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Occurrence of soil erosion after repeated experimental fires in a Mediterranean environment

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Abstract

In the Mediterranean area, forest fires have become a first-order environmental problem. Increased fire frequency progressively reduces ecosystem recovery periods. The fire season, usually followed by torrential rains in autumn, intensifies erosion processes and increases desertification risk. In this work, the effect of repeated experimental fires on soil response to water erosion is studied in the Permanent Field Station of La Concordia, Valencia, Spain. In nine 80 m^2 plots (20 m long x 4 m wide), all runoff and sediment produced were measured after each rainfall event. In 1995, two fire treatments with the addition of different biomass amounts were applied. Three plots were burned with high fire intensity, three with moderate intensity, and three were unburned to be used as control. In 2003, the plots with the fire treatments were burned again with low fire intensities. During the eight-year interval between fires, plots remained undisturbed, allowing regeneration of the vegetation–soil system. Results obtained during the first five months after both fire experiments show the high vulnerability of the soil to erosion after a repeated fire. For the burned plots, runoff rates increased three times as more than those of 1995, and soil losses increased almost twice. The highest sediment yield (514 g m^{-2}) was measured in 2003, in the plots of the moderate moderate fire intensity treatment, which yielded only 231 g m^{-2} of sediment during the corresponding period in 1995. Runoff yield from the control plots did not show significant temporal changes, while soil losses decreased from 5 g m^{-2} in the first post-fire period to 0.7 g m^{-2} in the second one.

Keywords: Water erosion, Repeated fire, Experimental plots, Runoff, Sediment yield, Mediterranean area.

1. Introduction

In recent years, increased forest and bush fires in the Mediterranean countries have become a major environmental problem. Although the total area affected by fires has decreased since the year 2000, the EU Mediterranean countries have experienced an increased number of fires (European Commission, 2002). In many cases, areas once burned and recovering their pre-fire conditions will be burned again. This circumstance clearly favours a progressive degradation of these ecosystems modifying their structural and hydrological soil conditions, reducing the total biomass and changing the dominant vegetal species. Although it is difficult to estimate an exact recovery time for burned zones, Inbar et al. (1998) suggested a period of 5-10 years after fire to return to background levels of sediment yield in the Mediterranean areas of Israel. Moody and Martin (2001) proposed a similar recovery period of 3-9 years for forest zones in Colorado.

In the Mediterranean region, fires usually occur in summer and are followed by torrential autumn rains, which results in a high potential for surface runoff and erosion (Díaz-Fierros et al., 1994; Andreu et al., 1996). These processes result in fire being one of the principal causes of desertification in the region (Rubio and San Roque, 1990; Trabaud, 1990).

Several studies indicate that the greatest increase in runoff and soil loss occurs within one or two years after burning (Robichaud and Waldrop, 1994; DeBano, 2000), but the amount and timing of erosion depends greatly on fire intensity and severity, as well as the characteristics, distribution and timing of post-fire rainfall events (Rubio et al., 1996). With the particular rainfall distribution of the Mediterranean region, four to six months after fire is often the period of highest soil susceptibility to water erosion (Sala et al., 1994; Andreu et al., 2001).

We studied the impact of repeated fires on soil erosion in 1995 and 2003, with eight years of vegetation recovery between the fires. Soil losses by surface runoff in the first five months after each fire were monitored and the results for the two periods were compared.

2. Materials and Methods

2.1. Study area

This work was carried out in the Permanent Field Station of La Concordia, in the municipality of Lliria (Fig. 1), 50 km NW of Valencia City, Spain (39º45' N and 0º43' W). The terrain where the Field Station is situated was ceded by the Forestry Services of the Valencian Governement (Generalitat Valenciana).

The study area is situated on the west side of the La Calderona range, which belongs to the coastal foothills of the Iberian Mountainous System. This mountainous chain is perpendicular to the Mediterranean Sea (NW-SE) and its altitude is very variable: 200-1200 m a.s.l. To the south, relief becomes smaller and ends in a gentle plain. The study area lacks perennial streams, but there are several *ramblas* (dry streams) with N-S direction that flow into the catchment of the Turia River. The Permanent Field Station is located on a forested concave hillside with a SSE aspect, with a 22º slope and an altitude ~575 m a.s.l. (Fig. 2).

Soil in the study area is a Rendzic Leptosol according to the FAO classification (FAO-UNESCO, 1988), developed on Jurassic limestones, with variable depths of < 40 cm. Soil texture is between sandy loam and silty loam with a high stoniness (40%). Some physico-chemical characteristics of this soil are reported in Table 1.

Mean annual precipitation of the area is ~400 mm, with a maximum in autumn (51.7 mm in October) and a less rainy period in spring (34.1 mm in April). The dry period usually ranges from April or May to September with a mean temperature of 34ºC. The mean annual temperature is 17.2ºC. Vegetation cover is characterized by a shrubland that developed after a wildfire in 1978. The most abundant species are

Rosmarinus officinalis, *Ulex parviflorus, Quercus coccifera, Rhamnus lycioides, Stipa tenacissima*, *Globularia alypum*, *Cistus clusii* and *Thymus vulgaris* (Gimeno-García et al., 2000).

The Permanent Field Station consists of a set of nine 80 m^2 erosion plots, 4 m wide by 20 m long, with similar pedologic, morphologic and vegetation cover characteristics. The selection of each plot location was made after intensive surveys on soil, vegetation (number of individuals of each species, height and diameter), slope angle and surface geology (rock outcrops number and bare soil percentage) based on 58 transects transversal to the slope allocated with a 2 m interval. Plots are oriented parallel to the slope and bounded by bricks. At the foot of each plot, there is a 2 m wide collector connected to a 1500 L tank to record all runoff and sediment produced during each rainfall event. Inside this tank, there is another of 30 L into which water and sediment first flow,is collected to permit accurate measurement when runoff is small. During the studied periods, the amount of runoff and sediment produced in each plot, in response to each rainfall event, was recorded.

