Journal of Environmental Management 206 (2018) 625–632

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

How clear-cutting affects fire severity and soil properties in a Mediterranean ecosystem

Marcos Francos [a,*], Paulo Pereira [b], Jorge Mataix-Solera [c], Victoria Arcenegui [c], Meritxell Alcañiz [a], Xavier Úbeda [a]

[a] GRAM (Grup de Recerca Ambiental Mediterrània), Department of Geography, University of Barcelona, Montalegre, 6, 08001, Barcelona, Spain
[b] Environmental Management Centre, Mykolas Romeris University, Vilnius, Lithuania
[c] GEA (Grupo de Edafología Ambiental), Department of Agrochemistry and Environment, Miguel Hernández University, Elche, Alicante, Spain

ARTICLE INFO

Article history:
Received 3 August 2017
Received in revised form
2 November 2017
Accepted 4 November 2017

Keywords:
Pre-fire management
Soil properties
Fire severity
Wildfire

ABSTRACT

Forest management practices in Mediterranean ecosystems are frequently employed to reduce both the risk and severity of wildfires. However, these pre-fire treatments may influence the effects of wildfire events on soil properties. The aim of this study is to examine the short-term effects of a wildfire that broke out in 2015 on the soil properties of three sites: two exposed to management practices in different years – 2005 (site M05B) and 2015 (site M15B) – and one that did not undergo any management (NMB) and to compare their properties with those recorded in a plot (Control) unaffected by the 2015 wildfire. We analyzed aggregate stability (AS), soil organic matter (SOM) content, total nitrogen (TN), carbon/nitrogen ratio (C/N), inorganic carbon (IC), pH, electrical conductivity (EC), extractable calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), microbial biomass carbon (C_{mic}) and basal soil respiration (BSR). In the managed plots, a clear-cutting operation was conducted, whereby part of the vegetation was cut and left covering the soil surface. The AS values recorded at the Control site were significantly higher than those recorded at M05B, whereas the TN and SOM values at NMB were significantly higher than those recorded at M05B. IC was significantly higher at M05B than at the other plots. There were no significant differences in C/N ratio between the analyzed sites. Soil pH at M05B was significantly higher than the value recorded at the Control plot. Extractable Ca was significantly higher at NMB than at both M05B and the Control, while extractable Mg was significantly lower at M05B than at NMB. Extractable K was significantly lower at the Control than at the three fire-affected plots. C_{mic} was significantly higher at NMB than at the Control. BSR, BSR/C and BSR/C_{mic} values at the fire-affected sites were significantly lower than those recorded at the Control. No significant differences were identified in C_{mic}/C. Overall, a comparison of the pre-fire treatments showed that NMB was the practice that had the least negative effects on the soil properties studied, followed by M15B, and that fire severity was highest at M05B due to the accumulation of dead plant fuel.

1. Introduction

Mediterranean ecosystems are characterized by the frequent occurrence and recurrence of fire (Tessler et al., 2016a, 2016b), which has, however, made these environments highly resilient to such events (Francos et al., 2016a; Keeley et al., 2012). Indeed, Mediterranean wildfires have been identified as one of the main disturbances suffered by these ecosystems (Bond and Van Wilgen, 1996), exacerbated by centuries of human impact and the use of fire for land management. More recently, land abandonment, fire suppression policies and climate change have increased the vulnerability of Mediterranean forests to wildfires (Pereira et al., 2016). In response, clear-cutting and prescribed fires are practices that seek to reduce the amount of fuel and, hence, the fire risk (Alcañiz et al., 2016; Cochrane et al., 2012; Corona et al., 2015). These forest management practices also reduce fire severity in Mediterranean environments (Corona et al., 2015; Keeley, 2009; Simard, 1991), an effect that can be maintained for up to 10 years. Yet, despite the medium- and long-term advantages of these practices, restrictions in the budget assigned to forestry management limit their implementation and, therefore, the capacity to mitigate the impact of wildfires (Martín-Alcón and Coll, 2016).

* Corresponding author.
E-mail address: marcosfrancos91@gmail.com (M. Francos).

https://doi.org/10.1016/j.jenvman.2017.11.011
0301-4797/

Recently, fire has been identified as a soil forming factor (Certini, 2014), and it has been widely reported as a temporary modifier of soil properties. The degree of this impact depends on pre-fire conditions, the type of soils affected and the severity of the fire. For example, low-to-moderate severity fires do not have a significant direct impact (e.g. heating) on a soil's physical and chemical properties (Francos et al., 2018). The changes recorded are attributable primarily to the ash produced by the fire in conjunction with the post-environmental conditions, including local topography and rainfall (Arcenegui et al., 2008; Certini, 2005; Francos et al., 2016a; Gordillo-Rivero et al., 2014; Pereira et al., 2014a, 2017). Thus, for example, low-to-moderate severity fires have been reported to increase soil aggregate stability (AS) (Mataix-Solera et al., 2011); soil organic matter (SOM) (Inbar et al., 2014; Pereira et al., 2014b; Úbeda et al., 2005); total carbon (TC) and total nitrogen (TN) (De Marcos et al., 2005; González-Pérez et al., 2004); pH; electrical conductivity (EC) and the major extractable elements (Alcañiz et al., 2016; Liu et al., 2017), as a consequence of ash incorporation into the soil profile (Bodí et al., 2014). However, fires can also have various direct impacts on soil microbiology. Indeed, even low temperature fires can reduce soil microbial biomass and respiration (Certini, 2005), given the increase in temperature at the soil surface. The duration of the fire episode is one characteristic that can have the greatest impact on soil biology: the longer the duration of the wildfire, the greater the impact on underground soils (Mataix Solera et al., 2009). However, low-to-moderate severity fires normally move rapidly and most of their heat is released in an upwards direction, which means their impact on soils is not great. Having said that, though, the heat generated in such fires might be enough to modify soil microbiology activity, since the threshold is low at between 40 and 121 °C (Mataix Solera et al., 2009), a temperature that is readily reached in the top few centimeters of the soil profile (Augustine et al., 2014; Kennard and Gholz, 2001). After the fire line is passed, the ash deposited on the soil surface, in conjunction with the post-fire environmental conditions, dictate the soil microbiology. Low-to-moderate fire severities produce reddish, black ashes (Pereira et al., 2012, 2014a), which can raise soil temperatures due to increased albedo, and provoke microbiological activity that contributes to a more rapid landscape recovery (Andersson et al., 2004; Bodí et al., 2014; Mataix Solera et al., 2009).

