Plant cover percentage (%), sediment yield (g $m^{-2}$) and runoff (mL $m^{-2}$) before and after fire and eighteen months after revegetation treatments

| Plot | Bare soil | Herb spp. | Woody spp. | Sediment yield | Runoff |
|---|---|---|---|---|---|
| Unburnt[a] | 50 | 2 | 99 | 1.18 | 1360 |
| Burnt[b] | 100 | 0 | 0 | 10.32 | 5100 |
| H[c] | 75 | 10 | 73 | 1.66 | 1300 |
| H[c] | 93 | 5 | 45 | 17.06 | 1310 |
| H[c] | 30 | 5 | 85 | 0.32 | 240 |
| HS[d] | 55 | 5 | 77 | 20.11 | 2220 |
| HS[d] | 99 | 10 | 31 | 10.38 | 2685 |
| HS[d] | 30 | 3 | 85 | 17.99 | 1920 |
| HO[e] | 70 | 5 | 69 | 5.16 | 210 |
| HO[e] | 100 | 3 | 28 | 5.11 | 250 |
| HO[e] | 90 | 5 | 37 | 12.07 | 4680 |
| HSO[f] | 90 | 5 | 44 | 8.80 | 2730 |
| HSO[f] | 85 | 5 | 58 | * | 2280 |
| HSO[f] | 80 | 3 | 67 | 14.23 | 3670 |
| C[g] | 70 | 5 | 77 | 4.94 | 1580 |
| C[g] | 80 | 3 | 63 | 11.23 | 1410 |
| C[g] | 80 | 8 | 55 | 4.49 | 170 |

[a] Before the experimental fire.
[b] Immediately after the experimental fire.
[c] Plots sown with herb species.
[d] Plots sown with herb and shrub species.
[e] Plots sown with herb and oak species.
[f] Plots sown with herb, shrub, and oak species.
[g] Plots unsown (control).
* Lost data.

but its content decreased greatly one and a half years after treatments. The same happened with the water stable aggregate index of the soil.

A regression analysis was carried out between sediment yield and runoff rate and the percentage of woody cover, herb cover, and bare soil (Figure 3, Table 3). A significant relationship was found for runoff and woody cover percentage. A decrease in runoff can be observed as cover increases. This can be explained by the important role that woody plants play in intercepting rain. Calvo de Anta, Paz, and

**TABLE 4** Cover values (n = 3) of sown and unsown species and bare soil for each revegetation treatment

| | H[a] | HS[b] | HO[c] | HSO[d] | C[e] |
|---|---|---|---|---|---|
| Sown species | 1.6 | 2.0 | 2.3 | 3.6 | 0.0 |
| Unsown species | 72.6 | 68.3 | 47.0 | 57.0 | 70.3 |
| Bare soil | 66.0 | 61.3 | 86.6 | 85.0 | 76.6 |

[a] Plots sown with herb species.
[b] Plots sown with herb and shrub species.
[c] Plots sown with herb and oak species.
[d] Plots sown with herb, shrub, and oak species.
[e] Plots unsown (control).

**TABLE 5** Soil properties (n = 3) before and after fire and eighteen months after revegetation treatments

| | Unburnt[a] | Burnt[b] | H[c] | HS[d] | HO[e] | HSO[f] | C[g] |
|---|---|---|---|---|---|---|---|
| pH[h] | 4.7 | 5.0 | 5.2 (0.1) | 4.9 (0.3) | 4.9 (0.2) | 5.2 (0.1) | 5.3 (0.4) |
| C (%)[i] | 9.8 | 15.0 | 5.3 (0.5) | 4.2 (0.5) | 5.6 (1.9) | 5.3 (0.2) | 4.5 (0.4) |
| S.S.I.[j] | 61.2 | 65.6 | 47.1 (7.9) | 55.0 (1.9) | 44.5 (6.1) | 53.5 (8.8) | 47.4 (5.3) |
| Sand (%)[k] | 83.4 | 83.3 | 83.6 (0.2) | 85.5 (1.6) | 82.3 (1.8) | 85.0 (0.9) | 82.1 (1.1) |
| Silt (%)[k] | 8.2 | 7.9 | 10.2 (0.1) | 8.6 (1.3) | 11.0 (0.7) | 9.2 (0.7) | 11.4 (1.3) |
| Clay (%)[k] | 5.3 | 5.6 | 4.2 (0.4) | 4.2 (0.5) | 4.5 (0.5) | 4.0 (0.4) | 4.7 (0.2) |