2.2. Fire design

The effects of fire on soil and its response to water erosion depend on fire characteristics, mainly fire intensity, which is related to the maximum temperature reached on the soil surface and its duration (Whelan, 1997). Two different fire intensity treatments were used. The assignment of the fire treatment to each plot was made completely at random, without blocking. In June 1995, two sets of three plots each were burned with high and moderate fire intensities. To achieve these intensities, the addition of different amounts of fuel load to the plots was necessary: 40 t ha^{-1} for high intensity and 20 t ha^{-1} for moderate intensity. This also guaranteed the continuous progression of the fire front. The quantity of dry biomass added was calculated using a methodology similar to that proposed by Etiene and Legrand (1994). This biomass, similar to that present initially in the plots, was taken from the surrounding area. The remaining three plots were maintained unburned to be used as the control treatment.

After the 1995 fires, all plots were left undisturbed allowing natural regeneration of the vegetation cover, although in the meantime the monitoring of climatic and erosion parameters continued. Eight years later, in July 2003, the plots corresponding to the fire treatments were burned again but without addition of biomass. In this way, the effect of repeated fires on ecosystems recovering from previous fires was well reflected. Only a small constant quantity of biomass (2.5 t ha^{-1}) was added to maintain the fire continuity in the plots.

In both experimental fires (1995 and 2003), the temperatures on the soil surface and their duration were measured by means of thermosensitive paints and thermocouples. From thermocouple measurements, direct estimates were made of the duration that the temperature in soil exceeded the threshold value of 100ºC. This value was selected because beyond this temperature changes in soil properties can occur.

In 1995, the mean soil surface temperature reached was 439ºC for the high intensity treatment plots and 232ºC for the moderate intensity ones, and temperatures higher than 100ºC lasted 36 and 17 min for each treatment, respectively (Gimeno-García et al., 2000). In 2003, the average temperature on the soil surface for all burned plots was 170ºC and the average time exceeding 100ºC was 4 min. These fires can be classified as of low intensity. To differentiate between treatments in this study, we conserve the same classification of the plots: high and moderate intensity.

2.3. Soil sampling and analysis

Four soil samples per plot were taken from 0-5 cm depth to determine some physico-chemical characteristics (4 x 3 = 12 samples per treatment: total n = 36). The samples were air-dried and screened to remove the >2 mm diameter fraction, and stored in plastic boxes until analysis. Standard laboratory analyses were performed (Table 1). Organic matter content was determined by the Walkley-Black method (Jackson, 1958). Soil pH was measured in water and KCl, and electric conductivity was determined in the saturation extract of soil (Richards, 1954). To assess soil aggregate stability, a wet-sieving procedure (0.25 mm mesh) was used (Primo-Yufera and Carrasco, 1973) and total carbonates were measured using the Bernard calcimeter method (MAPA, 1986). Water retention capacity was calculated using the pressure membrane method (Richards, 1947).

During the studied periods, after each rainfall event, the total amount of runoff and sediment generated from each plot was measured. When the total volume of collected water and sediment was < 30 L, the inner 30 L tank was used to measure those parameters. If the volume is larger, the content of the inner 30 L tank is poured into the 1500 L tank; where water and sediment is then mixed and homogenized; and a 1 L mixed sample is taken from different depths, usually three, depending on the height and volume of the runoff in the tank. This sample is filtered through a pre-weighed 5 µm filter paper to separate sediment from water. The filters with the sediments are dried at 105ºC for 24 hours and weighed to determine the sediment mass in each sample. The total sediment produced is calculated by extrapolating the sediment in the 1 L sample with the total volume of runoff collected.

Climatic parameters were monitored by a logging system of sensors with GSM data transmission, placed inside the Station enclosure. The rainfall parameters recorded were: total volume, rainfall intensity (I_{30}) and total duration of the rainfall event (D).

Analysis of variance and Tukey's test at α = 0.05 were performed to detect differences in the hydrological and erosive parameters between fire treatments, and to compare their variations between the studied periods. Standard statistical bivariate correlation analyses were applied, at 95 and 99% significance levels, between the main erosive rainfall parameters (total volume, I_{30} and D), runoff and sediment yields to determine the effects of rainfall characteristics on water erosion for the different fire treatments.

3. Results and discussion

3.1. Rainfall characteristics

Since the establishment of the Experimental Station, various precipitation characteristics have been recorded. Total annual rainfall has varied from a minimum of 204.5 mm in 1998 to a maximum of 556.1 mm in 2002. Standard deviation of total annual rainfall from 1995 to 2003 is 119.14 mm, corresponding to a variation of ~30-50%. In 1995, 344.9 mm of precipitation was received, including 134.9 mm for the five months period immediately after the fire (June-November). In 2003, the total annual rainfall was 464.0 mm, 241.7 mm of which was recorded during the first five months after the fire (July-December). The difference in total precipitation values between 1995 and 2003 is 119.12 mm, similar to the standard deviation of this period. The number of rainfall events increased, from 72 in 1995 to 113 in 2003. Distribution of annual precipitation also changed. In 1995, about 30% of the total annual rainfall was accumulated before the experimental fires; while 48% was collected before the fires in 2003 (Fig. 3). The more homogeneous rainfall distribution in 2003 could have allowed the maintenance of a certain soil moisture and faster runoff generation.

The above differences in the precipitation regime between the years are not reflected in the number of erosive rainfall events. During the five months following both fire events, eight erosive events with runoff generation were recorded (8 x 3 = 24 events per treatment: n = 72). However, the characteristics of these post-fire rainfall events were different (Fig. 4A). The duration of these events was 153.8 min in 1995 but almost double in 2003 (327.5 min). The I_{30} thresholds to produce runoff and sediment transport were 1.4 and 1.6 mm h^{-1} in 1995 but 1.6 and 2.2 mm h^{-1} in 2003, respectively.

In 1995, the first erosive rainfall occurred almost two months after the fire, while in 2003 the first erosive event took place only 10 days after the fire, producing the highest rates of runoff and sediment (Figs. 4 and 5). In 1995, after a dry month of July with only one rainfall event of 1.8 mm, two rainfall events were recorded: one on August 23rd (I_{30} of 20.8 mm h^{-1} and *D* of 90 min), and the other on August 30th (I_{30} of 14.6 mm/h and *D* of 285 min). In 2003, 3.0 mm of total rainfall in June was followed by two intense storms: one on 30 July with I_{30} of 65.4 mm h^{-1} and *D* of 30 min, and the other on 17 August with I_{30} of 21.0 mm h^{-1} and *D* of 60 min (Fig. 4A). These differences in the rainfall characteristics resulted in differences in the magnitude of erosion.

