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Effect of prescribed fire on soil properties and soil erosion in a Mediterranean mountain area

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A R T I C L E I N F O

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A B S T R A C T

Prescribed fires are a common management practice in the Mediterranean region and can be an alternative to reduce the quantity of fuel and hence decrease the wildfire risk. This research focused in effects of a prescribed fire, which was applied in Montesinho Natural Park (PNM), in soil properties and on soil erosion processes. Chemical soil properties were assessed before, two, six and thirty-six months after the fire. Despite low fire intensity, soil chemical changes were observed. Thirty-six months after the fire it turned out that the soil organic matter, pH values and electrical conductivity were similar to those seen before the fire. However, the same was not verified with the values of the exchangeable bases, extractable potassium and phosphorus and exchangeable acidity that differ from the observed ones before the fire. Runoff and soil loss were monitored in a set of 4 m^2 paired plots installed in the study area, during 14 months after the fire and summed annual losses equivalent to 10.3 mm runoff and 1.3 Mg ha^{-1} soil loss. Although corresponding to a short monitoring period, these results may add to a better knowledge of the potential susceptibility of burnt shrublands to soil degradation and their natural recovery rates.

1. Introduction

Large areas of shrublands and forests are destroyed by fire every year in the Mediterranean region, where wildfires are a most relevant environmental problem; nevertheless, in the ecological context of the Mediterranean mountains, fire is part of the vegetation and landscapes dynamics (IPB/ICN, 2007; Pausas et al., 2008). However, previous studies carried out in Mediterranean ecosystems highlight a wide variability fire effects on soil properties and hydrological processes (e.g., Certini, 2005; Bento-Gonçalves et al., 2012; Inbar et al., 2014; Alcañiz et al., 2016), contributing to soil degradation.

The use of prescribed fire, after careful planning and under controlled conditions, is one of the most important measures to prevent the occurrence of high intensity fires (Fernandes and Botelho, 2004; Bento-Gonçalves et al., 2012). There are many reasons to apply prescribed fire in forest management as, for instance, it reduces hazardous fuels and breaks up fuel continuity (Fernandes and Botelho, 2004; Fernandes and Loureiro, 2010), it prepares sites for seeding or planting of forest species, and controls the competing vegetation (Brooks and Lusk, 2009), it improves habitat and creates diversity needed by wildlife (Wasserman, 2015), it controls insects and diseases (Parker et al., 2006), it improves pasture quality for cattle (Fonseca et al., 2011), it improves access into forest stands, and it contributes to preserve fire-dependent plant species, particularly important in Mediterranean environments (Pausas and Keeley, 2009). Prescribed fire in shrublands applied to protect forests stands is a relatively common practice in Montesinho Natural Park (PNM), Northeast Portugal (IPB/ICN, 2007; Fonseca et al., 2011). Soil is a qualitatively scarce resource in this region and even more scarce in the marginal areas where the shrubs dominate (Figueiredo, 2002). The protection of this resource is essential due to its key role in ecosystem services provision, associated to the hydrological cycle, nutrient cycles and carbon dynamics and storage (Rashid, 1987; Thomas et al., 1999; Pardini et al., 2004; Bompastor et al., 2009; José, 2009; Fonseca et al., 2011; Fonseca et al., 2012). The knowledge of soil degradation processes and the context factors that determine them is a basic condition for the design of strategies, actions and practices focused in the soil resource protection.

During burning, plant cover and litter layers are consumed, and the mineral soil is heated, resulting in changes in physical, chemical, mineralogical, and biological soil properties (Hubbert et al., 2006). The combination of combustion and heat transfer produces sharp temperature gradients in the topsoil profile (Certini, 2005). The extent and duration of fire effects on soil properties depend on fire behaviour, especially related to fire severity, as well as on post-fire weather conditions, mainly the characteristics of subsequent rainfall events (de Luís et al., 2001; Certini, 2005; Francos et al., 2016). A direct effect of fire

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on soil surface is the formation of a continuous water-repellent film, which reduces permeability and increases runoff (Imeson et al., 1992). In Mediterranean ecosystems, where the torrential rainfall events are frequent in autumn and winter, October to March is a critical period when soil susceptibility to water erosion processes is increased after the summer wildfires (Andreu et al., 2001; Fonseca et al., 2011; Francos et al., 2016). Higher frequency of fire and intense rainfalls represents a large potential to reduce soil fertility by erosion and nutrient loss, therefore limiting burnt areas recovery and enhancing soil degradation (Thomas et al., 1999).

The effect of fire on soil organic matter content is widely variable, and depends on several factors including fire type, intensity and duration, and even land slope (González-Pérez et al., 2004; Shakesby, 2011). Depending on fire severity, the organic matter can suffer slight distillation, charring, or complete oxidation (Certini, 2005). Fire induces changes in nutrient cycles (Certini, 2005) and the majority of those nutrients released to the soil by burned vegetation are in highly soluble forms, with the exception of soil phosphorus, which increases insolubility after fire. In summary, fires cause changes on soil physical and chemical properties that, in turn, affect soil water permeability, rainwater intake rate, life forms support capacity and resistance to erosion and leaching processes.

This study aimed at evaluating the impact of a prescribed fire in a mountain scrubland area, applied to protect neighbouring pine forest stands, on topsoil properties (0–20 cm) and on hydrological processes, as runoff and soil loss.