[a] Before the experimental fire.
[b] Immediately after the experimental fire.
[c] Plots sown with herb species.
[d] Plots sown with herb and shrub species.
[e] Plots sown with herb and oak species.
[f] Plots sown with herb, shrub, and oak species.
[g] Plots unsown (control).
[h] Measured in water suspension.
[i] Walkley and Black (1934).
[j] Maluori and Cecconi (1962); SSI: Structural Stability Index.
[k] Gattorta (1953).

Diaz-Fierros (1979) recorded rainfall losses of between 60% and 70% from beneath *Ulex* and *Erica* shrubs. When water is intercepted by plant cover, it then falls to the ground more gradually and is incorporated into the soil much better. It also prevents the formation of surface water streams. There is a clear relationship between vegetation regeneration and soil infiltration capacity (Cerdá-Bolinches 1994).

The slope of the regression line between sediment yield and runoff rates was also positive (Figure 4). The higher the runoff rate, the greater the amount of soil that will be swept away. Navas (1993) and Commandeur (1992) recorded a strong positive correlation between the increase in runoff volume and the increase in sediment yield.

Figure 3 shows the regressions lines between sediment yield and runoff rate with the percentage of herbs and bare soil. In the case of the regression between sediment yield and bare soil percentage, a higher sediment yield can be observed as bare soil increases, although the amount of bare soil is very large in most cases. The herbs have a very low cover percentage throughout the study period, but a tendency can be observed for sediment yield to diminish as their cover increases. Woody plants give more variable values in the different treatments with a reduction in sediment yield seen as woody cover increases.

There is a positive slope of regression line between runoff rates and bare soil percentage and volume increases as bare soil does. On relating it to herb cover, a negative slope of regression line can be observed as runoff volume diminishes with the increase in this cover.

In spite of the fact that no significant differences ($P < 0.05$) were found in sediment yield and runoff between treatments, the differences observed in sediment yield (Figure 5) between the different treatments and within each of them are due to shrub species distribution in each plot rather than soil humidity content. Wan Harun, Marsom, and Manan (1990) found that soil loss was not very sensitive to small variations in soil moisture content when this was close to its field capacity. Robichaud and Waldrop (1994) also found that soil moisture was not correlated to runoff rates, and they indicate that the high variability can be attributed to the different conditions of forest floor cover and the amount of soil exposed postfire. The shrubs were not uniformly distributed in the study plots so the simulated rain fell directly on the bare soil in many cases, thus producing higher sediment yield.