3.2. Water erosion

The erosive rainfall / total rainfall ratio in 2003 was 56.2%, almost one-third lower than that in the 1995 period (70.3%). Therefore, it would be expectable that post-fire runoff in 1995 be greater than that in 2003. Nevertheless, the former generated runoff was smaller than the latter by 69.6%, with maximum values of 3.9 L m^{-2} in 1995 (high intensity, 18th September) and 9.7 L m^{-2} in 2003 (moderate intensity, 30th July), (Fig. 4). This variation is mainly due to the high intensity of 2003 post-fire rainfalls, as mentioned previously, but also to the different elapsed time between the fire impact and the first rainfall (Fig. 4A). In the control plots, both periods showed similar intensity thresholds for runoff generation (1.4 mm h^{-1} for 1995 and 1.6 mm h^{-1} for 2003), and, in fact, runoff yield levels are also quite similar, with average values of 0.13 and 0.15 L m^{-2} in 1995 and 2003, respectively (Table 2).

Burned plots responded differently to the trend described above with an average runoff in 1995 being 71.0% less than that in 2003 (149.7 L m^{-2}). Runoff differences between the burned and control plots increased from an average of 85.6% after the 1995 fire to 95.3% after the 2003 fire. Both differences are significant at $p < 0.05$ (Table 2). Although the runoff differences between the plots burned with high intensity in 1995 and those burnt with moderate intensity were not statistically significant, they increased from 5.3% in 1995 to 11.3% in 2003. In this last year the runoff values were higher in the moderate intensity plots contrary to 1995, where the high intensity plots showed the highest ones. This trend accords with the data reported by Benavides-Solorio and MacDonald (2001) in the Colorado Front Range, after rainfall simulations under very dry conditions conducted on similar soils burned with different intensities in both wild and prescribed fires. The lower soil temperatures reached in the moderate intensity plots in both years, in addition to dry soil conditions, could have created a hydrophobic layer at or near the surface that would have enhanced runoff generation (Shahlaee et al., 1991; Imeson et al., 1992; Doerr and Thomas, 2000).

Another factor that also could play an important role in the hydrological soil response is the ash layer that covers the soil surface after fires. It can contribute to increase runoff and sediment transport by surface sealing and can also act as a protective layer reducing the impact of rain drops and soil detachment. In the 1995 experiment, this layer was deeper and more homogeneously distributed in all plots than in 2003. These ashes could have contributed to mitigate the erosive effect of the first rains, as reflected by the runoff yield values of the studied periods. In 1995, even if the rain events of 23 August and 4 October had similar volumes and I_{30}, the runoff yield of the latter was ~3 L m^{-2} in both fire treatments, while that of the former was 0.2 and 0.4 L m^{-2} in high and moderate intensity treatments, respectively (Fig. 4). This increase in the runoff yield could have been due to the progressive disappearance of the ash layer removed by runoff.

The correlations between the parameters of erosive rainfalls and runoff yields for the 2003 post-fire period are not so evident as those for the 1995 period. In 1995, the runoff yield from the plots affected by fire seems to be controlled mainly by rainfall intensity, as indicated by the significant correlation coefficient ($r = 0.84$, $p < 0.01$), while in the control plots, rainfall volume had the greatest influence (Table 3). In 2003, runoff yield of the burned plots was positively correlated with rainfall volume and intensity, whereas for the control plots only I_{30} played a significant role. Erosive rainfalls of this year had higher duration, volume and intensity than those in 1995, and this fact could have conditioned the differences in the soil post-fire response to water erosion processes between both years.

Infiltration rates present a trend similar to that of runoff generation, i.e., always higher in 2003 than in 1995. In both studied periods, differences in these rates between the burned and control plots are statistically significant at $p < 0.05$ (Table 2). However, in 2003 the average infiltration rate was lower in the moderate intensity plots (9.3 mm h^{-1}) than that in the others (10.1 mm h^{-1} in the high intensity treatment plots and 12.2 mm h^{-1} in the control plots). This fact points out that an alteration of structural and hydrological soil conditions could have occurred in the moderate intensity treatment, despite the probable presence of a hydrophobic layer in the soil (Huffman et al., 2001).

Runoff coefficients in 1995 and 2003 are almost the same for all burned plots, although the values for the high intensity treatment in 1995 and those for the moderate intensity treatment in 2003 are slightly higher, confirming the trend described above. In addition, in both studied periods, runoff coefficients for the control plots showed similar values, ~0.8%, and the differences in these coefficients between burned and unburned plots were statistically significant (Table 2). In 1995, values in the control plots were six times lower than those in the burned ones, which are similar to the post-fire runoff coefficients reported by Sala et al. (1994) on a burnt slope of Collserola Natural Park near Barcelona, Spain. This difference increased up to 20 times in 2003. It is clear that, together with the differences in the precipitation regime between the studied years, the influence of a repeated fire on soil could contribute to increased degradation.

Temporal changes in the hydrological response of plots burned with different fire intensities is more evident for soil losses. Sediment production presents a tendency similar to runoff generation, with a significant correlation between sediment yield of the control plots and rainfall volume in 1995 (Table 3). In 2003, all treatments show a strong positive correlation between soil losses and rainfall intensity ($r = 0.9$, $p < 0.01$), but a less significant correlation for the rainfall volume. This could indicate a greater impact of the 2003 rainfall events as well as the higher degradation of the soil hydrological properties caused by the repeated fire, making the soil more sensitive to the energy and quantity of rainfall (Tables 2 and 3).

The impact of the repeated fire, together with the greater intensity and the earlier occurrence of the 2003 post-fire rainfalls led to the total soil loss almost twice as much as that in 1995 (Table 2). The maximum sediment yields in 1995 and 2003 were 186.8 g m^{-2} (high intensity, 18^{th} September) and 339.5 g m^{-2} (moderate intensity, 30^{th} July), respectively (Fig. 5). In addition, the possibility of a hydrophobicity enhancement, which favours that surface soil particles remain dry and easily detachable, increases the risk of removal by overland flow processes (Morgan, 1997; Shakesby et al., 2000).

