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Changes in soil water repellency after prescribed burnings in three different Mediterranean forest ecosystems

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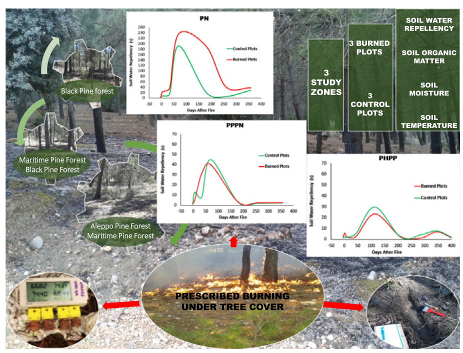
HIGHLIGHTS

- Soil water repellency increased after low-intensity prescribed fires to return to normal values over the year follow-up
- Soil water repellency fluctuated over the year inversely respect soil moisture and directly respect soil temperature
- Soil water repellency was higher in study forests with higher content of soil organic matter

GRAPHICAL ABSTRACT



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ABSTRACT

Prescribed burnings reduce the biomass and the risk of wildfires but can also alter soil water repellency. The objective of this study is to evaluate the impact of several prescribed burnings in soil water repellency (SWR). In spring 2016, prescribed burns were carried out at three forest sites located in: (i) Beteta in a pure forest of *Pinus nigra* Arnold ssp. *salzmannii*; (ii) El Pozuelo in mixed forest stands of *Pinus pinaster* Aiton and *Pinus nigra* Arnold ssp. *salzmannii*; (iii) Lezuza in mixed forest stands of *Pinus halepensis* Miller and *Pinus pinaster* Aiton. Six plots were established in each study area: three burned and three unburned. SWR was measured before and immediately after prescribed burns following a 1-year periodic evaluation. There were seven sampling dates at Beteta and El Pozuelo and nine at Lezuza with six plots and six measurement transects in each plot (36 measurement transects on each date). Soil water content (SWC), soil temperature (ST) and soil organic matter (SOM) were also measured. Our results showed that SWR increased after burning to quickly return to normal values in Lezuza, after 1 month in El Pozuelo and after 1 year in Beteta. Moreover, a significant positive relationship between SWR and both SOM and ST, but a negative one with SWC, were observed, which led SWR to increase after fire passage, also in the summer months. Continuous monitoring of these study sites is recommended to determine if low-intensity burnings promote mid- to long-term changes in soil characteristics.

1. Introduction

Wildfires in Mediterranean regions are one of the most important drivers that shape both the landscape and dynamics of these

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ecosystems (Keeley et al., 2011). Current climate trends with higher temperatures and reduced precipitation, plus vegetable fuel accumulation, are the main factors that increment the frequency and severity of wildfires. This scenario has a direct negative impact on physico-chemical and hydrological soil properties (Shakesby, 2011). Soil surface conditions change after a fire, and hydrological soil properties, such as soil infiltration or hydrophobicity, may also change (Úbeda and Outeiro, 2009). In order to reduce low-intensity fire risks, prescribed burnings have been widely used as a fuel reduction tool and as a silvicultural treatment in Mediterranean forest ecosystems (Vilén and Fernandes, 2011).

Prescribed burns are defined as the controlled application of fire. Environmental parameters and ignition strategies are specified in each area to fix fire intensity, which is programmed to meet the proposed objectives (Fernandes et al., 2013). The main objective of prescribed burning is to create areas with low fuel in order to reduce fire intensity that minimises large fires (Alcañiz et al., 2018). Maintaining fire regimes to promote the regeneration of fire adapted species (Finney et al., 2005) can also be useful for the regeneration of certain species and the elimination of invasive species (Williams et al., 2012). Forest managers are currently implementing prescribed burning as an ecosystem management tool to reduce fuel loads in landscapes prone to forest fires in order to minimise mainly the extent and severity of forest fires, or as a clearing treatment to facilitate the germination and growth of desired forest species (Alcañiz et al., 2018; Fernandes et al., 2013), and is even used as an opportunity for forest firefighters to learn about fire control. Prescribed burnings also offer important advantages as they efficiently reduce fuel load, and even trees, at a much more competitive cost than mechanical or manual clearing (Rodríguez y Silva, 2004).

There is growing interest in the effects of prescribed burning on soil properties in the scientific literature about the effect of wildfire on soil properties (Bento-Gonçalves et al., 2012). It is most important to understand and quantify the potential impact of prescribed burning on physico-chemical and microbiological soil properties once prescribed burns have been applied as this will allow better territorial management strategies to be established.

Soil water repellency (SWR) is influenced by the temperature reached in the ground during fire passage (Jiménez-Pinilla et al., 2016) and is considered important for post-fire hydrology as it reduces soil infiltration, and increases erosion and surface runoff rates (Bodí et al., 2013; DeBano, 2000; Jiménez-Pinilla et al., 2016; Jordán et al., 2013; Letey, 2001; Shakesby et al., 2000). Fire can create, strengthen or destroy SWR (DeBano, 2000; Doerr et al., 2000). Organic molecules vaporise on the soil surface, created by the combustion of soil organic matter (SOM), and then move in the soil profile along pronounced temperature gradients and condense as temperatures drop by forming a repellent coating to water on soil particles (DeBano, 1981). In addition, SWR is closely related to SWC (Doerr and Thomas, 2000).