2. Methods

Montesinho Natural Park (PNM) is a protected area in the northeast of Portugal, covering an area of 750 km^2, one third of which corresponds to shrub communities. The present study was carried out, in an area covered by shrubs (41°53′57.06″N, 6°40′55.39″W), located within a state ruled forest perimeter in PNM, which was subject to prescribed fire according to its management plan (Fig. 1). It is a plateau area, 800 m asl, cut by deep valleys, with 12 °C mean annual temperature and around 850 mm mean annual rainfall, concentrated from October to March (Agroconsultores and Coba, 1991). Soils are schist derived Umbric Leptosols, stony with medium-texture, acid and with medium/high organic matter content in the surface layer (FAO/UNESCO, 1988; Agroconsultores and Coba, 1991).

The study area was formerly occupied by *Pinus pinaster* species, but on August 1998 a wildfire destroyed part of the forest stand. Since then, shrub vegetation invaded the area and in 31 March of 2011 a prescribed fire was applied to 5 ha shrubland, as part of the management plan of the pine forest plots, in order to control shrub vegetation and reduce fire hazard in the remainder forest. A survey of the vegetation was carried out before the prescribed fire, identifying patches with clear dominance of species representative of the PNM shrub communities (IPB/ICN, 2007; Bompastor et al., 2009). The relative abundance of these species was evaluated in 11 sites randomly distributed in the area to be burned. Accordingly, prior to prescribed fire, the area was covered by *Erica australis* (44% of the surface), *Chaemespartium tridentatum* (30%), *Cystus ladanifer* (26%). The prescribed fire differently affected individuals of the three species, the former showing a high resistance to fire.

During prescribed fire, temperatures at surface and at 5 cm below ground were measured immediately after the fire with a portable infrared apparatus as shown in Fig. 2. These data, together with observations of the incompletely burned vegetation and the degree of litter consumption, allowed a qualitative evaluation of fire severity, concluding that it was a low severity fire (Hungerford, 1996).

In the same above mentioned 11 sites where the shrub vegetation inventory was carried out, disturbed soil samples were collected before prescribed fire (BF), two (2 M), six (6 M) and thirty-six months (36 M) after fire, at 0–5, 5–10 and 10–20 cm depths, to assess organic matter, nutrients concentration, soil pH and electrical conductivity. Methods applied in laboratory analysis comprised the Walkley-Black method for soil organic matter, the Egner-Riehm method for extractable phosphorus and potassium, the method proposed by Jones (2001) for electrical conductivity, and pH determination in a soil-water suspension (1:2.5 soil water ratio). Exchangeable bases were determined by atomic adsorption (Ca^{2+} and Mg^{2+}) and by flame emission spectrophotometry (K^+ and Na^+). Cation exchangeable capacity was calculated as the sum of exchangeable bases and exchangeable acidity.

Permeability was measured on 11 undisturbed samples randomly collected in 100 cm^3 cylinders in the surface layer (0–5 cm), at several moments: before the prescribed fire, soon after fire, and two and eight months after fire. The permeability was measured in a constant head closed circuit laboratory permeameter.

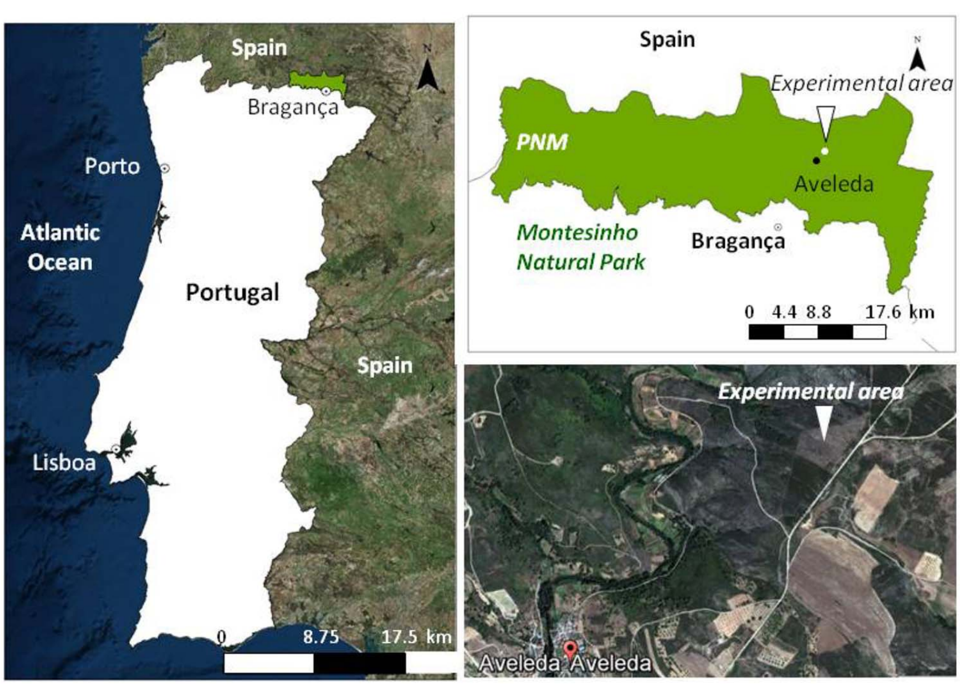

Fig. 1. Location of the study area in Montesinho Natural Park (PNM), NE Portugal.