

Water Erosion Trends Under the Impact of Different Forest Fire Intensities in a Mediterranean Environment

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Abstract: In this work, the temporal evolution of the incidence of fire on water erosion in a typical Mediterranean forest environment has been evaluated. The effects of fire intensity on soil and its influence on water erosion have been studied on a permanent field station (La Concordia, Valencia, SPAIN) equipped with devices to study climatic, soil and water erosion parameters. This station has nine experimental plots (4×20 m) installed in a calcareous hillside representative of Mediterranean shrubland areas. Experimental burnings of two intensity levels (high and moderate) were carried out on two sets of three plots each. The remainder three plots were used as control. The impact of water erosion processes has been monitored for each rain event occurred before and after the experimental fire from April 1995 to December 2000. Runoff production and soil loss were measured in each rain event during this period in all plots.

In the studied period 69 erosive rain events occurred, from them 55 produced sediment delivery. During the whole period, great differences have been observed between the plots not affected by fire and those correspondents to the fire treatments, with a maximum in 1999. In this year, the control plots reached average values of 97.32% in sediment production and 78.84% in runoff generation lower than the burned plots. The runoff and sediment production has been always higher in the plots affected by fire than in the control ones (mainly the treatment of high intensity) and this difference is maintained with time. Nevertheless, the differences between the plots that suffer high fire intensity and those that suffer a moderate one have decreased gradually with time, being the sediment production in the moderate intensity plots a 64.51% lower than in the high intensity treatment in 1996 (the year after the fire) and a 23.88% in the year 2000.

Climate variability during this period has also influenced significantly the action of the erosive processes and soil response to them. The effects of a drought period since 1998, with changes in the distribution and characteristics of rains have influenced the erosion trends in the different fire intensity treatments. In this sense, the three years period immediately after the fire shows the highest soil losses in all the treatments reaching a total of $35.62 \text{ t} \cdot \text{ha}^{-1}$ meanwhile in the sequent years (1998—2000) was of $3.81 \text{ t} \cdot \text{ha}^{-1}$.

Since the second half of 1999, the change in climate characteristics, mainly in the rain regime, has induced the slow recovery of the vegetation cover in the plots affected by fire and changes in the soil hydrological conditions that have allowed to a better response to water erosion reducing soil losses. However, this recovery has been not enough to reach, after six years, the level of the natural vegetation cover unaffected by fire. It clearly shows the fragility and difficulty of the Mediterranean ecosystems to recover under the impact of forest fires in a variable and drought prone climate.

Keywords: soil water erosion, forest fires, fire intensity, temporal evolution, Mediterranean environment

1 Introduction

Forest fires have played during millenniums a decisive role in the configuration of the earth's landscapes in a natural way. In the Mediterranean climate areas, fire is a usual ecological mechanism for

the forest regeneration and evolution conforming the typical configuration of its landscape, characterised by sparse forests, mainly of Pines and Oaks, with an important scrub substratum.

In the last decades, fires of human origin have substantially increased not only in its number but also in its frequency and extension, which have produced reduction in the recovery periods, which could drastically change or even eliminate the vegetation cover changing and degrading the ecosystem characteristics. This increase has been alarming in the Mediterranean environments. Its effects are contributing to the progressive degradation of forest ecosystems and in the intensification of the erosive processes, which is favouring a distressing advance of desertification risk.

In this paper it has been studied the temporal changes on the response to water erosion processes occurred in a typical Mediterranean forest environment affected by fires of different intensities, and compared with that of an unaffected area. The evolution of soil response in runoff generation and soil loss has been monitored in each rainfall event occurred during the period April 1995—December 2000.

2 Materials and methods

2.1 Study site

The study area of “La Concordia” is in the municipality of Liria (Valencia, Spain), 50 km NW of Valencia city. It is 575 m above the sea level, on land ceded by the Forestry Services of the Valencian Government (Generalitat Valenciana). The experimental fires were made under field conditions on a forested hillside facing South- South East, with a sclerophyllous shrub cover regenerated after a previous wildfire occurred in 1978. The dominant vegetation type belongs to the *Rhamno lycioidis-Quercetum cocciferae* association, which is typical of semi-arid Mediterranean areas. The most abundant species include *Rosmarinus officinalis*, *Ulex parviflorus*, *Quercus coccifera*, *Rhamnus lycioides*, *Stipa tenacissima*, *Globularia alypum*, *Cistus clusii* and *Thymus vulgaris* (Gimeno-García *et al.*, 2000).