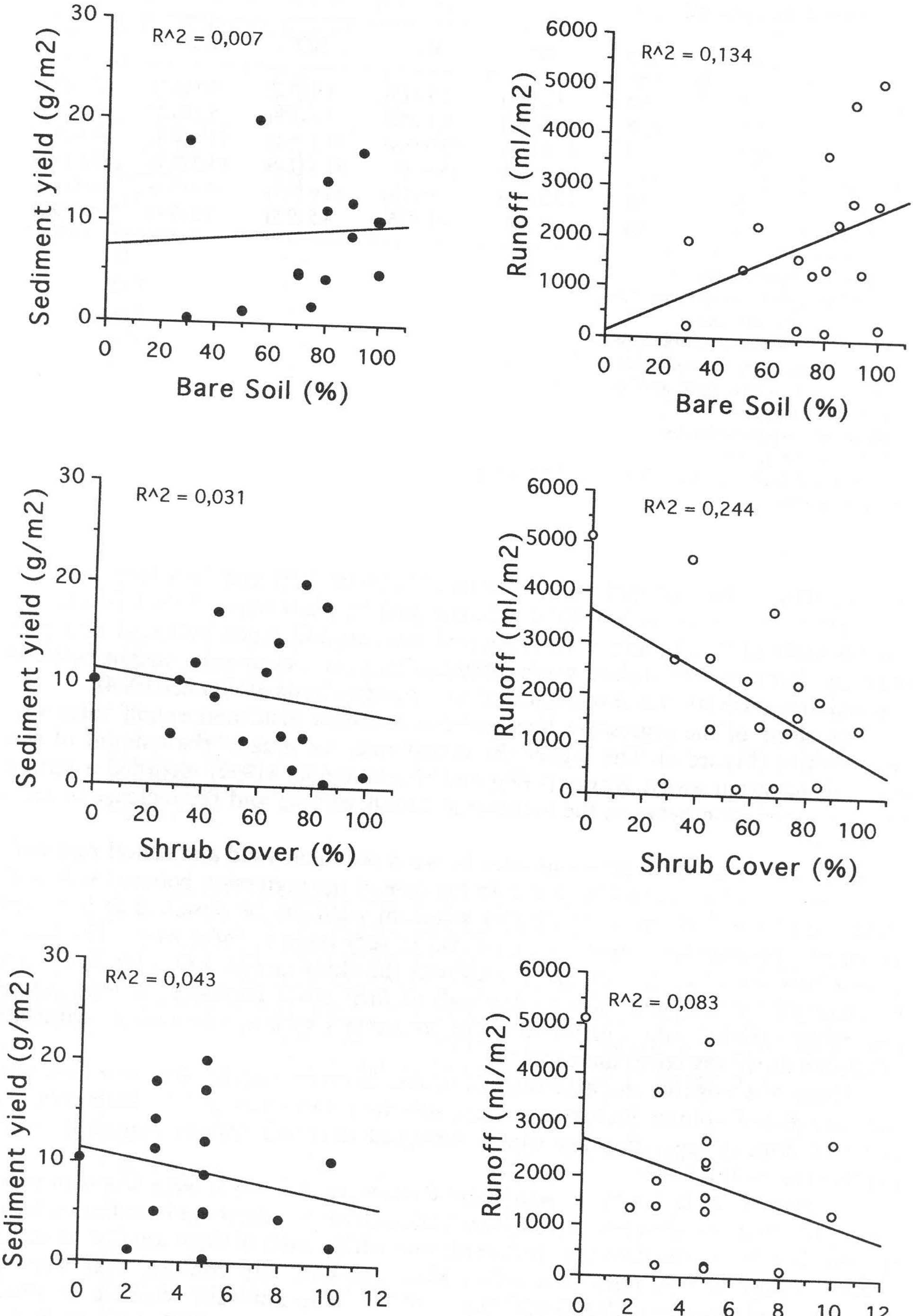



**FIGURE 3** Regression analysis between sediment yield and runoff with bare soil (%), shrub and herb cover (%). (Only regression between runoff and shrub cover is significant, $P < 0.05$).

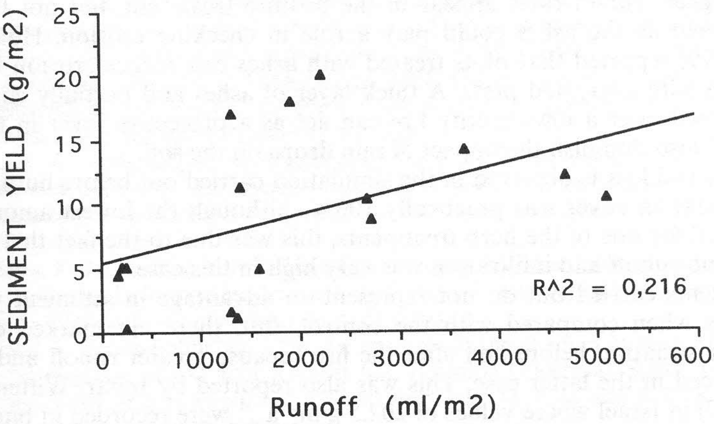
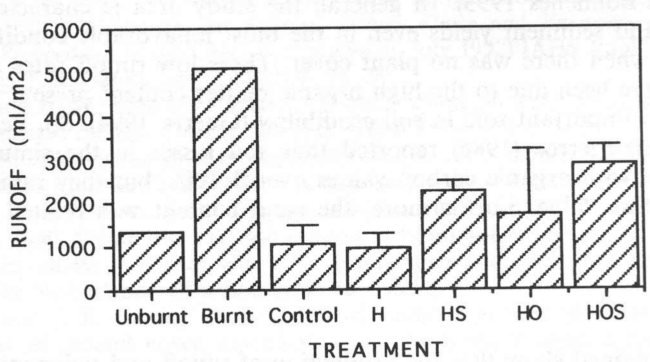