Differences in sediment yield between burned and unburned plots were two orders of magnitude in 1995 and three orders of magnitude in 2003, and both differences are significant at $p < 0.05$. These data accord with those reported by Inbar et al. (1998), DeBano (2000), Benavides-Solorio and MacDonald (2001) in arid and semi-arid environments in Israel and the United States. Although the differences are not statistically significant (Table 2), it is important to highlight that soil loss from the plots burned with high intensity in 1995 was 8.1% higher than the loss from the plots burned with moderate intensity, while in 2003 the moderate intensity plots produced 21.1% more sediment than those in the high intensity plots (Fig. 5),. The control plots showed a reduction in total sediment yield from 5 g m^{-2} in the first post-fire period to 0.7 g m^{-2} in the second one (Table 2), due to increased vegetation during eight years. In the high intensity plots, the estimated increase in vegetation amount was 69%, and in the moderate intensity plots it was 63%. The control plots showed an equivalent vegetation increase (50%) in the eight year period.

Most of the eroded sediment from the plots could be rapidly transported to the drainage network formed principally by gullies and *ramblas,* mostly due to torrential rainfalls in autumn. Most of the transported sediments could be stored as floodplain deposits and/or alluvial fans in the watershed of the Turia River.

The observed soil losses are critical for Mediterranean mountain ecosystems, considering that the estimated rate of soil formation in Mediterranean areas is ~200 g m^{-2} $year^{-1}$ (Hudson, 1981). This clearly indicates the importance of the effects of repeated fires on soil erosion. The level of vegetation recovery, the time between fire and the first rainfall and its intensity are key factors in the response of soil to water erosion processes (Emmerich and Cox, 1994; Inbar et al., 1998) mainly in fragile ecosystems like those in the Mediterranean region.

Differences in sediment concentration in runoff between the years 1995 and 2003 are less evident. As shown in Figure 6, the concentrations are lower in 2003 post-fire period than in 1995. In 1995, the difference in sediment concentration between the control plots and the burned ones is not statistically significant, but in 2003, it is statistically significant at $p < 0.05$ (Table 2). The increased soil loss on the moderate fire treatment is again confirmed by sediment discharge in 2003, which is higher in plots affected by this treatment than in those of high intensity. Sediment concentration for the control plots was remarkably smaller, confirming the importance of vegetation cover in protecting land from erosion (Andreu, 1994; Cammeraat and Imeson, 1999). A higher vegetation cover favours macropore fluxes and allows higher soil hydraulic conductivity that diminishes runoff and therefore soil loss (Cerdà et al., 1995).

4. Conclusions

The increasing frequency of fires and their repeated incidence in previously affected zones accelerates soil degradation processes by enhancing the effect of water erosion. This has been clearly demonstrated with the data obtained from the studied plots burned in the summers of 1995 and 2003. During the five months period after both experimental fires, the soil was highly susceptible to water erosion, especially on the occasion of torrential rainfall typical of the Mediterranean region. Rainfall characteristics (mainly I_{30} and total volume) and the time between fire and the first intense rain are key factors influencing runoff and sediment yields on burned slopes. In 2003, the occurrence of an intense rainstorm only 10 days after the fire produced runoff yields almost three times more and soil losses twice as much as those after the previous fire in 1995. Sediment yield of the burned plots in this rain event reached >300 g m^{-2}, outstripping the estimated annual rates of Mediterranean soil formation. In contrast, the improvement on soil hydrological properties due to the natural growth of vegetation, besides its protective effect against water erosion, led to the very low rate of soil losses in the control unburned plots.

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Table 1

Physico-chemical characteristics of the studied soils in 2003, subjected to different treatments of fire intensity (n = 36).

	Fire treatments		
	High [a]	**Moderate [a]**	**Control**
Sand (%) (2000-50 μm)	36.48	34.25	37.16
Silt (%) (50-2 μm)	44.20	46.84	44.31
Clay (%) (<2 μm)	17.93	17.94	17.94
Water retention capacity (%)	29.55	28.54	30.83
Aggregate stability [b](%)	34.97	30.49	30.71
pH	7.70	7.60	7.60
Electrical conductivity (dS/m)	0.73	0.77	0.90
Total carbonate content (%)	54.37	54.21	53.65
Organic matter (%)	7.66	7.99	8.17

[a] These intensities correspond to fire treatments applied to plots in 1995.

[b] Stable aggregates whose diameters are larger than 0.25 mm were measured with a wet-sieving procedure.

Table 2

Values of hydrological and erosion parameters, by fire treatment intensity, for the studied periods in 1995 and 2003 (n = 72). Values with different superscripts (a-c) indicate significant differences between fire treatments detected by Tukey's test ($p < 0.05$) in each studied period.

		1995			2003		
		High	**Moderate**	**Control**	**High** [a]	**Moderate** [a]	**Control**
Runoff yield ($L\ m^{-2}$)	Total	7.45[a]	7.05[a]	1.04[b]	23.45[a]	26.44[a]	1.18[b]
	Mean	0.93[a]	0.88[a]	0.13[b]	2.93[a]	3.31[a]	0.15[b]
Sediment yield ($g\ m^{-2}$)	Total	251.91[a]	231.44[a]	4.95[b]	405.53[a]	514.25[a]	0.69[b]
	Mean	31.48[a]	28.93[a]	0.57[b]	50.69[a]	64.28[b]	0.09[c]
Sediment discharge ($g\ L^{-1}$)	Total	33.83[a]	32.81[a]	4.36[b]	17.29[a]	19.45[a]	0.58[b]
	Mean	13.87[a]	23.37[a]	4.65[a]	10.06[a]	10.22[a]	0.34[b]
Mean infiltration rate ($mm\ h^{-1}$)		5.64[a]	5.67[a]	6.00[b]	10.11[a]	9.34[a]	12.23[b]
Mean runoff coefficient (%)		4.83[a]	4.65[a]	0.78[b]	17.08[a]	17.95[a]	0.86[b]

[a] The intensities correspond to the treatments applied to the plots in 1995 fire experience.

Table 3

Pearson's correlations between rainfall parameters and mean runoff/sediment yields, and by the intensity of fire treatment (n = 72).