Several studies have evaluated the relationship between SWR and soil heating temperature, and marked increases in SWR have been reported in soil with temperatures in soil below 175–200 °C (DeBano, 1981) or 200–400 °C (Girona-García et al., 2018). Other studies have obtained a lower or a destroyed SWR when soil was heated between 185 °C and 400 °C (Sala and Rubio, 1994), or above 280 °C (DeBano, 2000), 310–340 °C (Doerr et al., 2004) or 250 °C (Zavala et al., 2010). In relation to erosion, SWR can increase by splashing raindrops (DeBano, 2000; Shakesby et al., 1993). The wide spatial variability of SWR must be considered because it is even more noticeable in low-intensity fires or prescribed burnings as they leave many unburned areas behind. These unburned patches play an important role in reducing runoff and erosion on the stand scale (Cawson et al., 2012; Cawson et al., 2013).

As previously stated, the hydrological properties of soil can be altered by fire as SWR increases and surface runoff and erosion are enhanced. A better understanding of the hydrologic behaviour of that affected by fire action is necessary (and also in low-intense burning), particularly in areas prone to runoff and erosion risks, such as Mediterranean forests. Therefore, this study aims to quantify the effects of prescribed burns on SWR across different Mediterranean forest ecosystems. We hypothesise that prescribed burnings may increase SWR since incomplete plant and litter combustion generated by low-intensity fires favours the accumulation of hydrophobic compounds, but this alteration have a short-time duration.

2. Materials and methods

2.1. Study areas

The study was carried out in three different areas of Castilla-La Mancha (Spain), which were chosen to characterise the three commonest pine forests in Spain: a mix stand with Aleppo and Maritime pine (PHPP) (557,588 E, 4,306,475 N UTM) at an altitude of 1025 m.a.s.l. in the municipality of Lezuza, the province of Albacete; a mix stand with Maritime and Black pine (PPPN) (561,373 E, 4,490,691 N UTM) at an altitude of 1050 m.a.s.l. in the municipality of El Pozuelo, the province of Cuenca; a pure stand of Black pine (PN) (UTM: 575,451 E, 4,489,248 N) at an altitude of 1250 m.a.s.l. in the municipality of Beteta, the province of Cuenca (Fig. 1).

The three areas are public forests with a Mediterranean continental climate, and a hot and dry summer season. The average annual temperature at PHPP is 13.5 °C (mean lowest temperature of the coldest month = 0.9 °C; mean highest temperature of the hottest month = 31.8 °C). At PPPN it is 11.3 °C (mean temperatures of the coldest month = 2.7 °C; mean highest temperatures of the hottest month = 23.0 °C). At PN the annual average temperature is 10.2 °C (mean lowest temperatures of the coldest month = 1.7 °C; mean highest temperatures of the hottest month = 20.1 °C). The rainfall regime concentrates between autumn and spring, with an annual average rainfall regime of 450–500 mm at Lezuza (National Meteorological Organization, period 1950–2016), which is the area with the least rainfall. Pozuelo and Beteta receive more rainfall with 550–600 mm and 600–650 mm, respectively. The stand at Lezuza consists of a mixed pine forest with Aleppo pine (*Pinus halepensis* Miller) and Maritime pine (*Pinus pinaster* Aiton), and undergrowth with some individuals of *Quercus ilex* subsp. *ballota* (Desf.) and *Quercus faginea* Lam. El Pozuelo is a mixed forest of Maritime pine (*Pinus pinaster* Aiton) with Black pine (*Pinus nigra* Arnold ssp. *salzmannii*) and some individuals of *Quercus faginea* Lam. in the undergrowth. Beteta consists of a monospecific forest of Black pine (*Pinus nigra* Arnold ssp. *salzmannii*). More details about the forest stands are included in Table 1.

2.2. Experimental design

In spring 2016, the Regional Forestry Service performed prescribed burns in the delimited plots of each study area. Six plots were established per area (PN, PPPN and PHPP), with dimensions of 50 × 50 m as the burned area. Only the 30 × 30 m within the plot was studied to avoid the edge effect. Three of the six plots were randomly selected to be taken as the control (without treatment) and the other three were assigned to be treated with prescribed burnings. Prescribed burnings were carried out manually using lines of fire separated 1 m from one other, which ran perpendicular to, and lay opposite, the direction of the wind. The meteorological conditions for the burning were: PN (wind speed and direction: 10 km/h southwest, ambient temperature: 15 °C, relative humidity: 62%); PPPN (wind speed and direction: 8 km/h south, ambient temperature: 18 °C, relative humidity: 58%); PHPP (wind speed and direction: 14 km/h southeast, ambient temperature: 14 °C, relative humidity: 63%). To avoid affecting the tree stratum, a low-intensity fire was sought. However, some effects occurred, such as increased needle fall in the months following the prescribed burning (Espinosa et al., 2018) (Fig. 2). The temperatures at PN were 361 ± 29 °C in the organic layer, 37 ± 4 °C on the mineral soil surface and 18 ± 3 °C on the 2-cm depth soil surface; At PPPN, temperatures were