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Repeated experimental fires and window of disturbance in relation to runoff in a Mediterranean shrubland

E. Gimeno-García (1, 2*), J. Campo (1), O. González-Pelayo (1), V. Andreu (1), J.L. Rubio (1)

(1) Centro de Investigaciones sobre Desertificación – CIDE (CSIC, UV, GV). Carrtera Moncada-Náquera, Km 4.5, 4613, Moncada, Valencia, Spain
(2) Fundació General Universitat de València.
*Corresponding author: eugenia.gimeno@uv.es

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Abstract

This study is focused on exploring the effect of repeated experimental fires on post-fire runoff generation through a sixteen years monitoring runoff yield from erosion plots (eight years after the first fire and other eight years after the second one) in a Mediterranean shrubland area (La Concordia Experimental Station), considering the fire severity and the post-fire erosive rainfall events. The conceptual framework of the window of disturbance is used to analyze how long the runoff yield in burned plots shows clear differences respect to the unburned ones, as well as, the recovery-rate model for multiple fire events.
Results show that the effect of repeated fires on runoff yield is related to a combination of fire severity, climatic conditions (mainly rainfall intensity, I30), soil hydrological properties (infiltration capacity, steady state infiltration and soil water retention capacity), and rate of vegetation recovery. Eight years after the first fire, even though soil hydrological properties are recovered as well as vegetation cover did, rainfall events with I30 ≥20 mm h^{-1} still promoted differences between burned and control plots. The second post-fire disturbance period was associated with the low vegetation recovery, and also with rainfall events with I30 ≥20 mm h^{-1} even seven years after the repeated fires.

1 Introduction

Fire is a natural disturbance to landscapes that can affect soil loss by reducing their resistance to be eroded and by increasing the energy of runoff. The magnitude of changes on soil system induced by fire severity such as degree of combustion of litter and vegetation cover, alteration of soil aggregation, partial or complete combustion of soil organic matter, modification of the porosity and bulk density, changes in soil hydrophobicity and infiltration rates, are considered as key factors controlling post-fire water erosion (Prosser & Williams, 1998; Shakesby, 2011). Moreover, the effect of fire on soil erosion depends on the timing of rainfall and runoff events and their magnitude. Storms immediately following the fire are most critical since they have the greatest potential for water erosion. In the Mediterranean area, the first 4-6 months after fire is often the period of highest vulnerability to erosion because of the maximum fire risk in summer is followed by aggressive storms at the end of this season, and by the autumn raining season (Andreu et al., 2001; Rubio & Calvo, 1996).

Many of the aforementioned changes on soil system

Table 1. Some characteristics of the erosive rainfall events for the 16 years study period. * Year refers to the twelve month period starting at the day of fire; ** Range of variation of rainfall volume (mm) in individual erosive events.

Year *	Erosive rainfall events	Range of rainfall volume (mm) **	Rainfall events with $I_{30} \approx$ 20 mm h^{-1}	Range of variation of I_{30} (mm h^{-1}) in individual events
1995/1996	24	2.60-33.54	4	1.40-35.36
1996/1997	16	4.90-26.10	1	1.00-30.20
1997/1998	11	2.30-32.00	2	1.00-26.80
1998/1999	6	3.20-22.40	1	1.20-19.45
1999/2000	8	3.80-38.60	3	4.60-40.40
2000/2001	7	4.30-132.8	2	4.00-28.60
2001/2002	6	7.40-96.50	1	3.10-30.00
2002/2003	12	5.70-67.10	1	1.60-21.20
2003/2004	18	5.20-33.30	4	2.20-65.40
2004/2005	14	0.30-61.50	4	0.3-91.80
2005/2006	12	3.20-46.50	3	2.80-35.20
2006/2007	12	5.30-25.40	2	2.20-37.40
2007/2008	14	5.20-45.20	5	1.80-46.40
2008/2009	9	4.30-54.50	1	1.80-39.60
2009/2010	16	5.80-33.60	2	1.40-40.20
2010/2011	9	3.40-28.20	2	3.20-29.80