Climatically the area belongs to the dry ombroclimate of the lower mesomediterranean belt, according to Thornthwaite’s classification. The average annual precipitation is around 400 mm with two maximums, autumn and spring, and a dry period from June to September. Mean monthly temperatures range from 13.3°C in January to 25.8°C in August.

The soil is a Rendzic Leptosol (FAO-UNESCO, 1988) developed on Jurassic limestones. This soil has a variable depth, always less than 40 cm, many stones (\cong 40%), good drainage, a sandy-loam texture, and an alkaline pH (7.4).

2.2 Experimental plots and fire treatments

The experimental set-up consists of nine plots, each 20 m long by 4 m wide, with similar morphology, slope gradient, rock outcrops, soil and vegetation cover. The location of each plot was made after intensive survey of the vegetation, soil and morphology patterns, based on across-slope transect every 2m.

The plots were oriented parallel to the slope and bounded by bricks. At the foot of each plot a 2 m wide collector ran into a 1500-l tank to collect all the runoff and sediment produced during each rain event. Inside this tank a 30-l tank facilitates the collection of sediments produced.

A design of two different fire intensity treatments, with three plots each, was used. Contrasting amounts of fuel, obtained from the surrounding shrub, were added to obtain two different fire intensities, moderate and high. The remaining three plots were used as control. The assignation of fire treatment to each plot was made by lot, at random without blocking. The fire progression in the different plots was, in general, quite uniform. The residence time in soil of temperatures greater than 100°C was 36’22” in the high intensity treatments, and 17’45” in the moderate fire intensity. The mean soil surface temperatures reached for high and moderate fire intensities were 439°C and 232°C, respectively.

During the studied period, before and after the experimental fires, climatic parameters and the characteristics of the different rainfall events were monitored by a logging system of sensors placed close to the plots.

2.3 Soil and sediments analysis

Soil samples were taken to the first 10 cm depth, were air-dried and sieved, to remove the >2 mm diameter fraction, and stored in airtight plastic boxes until analysis. Standard laboratory analytical methods were applied to the samples.

The sediments and runoff generated from each rain event were quantified for all plots in each rain event. General statistical analysis, analysis of variance and Turkey's test were applied to the obtained data.

3 Results and discussion

The study area has suffered a marked change in its pluviometry that becomes more evident from 1998. Starting from this year, an important reduction in the annual quantity of precipitations received in the area has been observed. The annual average of the period 1998—2000 was of 286.35 mm, 28.61 % lower than the annual average of 1995—1997 and 41.05 % lower than the annual average calculated for the period 1961—1990 in the closest climatology station, Alcublas (485.8 mm). This drastic decrease is reflected clearly not only in the annual average values but also for the annual total quantities of rainfall. The year 1998 supposed a drastic rupture in the normal rain regime of the study area. In 1998 they were collected 196.65 mm less rain, almost the half, of average annual rain of the three precedent years. This tendency only seems to be broken in year 2000, which showed in one month (October) the 64.1% of the whole annual rain, almost duplicating in this year the quantities collected annually in 1998 and 1999.

The changes observed in the rain regime and in the distribution of the precipitations, it has also been reflected in the number of episodes of erosive rain - with runoff generation - that have been observed in the study area. In Figure 1, the characteristics of each erosive rain event occurred from 1995 to 2000 in the area of La Concordia are presented. A clear change in the number of erosive events can be appreciated. In the period 1995—1997, 49 erosive events were recorded with a total of 689.08 mm of rain, while from 1998 to 2000 only 20 episodes occurred with a total of 423.72 mm of rain. This represents a 38.50 % decrease in erosive rain in this last period.

