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Long-term impact of wildfire on soils exposed to different fire severities. A case study in Cadiretes Massif (NE Iberian Peninsula)

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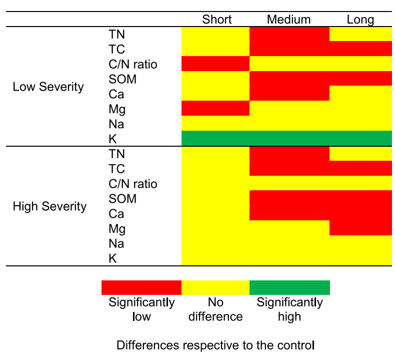
HIGHLIGHTS

- Severe wildfires affect soil properties to long-term.
- Soil nutrients responded differently to time and to fire severity.
- Soils need more time to recover its properties in high- than in low-severity areas.

GRAPHICAL ABSTRACT



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ABSTRACT

Wildfires affect ecosystems depending on the fire regime. Long-term studies are needed to understand the ecological role played by fire, especially as regards its impact on soils. The aim of this study is to monitor the long-term effects (18 years) of a wildfire on soil properties in two areas affected by low and high fire severity regimes. The properties studied were total nitrogen (TN), total carbon (TC), C/N ratio, soil organic matter (SOM) and extractable calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K). The study was carried out in three phases: short- (immediately after the wildfire), medium- (seven years after the wildfire) and long-term (18 years after the wildfire). The results showed that in both fire regimes TN decreased with time, TC and SOM were significantly lower in the burned plots than they were in the control in the medium- and long-terms. C/N ratio was significantly lower at short-term in low wildfire severity area. Extractable Ca and Mg were significantly higher in control plot than in the burned plots in the medium-term. In the long-term, extractable Ca and Mg were significantly lower in the area exposed to a high severity burning. No differences were identified in the case of extractable Na between plots on any of the sampling dates, while extractable K was significantly higher in the plot exposed to low wildfire than it was in the control. Some restoration measures may be required after the wildfire, especially in areas affected by high severity burning, to avoid the long-term impacts on the essential soil nutrients of TC, SOM, extractable Ca and Mg. This long-term nutrient depletion is attributable to vegetation removal, erosion, leaching and post-fire vegetation consumption. Soils clearly need more time to recover from wildfire disturbance, especially in areas affected by high severity fire regimes.

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1. Introduction

Wildfires are a global phenomenon and a natural element of ecosystems, where their impact is dependent upon the fire regime (Bento-Gonçalves et al., 2012; Gill, 1975; González-Pérez et al., 2004). Soils are an essential component of ecosystems, and can undergo substantial modifications because of the direct (e.g. heating) or indirect (e.g. ash) effects of fire; although, they normally return to their pre-fire conditions with time. These effects are largely confined to the first few centimeters of the soil profile. It has been well documented that the impact of fire on soils depends on soil type, fire history, the ecosystem and species burned, the topographical conditions of the affected area, the meteorological conditions during and after the fire and the severity of the fire. Low fire severities can increase soil organic matter (SOM), total nitrogen (TN), total carbon (TC) and total extractable cations, whereas high fire severities consume all the SOM, reduce TN and TC considerably, and substantially increase the amount of major cations in solution. The ability of the burned area to recover its pre-fire levels depends on the ecosystem affected, fire severity, the topography of the fire-affected area and the post-fire meteorological conditions. Soil status in post-fire environments is a key element for ecosystem recovery (Badia et al., 2014; Bodi et al., 2014; Caon et al., 2014; Pereira et al., 2016).

The large majority of studies examining the impact of wildfires on soil focus on their short- (e.g. Romanya et al., 2001; Snyman, 2003; Tessler et al., 2008; Pereira et al., 2017) or medium-term effects (e.g. Lozano et al., 2016; Martinez-Garcia et al., 2017); and owing to constraints of time, logistics and finances, little research has examined their long-term effects. However, long-term studies are essential to gain a good understanding of the ecological role of fire. Most of the long-term studies that have been reported were undertaken in North America (Ojima et al., 1994; Slaughter et al., 1998; Yermakov and Rothstein, 2006; LeDuc and Rothstein, 2010; Johnson et al., 2012), although some data are available from other parts of the world, including South America (Roscoe et al., 2000; Silvana-Longo et al., 2011), Australia (Muñoz-Rojas et al., 2016) and Europe (Kaye et al., 2010). Moreover, while some authors have looked at how soils change up to hundred years after the last known fire (DeLuca et al., 2006; McNamara et al., 2015), they neither monitor the evolution of post-fire soil properties nor record the severity of the fire regime to which they were exposed, a critical parameter in determining the recovery of the ecosystem. As such, there is clearly a pressing need for greater insights into the long-term effects of wildfires on soil properties, especially in fire-prone ecosystems, like the Mediterranean, in order to develop a better understanding of their resilience and capacity to respond to such disturbances. These studies are especially relevant in the current context of climatic change, with predictions that the number and size of fires will increase and that fire regimes will change (e.g. a larger number of high severity fires during longer fire seasons) (Brotons et al., 2013; Turco et al., 2014, 2017).