High severity wildfires, in contrast, can consume the entire litter layer and the SOM. This greatly undermines soil protection (Pereira et al., 2015a) and leads to major changes in the top layer of the soil. Such fires have been reported as both reducing (Badia-Villas et al., 2014) and increasing (Jiménez-Pinilla et al., 2016) soil AS, depending on the temperature of combustion. Indeed, AS may fall as a result of organic matter consumption or increase due to mineralogical changes induced by high temperatures. Several studies have reported a fall in SOM (Holden et al., 2015), TC and TN (Badia et al., 2014; Ulery et al., 2017), because of high temperatures. As in low to moderate severity fires, pH and EC normally increase as a result of high organic matter mineralization, which increases the availability of the major cations (Lombao et al., 2015; Úbeda and Outeiro, 2009). The ash layer is grey and/or white in color, as a consequence of the total combustion of organic matter, which increases the amount of inorganic cations in soil solution (Pereira et al., 2012). High severity wildfires reduce microbial activity significantly in the immediate post-fire period due to the high temperatures recorded in the soil surface; however, normal activity is usually recovered a few months after the fire as a result of an increase in soil moisture, nutrients and vegetation recuperation (Fultz et al., 2016; Muñoz-Rojas et al., 2016).

While a considerable amount of information has been gathered about the impact of pre-fire treatment on fire severity and the short-, medium- and long-term implications of such events, little research has been conducted into their respective effects on soil properties, especially in the immediate post-fire period, when the impact is most evident, and it is possible to evaluate the impact of pre-fire management and its effectiveness in reducing the impact of fire on soils. Moreover, the degree to which fire affects soil and soil conditions in the period immediately following a fire is crucial for plant recuperation (Pereira et al., 2016). This study of pre-fire management impact on soil properties is essential to understand the effectiveness of land management in sites, such as those in areas of Catalonia, that are prone to fire.

The objectives of this study are easily stated:

a) To examine the impact of clear cutting on soil AS, TN, SOM, inorganic carbon (IC), C/N ratio, pH, EC, extractable calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), microbial biomass carbon (Cmic), basal soil respiration (BSR), and the Cmic/C, BSR/C and BSR/Cmic ratios
b) To examine the influence of the time lapse between the management of the site and the wildfire and to determine if the treatment results in differences in the soil's post-fire properties.

2. Materials and methods

2.1. Study site

The study site is located in Ódena, Barcelona (41°38′42″N - 1°44′21E 420 m a.s.l.) in North-East Spain (Fig. 1). A fire broke out in El Bruc, on 26th July 2015 and affected a total of 1274 ha of *Pinus halepensis* Miller, *Pinus nigra* Arnold and *Quercus ilex* L. Understory vegetation was mainly composed of *Pistacea lentiscus* L. and *Genista scopius* L. The forest had last been affected by wildfire in 1986. The geological substrate is composed mainly of sediments originated from Paleocene shale (Panareda-Clopés and Nuet-Badia, 1993). Soil is classified as a Fluventic Haploxerept (Soil Survey Staff, 2014). The mean annual temperature of the study site is 14.2 °C and the mean annual rainfall ranges between 500 and 600 mm.

2.2. Experimental design and sampling

In this study, four different sites were selected within the site and sampled three months after the 2015 wildfire: one was not exposed to any management (NMB), one underwent management in 2005 (M05B), another was the target of a management program in 2015 – just two months before the wildfire event (M15B), and as a reference, a control plot was selected (Control), which had not been exposed to any management after the fire of 1986 and was unaffected by the wildfire in 2015 (Table 1). The management treatment involved a clear-cutting operation, leaving 1000 trees per ha and leaving the cut vegetation over the soil surface in stems no taller than 1 m. In the case of the trees that were not felled, up to a third of their branches were removed. The wood was cut to a height of 1 m, leaving waste of fine-to-medium thickness. At each site, we collected nine topsoil samples (0–5 cm), giving a total of 36. The plots were designed in sites of similar soil type, vegetation composition, and topographical characteristics (slope <10% and north-east aspect). The severity of the wildfire of 2015 was classified as high in accordance with Úbeda et al. (2006), given that 100% of tree crowns were combusted.

2.3. Laboratory methods

Soil samples were dried to constant weight at room temperature (approx. 23 °C) for 7 days. To analyze aggregate stability (AS), the ten-drop impact (TDI) method (Low, 1954) was used. The samples