induced by fire potentially make the soil more erodible, are less likely to allow infiltration and more likely to promote overland flow (Shakesby, 2011) with the subsequent soil detachment and downslope transport. Over time, these levels usually tend to decrease until returning to pre-fire values. The period of high post-fire erosion rates has been termed the 'window of disturbance' (Prosser & Williams, 1998) and typically ranges between 3-10 years (Shakesby, 201). Increments in runoff and sediment yields after fires have been measured in different Mediterranean-type shrublands, but they are generally focused on a few months or years after fire (Gimeno-García et al., 2007). However, there are few studies assessing the soil response to water erosion at medium or long-term as a consequence of repeated fire impacts. In relation to this fact, recent research on multiple fire events over few years (Wittenberg & Inbar, 2009) has proposed a recovery-rate model which expands the window of disturbance and the 'baseflow' level of sediment yield is raised with each successive wildfire. Generally, in most studies this effect is not perceived because their short period of monitoring.

2 OBJECTIVES

This study is focused on exploring the effects of repeated fires on post-fire runoff generation through a sixteen years monitoring runoff yield from erosion plots (eight years after the first fire and other eight years after the second one) in a Mediterranean shrubland area, considering the fire severity and the post-fire erosive rainfall events. The conceptual framework of the window of disturbance is used to analyse how long the runoff yield in burned plots show clear differences respect to the unburned ones.

3 METHODOLOGY

The study has been carried out at La Concordia Experimental Station (39°45' N and 0°43' W), which includes nine erosion plots (20 m x 4 m). A more complete description of the Station and experimental fires set up could be found in Gimeno-García et al. (2004). The soil was a Rendzic Leptosol (IUSS Working Group WRB, 2006) developed on Jurassic limestone. Vegetation belongs to the *Rhamno lycioidis-Quercetum cocciferae* association. Mean annual precipitation is 377 mm with two maxima, autumn and spring, and a dry period from June to September. An automatic meteorological station registered values at 5-minute intervals. These data are used to determine the duration, total volume and intensity of rainfall events. Rainfall intensity is measured as I30, the maximum amount of rain during a 30-minutes period and expressed as millimeters per hour.

In 1995, experimental fires were carried out in a set of six plots, based on the addition of contrasted amounts of extra-biomass (4 and 2 kg m^{-2}) to obtain different severities. Fires were repeated in 2003 on the same plots,

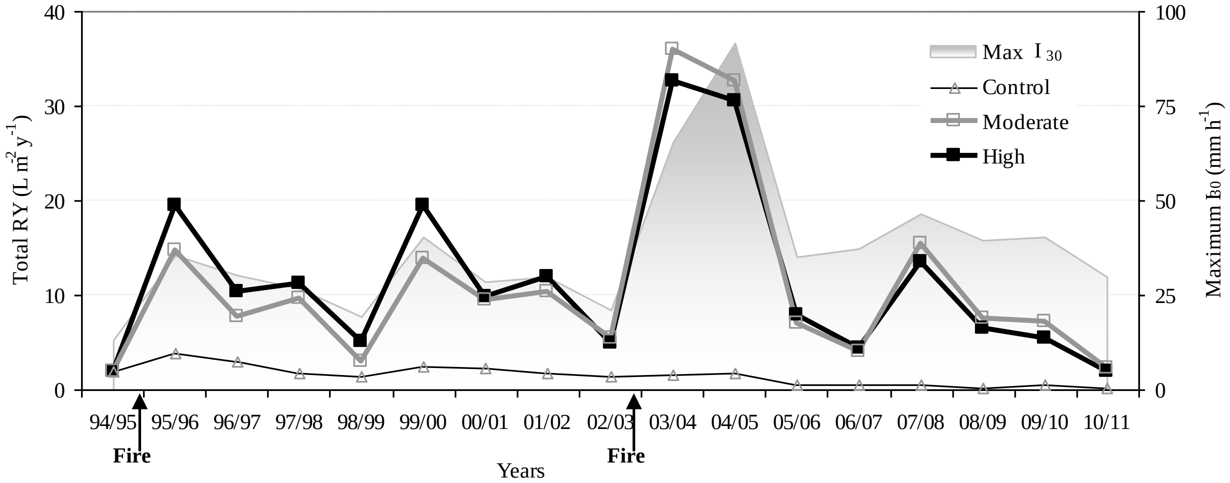

Figure 1. Total annual runoff yield values for the studied period.