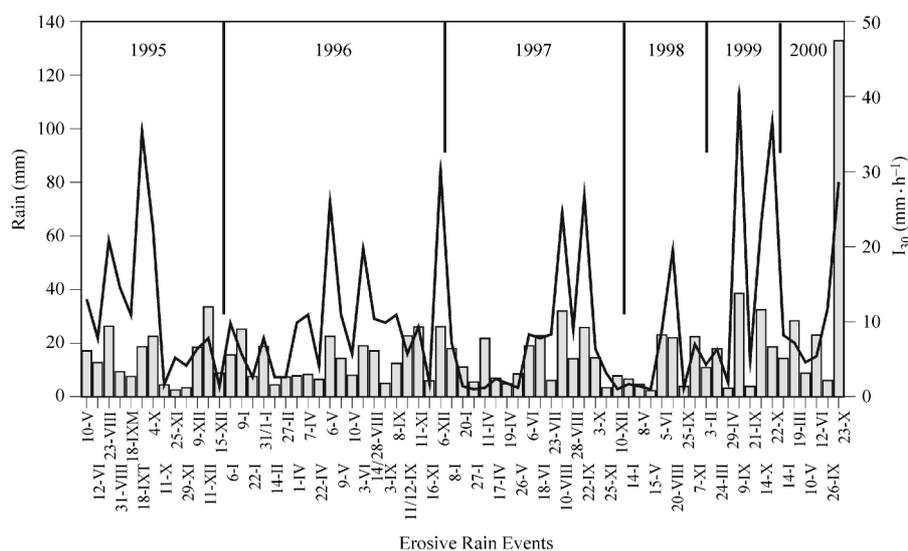


Fig.1 Characteristics of the erosive rain events occurred from 1995 to 2000 in the experimental station of La Concordia

The year 2000 constitutes an anomaly in the course of precipitations in the studied period, mainly with regard to the rains occurred in October. Year 2000 also presents a substantial variation in the duration of the rain episodes with an average of 627 minutes and a maximum of 1440 min, which

corresponds to the episode of October 23rd of that year that almost duplicates the ranges corresponding to 1995, 1998 and 1999 and is higher than in 1996 and 1997.

These changes in the rains characteristics have pointed out the erosive trends of the different treatments, mainly in the distribution and duration of the precipitations independently of this intensity. With a similar number of erosive events (7 in 1998 and 1999, 6 in 2000), annual runoff and sediment production have been very different, and lightly inferior to those of the years immediately after the experimental fire (1995—1997).

If we consider the quantities generated annually by surface unit with regard to the effective rain corresponding to the erosive episodes, it is observed that the average percentage between these in both periods, 1995—1997 and 1998—2000, is similar with 51.30 % and 47.38 %, respectively. It can be appreciated that, seemingly, 1998 are the year that presents lowest of runoff/erosive rain (29.74%) in the whole period, but year 2000 gave a lightly smaller value (29.46%). This, nevertheless, reflects two different conditions. In the first case, the effect of a drastic decrease in the rain regime, with events of moderate to low intensity (maximum of $19.50 \text{ mm} \cdot \text{h}^{-1}$), gives place to a quick infiltration of the scarce water by the soil reducing runoff generation. While in the second case, year 2000, episodes of a bigger precipitation volume occurs (up to 132.8 mm) but their duration is much bigger and so a progressive infiltration is favoured, which could indicate an improvement of the soil hydrological conditions.

Although the number of erosive rains was higher during 1995—1997 (49) than during 1998—2000 (20), total runoff generation has been lower in the last one (19.75 %). From 1995 to 2000 big differences in annual runoff are appreciated, being observed the smallest values in 1998 (2,018.11 l) comparing to the maximum in 1999 (8,327.50 l), four times higher to the first one, the remainder years show similar values with an annual average of 6,795.77 l. Fig.2 shows the annual evolution of runoff generated in the different treatments from 1995—2000. The evolution of runoff through the different erosive rain events is directly influenced by the quantity of rain and its intensity (correlation of 99% of probability). Year 1999 presented the highest rates of runoff production in the different treatments, with maxim of 1250 l in a single rain event (September 9th). Along the whole study period, a clear decrease in the differences in runoff production between the fire treatments has been observed. In this sense, the plots that had suffered a fire of moderate intensity generated in 1996 an average of 32.20 % less runoff that those that suffered a high fire intensity, while in 2000 this difference has decreased to a 6.52 %. This is confirmed statistically by the absence of significant differences among the different fire treatments. Nevertheless, these differences become highly significant and marked between these treatments and the unburned plots; with mean values of this period for these last of 73.76% and 81.11 % lower than the plots of moderate and high fire intensity, respectively.