	Year	Treatment	Rain volume	Duration	I_{30}
Runoff Yield	1995	High	0.594	0.140	0.839(**)
		Moderate	0.636	0.176	0.840(**)
		Control	0.835(**)	0.289	0.768(*)
	2003	High[a]	0.774(*)	-0.480	0.769(*)
		Moderate[a]	0.825(*)	-0.537	0.876(**)
		Control	0.693	-0.524	0.830(*)
Sediment Yield	1995	High	0.457	-0.075	0.838(**)
		Moderate	0.513	-0.057	0.865(**)
		Control	0.801(*)	-0.209	0.557
	2003	High[a]	0.762(*)	-0.530	0.915(**)
		Moderate[a]	0.793(*)	-0.410	0.904(**)
		Control	0.803(*)	-0.360	0.901(**)

** Significant correlation at p < 0.01 (bivariate).
* Significant correlation at p < 0.05 (bivariate).
[a] Intensities correspond to treatments applied in 1995.

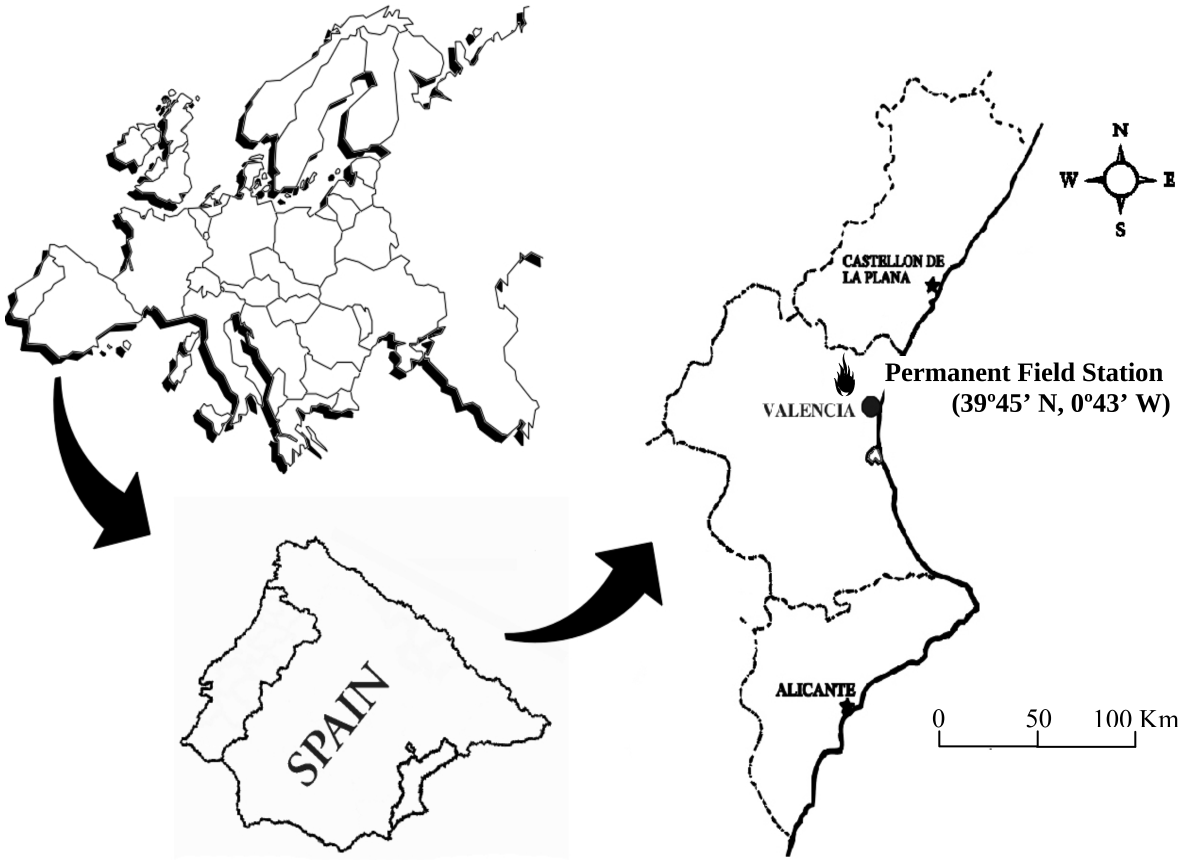

Fig. 1. Approximated location scheme of the study area.