but without addition of biomass. Fire severity in 1995 was classified as high (in three plots) and moderate (other three plots), whereas 2003 experimental fires were classified as low severity (in the six plots) (Gimeno-García et al., 2004). In both years, the remainder three plots were left unburned (control plots).

The study period covers 16 years (from summer of 1995 to summer of 2011), where a total of 194 erosive rainfall events were registered (Table 1). After each rainfall event, runoff was collected and quantified from each plot. Those events that show at least runoff production were considered as the erosive ones. In our case, runoff yields from unburned plots were used to establish the "baseflow" level of this soil. To facilitate data interpretation and reveal the medium-term variations of runoff attributed to fire treatments, the runoff yield values obtained from burned plots are normalized and fluctuations of the control plots over time are considered. For each rainfall event, runoff yield values were reduced to standardized variables $Zij = (Xij\text{-}X)/SD$, where Xij is the value for runoff i in burnt plot at the rainfall event j, and X and SD are the mean and standard deviation, respectively, for all the corresponding control plots.

4 RESULTS AND CONCLUSIONS

Regarding runoff yield (Figure 1), a first period of disturbance after the 1995 fires is observed, with an approximate duration of two years. Its maximum runoff yield corresponds to the period from summer 1995 to summer 1996, when 19.4 and 14.7 L m^{-2} y^{-1} has been quantified in high and moderate fire severity plots, respectively. In the following years (1996-1999), only 4 rainfall events with $I30 \approx 20$ mm h^{-1} were registered, resulting in a substantial reduction of annual runoff production in both fire treatments. However, the high rainfall aggressiveness registered after the summer of 1999 (3 rainfall events with $I30 > 20$ mm h^{-1}, Table 1), allow us to identify a second period of disturbance with the same duration and with similar runoff yield values, also proportional to fire severity, as the observed in the two post-fire years. Until the summer of 2002, the runoff exceeds the baseflow level. As Figure 2 shows, runoff yield from burned plots was still greater than the measured for control ones. One year later and prior to the repeated fires, runoff yield went down almost to the baseflow level (Figure 2). Thus, eight years later the 1995 fire impact, although the recovery of the hydrological characteristics of the burned soils was reported (González-Pelayo et al., 2010), as well as the vegetation grew to 30-40% of soil cover, rainfall intensity and fire severity are still key factors controlling runoff yield in burned soils.

After the 2003 repeated fires, in spite of their low severities, the short elapsed time between fire impact and the first rain storm has greatly influenced the runoff production. Peak flows were produced at the first and second post-fire years, with total runoff volume of 36 and 32.6 L m^{-2} y^{-1} from burned plots, which contrast with the 1.7 L m^{-2} y^{-1} from the baseflow level registered in control