Although a long-term study of the effects of fire on soil properties in the Mediterranean has been conducted (Kaye et al., 2010), to the best of our knowledge, no study has examined the effects of different fire severity regimes from a long-term perspective. Yet, note that a number of studies have examined the short- and medium-term effects of low (Inbar et al., 2014), moderate (Faria et al., 2015) and high severity fires (Badia et al., 2014; Lombao et al., 2015; Francos et al., 2016b). The importance of long-term studies of the effects of varying fire intensities is that they should shed light on the capacity of soils to respond to different levels of disturbance. This is critical for determining how long low and high fire severity regimes can modify a soil ecosystem. Thus, the aim of the study reported here is to monitor the long-term impact of a wildland fire of different severities on the chemical properties of soil.

2. Materials and methods

2.1. Study area

The study area is located in Cadiretes, Girona, in the north-east of the Iberian Peninsula, at an altitude of between 190 and 250 m a.s.l. (Úbeda et al., 2005) (Fig. 1). The parent material consists of metamorphic rock. The massif is covered by dense Mediterranean vegetation, and includes such species as *Quercus suber* L., *Arbutus unedo* L., *Erica arborea* L. *Pinus pinaster* ssp. Mean annual rainfall ranges between 700 and 800 mm, with an autumn maximum and a summer minimum (Úbeda, 2001). Summer temperatures often exceed 25 °C; while winters are generally mild, rarely below 0 °C. Evapotranspiration exceeds precipitation in summer months, from June to August (Úbeda, 1998). According to US Soil Taxonomy (Soil Survey Staff, 2014), the soils of the control and low severity zone can be classified as Typic Haploxerept while those in the high severity fire zone are classified as Lithic Haploxerept. The area was affected by a fire that broke out on 5 July 1994 burning an area of 55 ha. In 1994, the area was a plantation of *Pinus pinaster* ssp. with potential for *Quercus suber* L. (Francos et al., 2016a). After the wildfire, no restoration measures were carried out in the forest affected area.

2.2. Experimental design and field sampling

One day after the fire, two plots were designed in an area affected by both low and high severity wildfires (henceforth L-S and H-S plots), respectively. Both plots were on south-facing slopes with a gradient of approximately 10%. Fire severity was assessed by means of ash color and the number and diameter of surviving branches. Soils covered with black ash were considered to be indicative of low fire severity, while those covered with grey/white ash were deemed indicative of high fire severity (Moreno and Oechel, 1989). An unburned area was selected as control. All three areas present similar environmental characteristics in terms of their parent material, topography and vegetation. Inside each area, we designed a transect, and we sampled the soils each 2 m. In the first sampling campaign, conducted immediately after the fire, we collected five topsoil samples from each plot (0–3 cm). In the second (seven years after the wildfire) and third (18 years after the wildfire) sample campaigns, we collected a further 10 samples per plot per campaign. In total, we collected 75 soil samples. After the fire, no forestry management measures were implemented. Thus, the only impacts on soil properties were those induced by the wildfire and the post-fire natural plant recovery. Two previous studies have been published reporting the results from the data collected in the short- (Úbeda, 2001) and medium-terms (Úbeda et al., 2005).

2.3. Laboratory methods

Samples were dried in the laboratory at room temperature (±23 °C) for 48 h. Soils were sieved with a < 2 mm mesh to discard the coarser material. TN and TC content were analyzed with a Flash EA 112 Series (Thermo-Fisher Scientific, Milan). Data acquisition and calculations were carried out using Eafer 300 software (Thermo-Fisher Scientific, Milan) (Pereira et al., 2012). SOM was measured using the loss-on-ignition (LOI) method described in Henri et al. (2001). For each sample, 1 g of soil was pulverized and dried in a muffle furnace at 105 °C for 24 h. To estimate SOM, the dried samples were heated at 550 °C for 4 h. Soil extractable Ca, Mg, Na and K were analyzed with the method proposed by Knudsen et al. (1986).

2.4. Statistical analysis

Statistical comparisons between sampling times and plots were carried out with a two-way ANOVA test. Significant differences were considered at $p < 0.05$. If significant differences were identified, a Tukey HSD post-hoc test was applied. A redundancy analysis (RDA) was