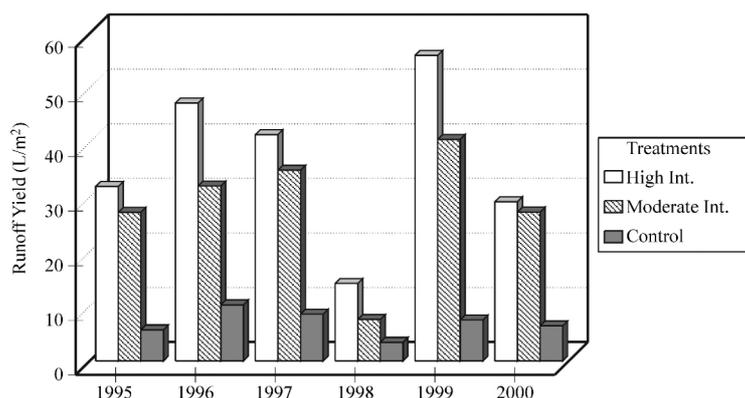


Fig.2 Evolution of runoff yield in the different treatments during the study period

The trends of the different treatments are also reflected in the values of the runoff coefficient and the infiltration rate, although in a more attenuated way. In this case, the differences between the plots corresponding to the treatment of high fire intensity and those of moderate intensity are reduced, in year 2000, to only an average of 2.19%. During the period 1995-2000, the mean values of infiltration have

always been lightly higher (5.51%) in the control plots regarding the fire treatments. Similar temporal tendencies were observed by Sala *et al.* (1994) studying different Mediterranean burnt areas.

A remarkable change on soil loss could be observed between the years immediately after the experimental fire (1995—1996) and the following ones, with an important decrease in this parameter starting from 1997. The total sediment production during the period 1995—1997 was $35.62 \text{ t} \cdot \text{ha}^{-1}$, meanwhile during 1998—2000 reached only $3.81 \text{ t} \cdot \text{ha}^{-1}$, what implies 89.30% decrease respect to the previous period. The year that presented the biggest soil loss was 1996 with $15.54 \text{ t} \cdot \text{ha}^{-1}$ that contrasts with the maximum reached in 2000 with $0.42 \text{ t} \cdot \text{ha}^{-1}$.

The evolution observed for the parameters related to the hydrological cycle response to the erosive processes is also observed for the variables related to soil loss, but in a more accentuated way (Fig.3). In this case, the sediment yield and the discharge are influenced directly by the rain intensity (correlated at 99 % of probability), so the maximum values are observed in 1999. Inbar *et al.* (1998) noted this influence after a wildfire in a typical Mediterranean forest in Israel, although with slightly lower rates of soil loss. The quantity of fallen rain in each event and its duration do not have significant correlations regarding these parameters. It has been observed that the behaviour of the plots of the different treatments, for sediment production, does not show significant differences for rain intensities lower than to $15 \text{ mm} \cdot \text{h}^{-1}$, but above this intensity the response differs remarkably in some cases.

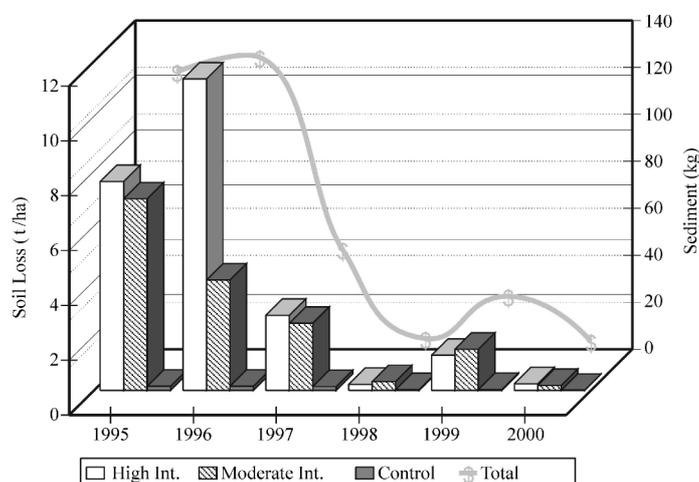


Fig.3 Soil loss evolution in the different treatments of fire during the studied period (1995—2000)

The difference in sediment production between the control plots and those corresponding to the treatments of high and moderate fire intensity reaches very high values during the whole period of study, with maximum in the years 1999 and 2000. The plots not affected by fire, during the period 1995—2000, produced an average of 96.38% and 96.19% less sediment than those of high fire intensity and moderate intensity, respectively. On the other hand, the differences among fire treatments have been reduced progressively from 64.51% in 1996 to 23.88% in 2000, even smaller than those observed for runoff generation.