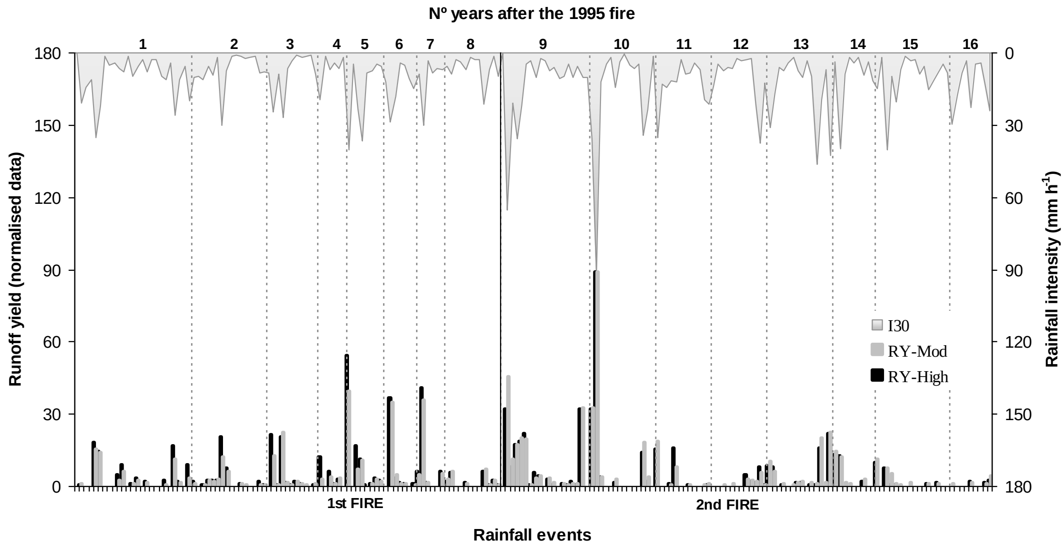

Figure 2. Medium-term variations attributed to fire treatments for runoff yield values reduced to standardised variables.

ones. In these years, the maximum I30 (65.40 and 91.80 mm h^{-1}) of the whole study period were registered (Table 1), being the main extrinsic factor that control the runoff production. In burned soils, the decrease of the infiltration at plot scale, and the significant differences in soil water retention capacity between burned and control plots (González-Pelayo et al., 2010), are soil intrinsic parameters that increased runoff production.

However, four years after the repeated fires (2006-2007), there is an appreciable decrease of the annual runoff yield (with near 4 L m^{-2} $y^{-}1$ in burned plots). This different runoff response could be indicative of a certain soil recovery (González-Pelayo et al., 2010) and to the protective effect of vegetation cover (in 2008 there was 0.14 kg m^{-2} of biomass, which covered approximately the 24% of soil surface on burned plots). However, it is not possible to sustain a constant runoff decreasing trend, because as it was observed in the following years and also in the same way as occur after the 1995 fire, rainfall intensity greater than 30 mm h^{-1} generate a new increase in runoff yield, raising the differences between burned and control plots (Figures 1 and 2). Thus, runoff production at La Concordia is highly dependent on rainfall intensity even seven years after the repeated fire. Although a clear recovery on the soil hydrological properties has been found over time (González-Pelayo et al., 2010) and there was some soil protection offered by the regenerated vegetation on burned plots, those factors are not enough to decrease the runoff yield up to the baseflow of control ones. It is seven years later from the repeated fire, when rainfall events with I30 ≥30 mm h^{-1} did not give a substantial increase in runoff.

It is important to note that in the case of results for sediment yield (Gimeno-García et al., 2012) they fit best with the theoretical model proposed by (Wittenberg & Inbar, 2009) than the observed for runoff yield, showing defined durations of the window of disturbance (two years after 1995 fires and three years following the 2003 repeated ones). Lower sediment yield oscillations than the measured for runoff in response to high rainfall aggressiveness were identified five years after the two fire events (Gimeno-García et al., 2012).

The effect of repeated fires on runoff yield is related to a combination of fire severity, climatic conditions (mainly rainfall intensity), soil properties and rates of vegetation regeneration. After the first fire, it is difficult to establish clearly the duration of the window of disturbance regarding runoff yield, because even though the soil hydrological properties are recovered as well as the vegetation cover did, rainfall events with I30 ≥30 mm h^{-1} still promoted differences between burned and control plots. The second post-fire disturbance period was associated not only with the low vegetation recovery, because the slower rates of regeneration cover under recurrent fires, but also with the occurrence of the rainfall events with I30 ≥30 mm h^{-1} seven years after the repeated fire.

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