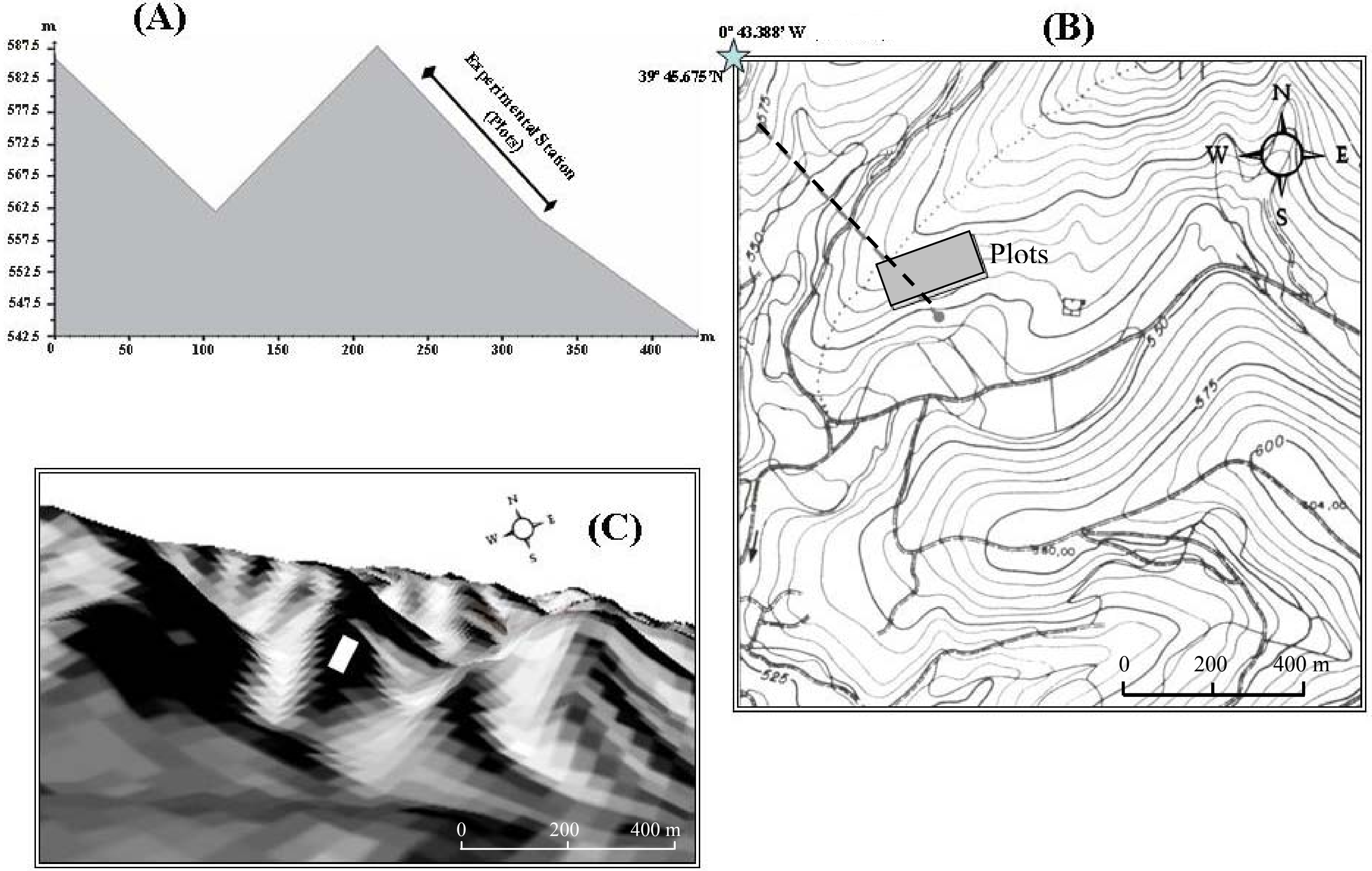

Fig. 2 Morphological characteristics of the study area. (A) Profile with altitudes and distances. (B) Topographic map with altitudes and coordinates. Grey broken line indicates the profile A. (C) Digital terrain model with the location of the plots (white rectangle).

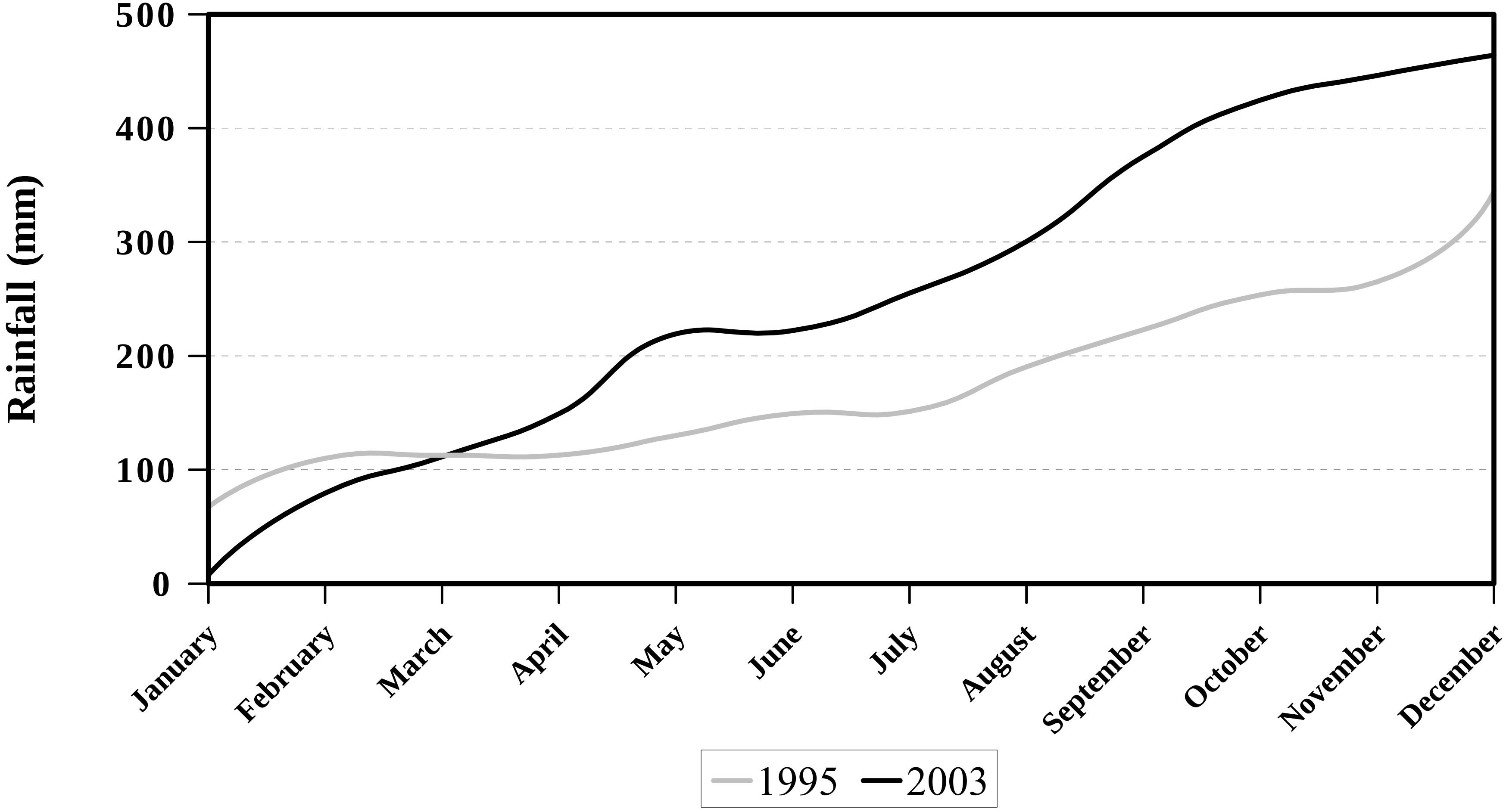

Fig. 3. Accumulative monthly rains during 1995 and 2003.