**FIGURE 4** Regression analysis between sediment yield and runoff rates ($P < 0.05$).



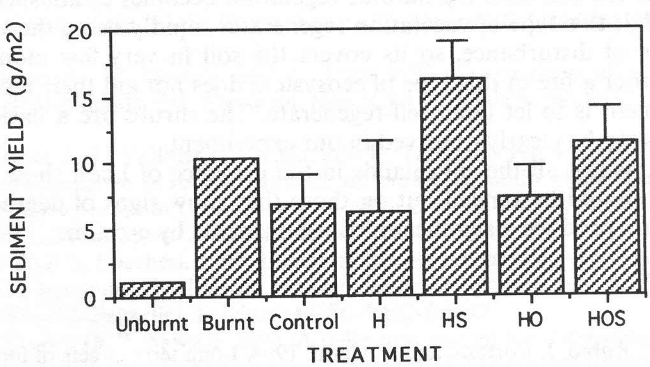




**FIGURE 5** Mean and standard error of sediment yield and runoff rates in the different treatments. (Unburnt = Before the experimental fire; Burnt = Immediately after the fire; C = Plots unsown 18 months after fire; H = Plots sown with herb species; HS = Plots sown with herb and shrub species; HO = Plots sown with herb and oak species; HOS = Plots sown with herb, shrub, and oak species).

The highest runoff rates appear in the postfire treatment, but not the highest sediment yield as the ashes could play a role in checking erosion. Holcomb and Durgin (1979) reported that plots treated with ashes can reduce erosion by 36% in comparison with untreated plots. A thick layer of ashes and partially charred residues produced after a low-severity fire can act as a protective layer in the face of erosion and also diminish the impact of rain drops on the soil.

A lower soil loss is observed in the simulation carried out before burning, where woody vegetation cover was practically 100%. Although the lowest amount of soil was recorded for one of the herb treatments, this was due to the fact that there was practically no runoff and infiltration was very high in this case.

Treatments carried out do not represent an advantage in sediment yields and runoff rates when compared with the control. But, there are marked differences between the situation before and after the fire because greater runoff and sediment were produced in the latter case. This was also reported by Inbar, Wittenberg, and Tamir (1997) in Israel where values of 202.5 g $m^2$ $a^{-1}$ were recorded in burned areas in contrast to 0.001 g $m^{-2}$ $a^{-1}$ in the control area. Although some differences between treatments were detected, in all cases, runoff began after some minutes (even with the high water content present in the soil) except in the simulation after the fire which was very rapid. This situation contrasts with that found in degraded soils from the south of Spain where flooding and runoff is produced rapidly even with a minimum of precipitation, so high runoff rates and sediment yields are produced (Cerdá-Bolinches 1993). In general, the study area is characterized by low runoff rates and sediment yields even in the most unfavorable conditions, such as after the fire when there was no plant cover. These low runoff rates and sediment yields may have been due to the high organic matter content present in these soils, which play an important role in soil erodibility (Guerra 1994). So, Benito, Gómez-Ulla, and Diaz-Fierros (1986) reported that soil losses in the simulator rainfall were very low with organic carbon values over 8–10%, but they rapidly increased when below this value. Furthermore, the sand content was related to the more stable soils.

## Conclusions

The results obtained show that the production of runoff and sediments in this type of ecosystem is low. This may be due to the fact that the fire was of low-medium intensity, similar to those occurring in this area, so that a residual forest floor is left which protects the soil until the natural vegetation becomes established. It has to be pointed out that this type of vegetation regenerates rapidly using the vegetative way after this type of disturbance, so its covers the soil in very few months. Planning revegetation after a fire in this type of ecosystem does not aid their recovery and the best management is to let them self-regenerate. The shrubs are a basic tool for soil protection, as can be clearly observed in our experiment.

However, as not all the shrublands in the province of León show these characteristics, tests should be carried out on those that show signs of degradation and in which fire could produce a significant loss of nutrients by erosion.

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