The statistical study of the influence of the climatic parameters on soil loss, for the different treatments, shows that for the plots affected by fire the decisive factor is the rain intensity meanwhile in the control plots, besides this factor, the rain fall volume has also great incidence. This is due to the protective effect of the vegetation cover, since it presents cushion effect of the rain intensity in their impact on soil modifying the rain distribution and their reception (Cammeraat and Imeson, 1999). Other factors could also affect these conditions, such as the cortical flow, the height of the vegetation or the effect of the fall of the raindrops from the different strata of the vegetation cover.

As a parameter related with soil hydrological conditions, the sediment discharge or quantity of silt transported by litre of generated runoff can give us a global idea of the trends observed in the different treatments regarding water erosion. Their study confirms the tendencies observed for the other parameters in its temporal evolution, differing clearly the years immediately after the fires from the later ones. The highest discharge reached in the Experimental Station of La Concordia from its establishment

corresponds to the rain of September 18th 1995, where $647.96 \text{ g} \cdot \text{l}^{-1}$ were reached (plot 6). On the other hand, the mean value of discharge during 1995-97 was of $7 \text{ g} \cdot \text{l}^{-1}$ while in the period 1998—2000 it was of $1.61 \text{ g} \cdot \text{l}^{-1}$. Statistically also significant differences are observed between both periods, and mainly highly significant differences are appreciated among year 1995 and the rest.

On sediment discharge, the intensity of rain is also the environmental factor that exerts strongest influence, and in the same way that in soil loss. It has been observed significantly different performance between treatments at rain intensities smaller than $15 \text{ mm} \cdot \text{h}^{-1}$ and bigger than this. If the influence of these factors on the answer of the different treatments is studied, it can be noted that while for the burned plots the rain intensity is the main influencing factor (at 99% of probability), for the control plots is also the duration of the event (at 95% of probability), although in an inverse trend.

For the whole period of study, the sediment discharge maintain in time significant differences between the plots not affected by fire and the control ones, with mean values 80.22 % lower. However, for this parameter, the difference between plots affected by high fire intensity and those affected by a moderate intensity, although decreases progressively with time, it is not made at the rates observed in other parameters. These differences changed from 77.15 % during 1995—1997 to 42.02 % in 2000.

4. Conclusions

The effects of fire incidence on soil and vegetation in Mediterranean conditions have been evaluated during the studied period. The impact of high intensity and moderate intensity fires produced important changes in the system, which are more intense during the first months after burning. With time, the differences among plots affected by intense and moderate fires decrease gradually. Nevertheless, five years after the fires, these differences are still significant reaching more than 20 % in soil loss. The differences between the fire treatments and the plots with the unaffected vegetation have remained weighty with time on runoff generation and soil loss, reaching values around 90%. These circumstances show the sensibility of the Mediterranean forest ecosystems to fire impacts.

In our case it has also to be considered that after the experimental fires an important drought period affects the study site. The hard climatological conditions and the water deficit suffered since 1998 have difficulted the normal recovery of vegetation in the plots that suffered the impact of fire.

However, since the second half of 1999 the slight increment in the volume and duration of the precipitations and the changes in its distribution along the year have affected the evolution of the vegetation cover and, in turn, the improvement of the structural and hydrological soil conditions. This has been reflected, in general, in an increase in infiltration capacity and in a decrease on sediment production regarding previous years.

In general, a positive and gradual recovery of the soil and vegetation conditions has occurred in the plots affected by fire. It has influenced the improvement in the hydrological and structural conditions of the soil and a decrease in its losses by the effect of water erosion during the studied period. Nevertheless, after five years from the fire occurrence the ecological conditions of the burned plots still are far from the initial ones.

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