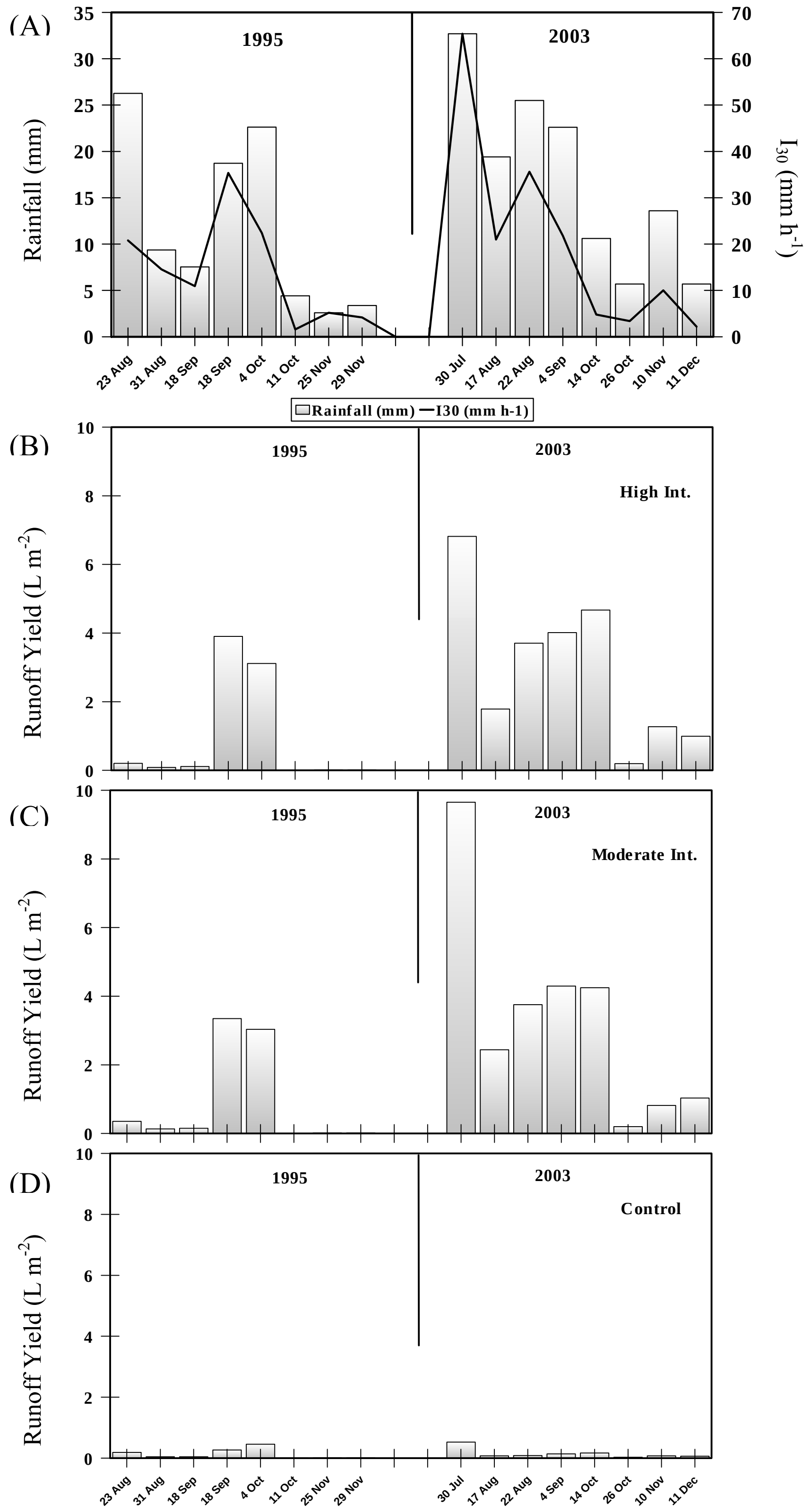

Fig. 4. (A) Characteristics of erosive post-fire rain events in 1995 and 2003 studied periods (rain volume in bars and I_{30} in line). (B)(C)(D) Mean runoff yield produced in each erosive rain event for the different fire treatments, in the post-fire studied periods.

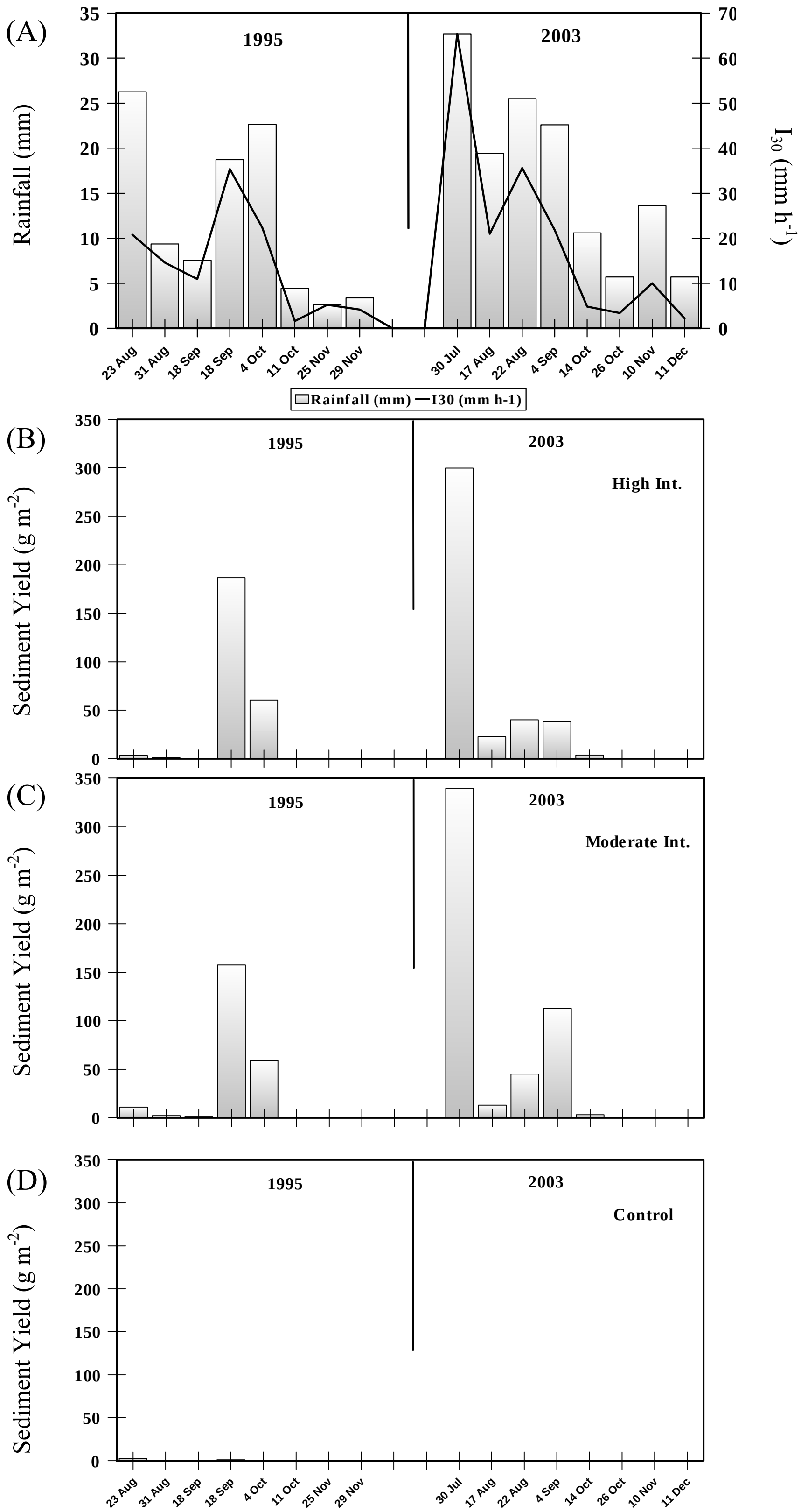

Fig. 5. (A) Characteristics of erosive post-fire rain events in 1995 and 2003 studied periods (rain volume in bars and I_{30} in line). (B)(C)(D) Mean sediment yield produced in each erosive rain event for the different fire treatments, in the two post-fire studied periods.

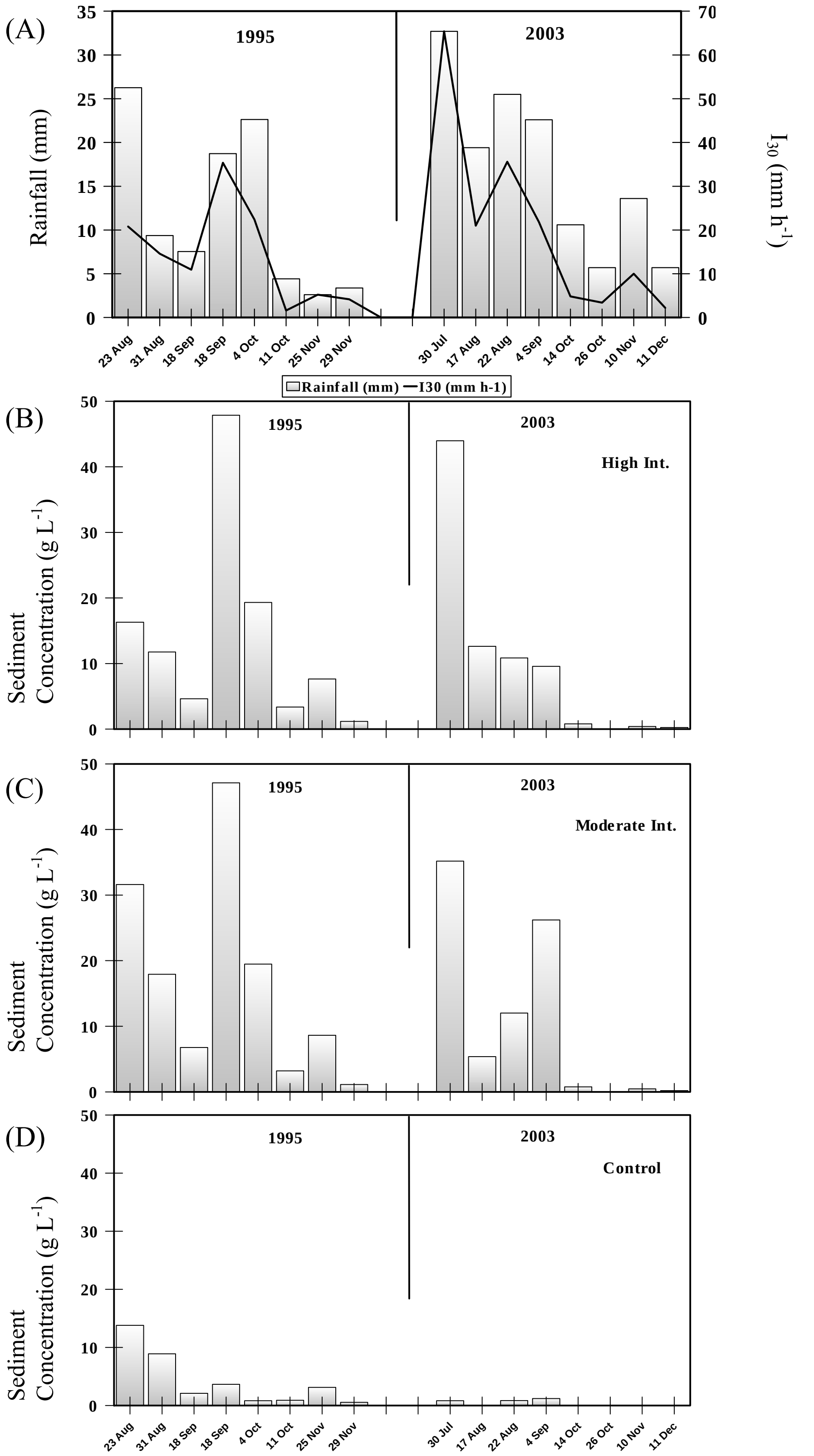

Fig. 6. (A) Characteristics of erosive post-fire rain events in 1995 and 2003 studied periods (rain volume in bars and I_{30} in line). (B)(C)(D) Mean sediment concentration produced in each erosive rain event for the different fire treatments, in the two post-fire studied periods.