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Water repellency and moisture content spatial variations under *Rosmarinus officinalis* and *Quercus coccifera* in a Mediterranean burned soil

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ABSTRACT

Variations in the distribution pattern of soil water repellency (SWR) and soil moisture are of major importance for the hydrological and geomorphological processes in Mediterranean burned areas, and also for their ecological implications concerning to re-establishment of the vegetation cover. This paper studies the influence of *Rosmarinus officinalis* L. and *Quercus coccifera* L. vegetated patches on SWR and their relationships with soil moisture content (SMC) and soil organic matter (SOM) in burned and unburned calcareous soils of a Mediterranean shrubland ecosystem, considering the first rainfall event occurred after the wildfire in Les Useres (Castellón, eastern Spain).

In a burnt SSE facing hillslope (739605 West, 4449022 North), 8 microsites were selected under *Q. coccifera* and 20 under *R. officinalis*. Three concentric zones were distinguished around the plants: Zone I (stump), Zone II (intermediate) and Zone III (bare soil), showing differences on its soil surface appearance, which were considered for soil sampling and for field moisture measurements. In the nearest unburned zone, at the same hillslope, 8 microsites for each of the same species were also selected, on the basis that they were representative of the pre-fire conditions.

The obtained results imply that fire caused a significant increase in SWR at *R. officinalis* stumps (measured by means of the water drop penetration time test, WDPT). However, at burned *Q. coccifera* microsites, SWR was destroyed by fire, at least in the 2 mm soil fraction (WDPT < 5 s). Results also showed the presence of a gradient from the highest WDPT and SOM at Zone I to the lowest at Zone III for the two studied species, in that way that bare soil was wettable at burned and unburned microsites and this fact is also reflected on the spatial distribution of SMC. Field SMC showed an increasing gradient from the stumps towards the outer zone, and the differences between SMC in the stumps and bare soil were greater from burned than unburned microsites. Field SMC showed significant and negative correlation coefficients with the WDPT and SOM content for the two studied species. Moreover, a positive relationship between WDPT and SOM was found. Partial correlation analysis at burned microsites revealed that SMC and WDPT are influenced by the SOM. The hydrological and ecological implications of these results are discussed.

1. Introduction

Due to the persistence, extensive dispersion, and long term environmental and socioeconomic impacts, Mediterranean wildfires have been widely studied. The region could be considered as one where fires are among of the most permanent threats to the environment in the northern hemisphere (Pascual Aguilar et al., 2008). Within the specific scope of environmental impacts, forest fires act as a triggering factor to initiate changes in Mediterranean ecosystems. Post-fire interactions between different components of the vegetation/soil interface have been widely studied. Most works have focused in the soil and vegetation changes, assuming that fire impacts affect soil properties and hydrological processes at different degrees, which are determined largely by fire severity and the immediate post-fire rain regime (Gimeno-García et al., 2004, 2007; Campo et al., 2006; Doerr et al., 2006; Llovet et al., 2009). Thus, existing research has been concentrated mainly on infiltration, soil moisture storage and runoff, which can be significantly affected by fire and are directly related with the soil water cycle (Imeson et al., 1992; Rubio et al., 1997; Robichaud et al., 2000; González-Pelayo et al., 2006; Cerdá and Doerr, 2005).

The pattern of vegetation structure and other soil surface components (superficial stoniness, rock outcrops, soil crust and bare soil), although less studied in the literature, are an increasing recognized factor of importance regarding runoff generation and water redistribution during the infiltration process, being specially

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emphasised where banded or spotted vegetation patterns occur like in Mediterranean landscapes (Bergkamp et al., 1996; Valentin and Poesen, 1999; Calvo-Cases et al., 2003; Boix-Fayos et al., 2006; Arnau-Rosalén et al., 2008). The role of bare soil patches, outcrops and the crusted bare areas between vegetation clumps as runoff generating areas (source areas), and the vegetation-covered areas as water-adsorbing patches (sink areas) is one of the most important features in patchy or banded vegetation types under Mediterranean conditions (Cammeraat, 2004). This distribution of vegetation cover also plays an important role in controlling the soil organic matter inputs and the soil moisture contents.

Within this soil-vegetation interface transition, the topsoil moisture pattern has implications for understanding environmental processes such as infiltration regime, runoff generation and its superficial continuity across slope, and erosion and sedimentation driven by overland flow (Katra et al., 2007). At small scales, soil moisture responds to variations in soil properties, topographically driven changes in lateral flow, radiation, and vegetation (Western et al., 2002). Soil variables that affect infiltration and water storage include texture, structure, porosity, bulk density, organic matter, and so forth. Another soil property that influences these processes is soil wettability. Soils in some vegetative types and regions can develop characteristic water repellency, caused by hydrophobic, long-chained organic molecules, released from naturally decomposing plant litter, from the root zone and the leaf surfaces of living plants, from fungal hyphae and soil microorganisms, or by volatilisation and condensation of such compounds during fire (Doerr et al., 2000). Soil water repellency has important effects in burned ecosystems, by modifying infiltration capacity, water movement in soil, and on the post-fire erosion processes, mainly rain drop splash and rill formation (DeBano, 2000; Doerr et al., 2000; Shakesby and Doerr, 2006).

Soil moisture influences water repellency of the soil surface in vertical and lateral reallocation of water at the finest scales (Imeson et al., 1992). It seems that cover density and plant species have a relationship with the persistence and distribution of SWR (DeBano, 1981; Doerr et al., 2000), and fire could act as a triggering factor enhancing or decreasing it related to their severity. Although recent studies on calcareous Mediterranean environments have demonstrated that water repellency can be found in both burnt (Mataix-Solera and Doerr, 2004; Arcenegui et al., 2008; Llovet et al., 2009) and non-burnt environments (Verheijen and Cammeraat, 2007), the post-fire hydrological implications of the fire-induced water repellent soils, when the vegetation is spotted or there is a patchy shrub mosaic, is still poorly studied. Moreover, there are few studies that consider the implications of the first rainfall event on natural wildfire areas.

The present paper studies the influence of burned and unburned *Rosmarinus officinalis* and *Quercus coccifera* vegetated patches on soil water repellency (SWR), and their relationships with soil moisture content (SMC) and soil organic matter (SOM), considering the first rainfall event occurred after the wildfire. Since surface SMC, SOM, and SWR are influenced by vegetation and fire, and soil water and vegetation dynamics are functionally related, it could be expected to find some changes on these variables after fire occurrence.

2. Materials and methods

2.1. Study area

The study area is located at Serra de la Creu, in the municipality of Les Useres, 40 km of Castellón city (Eastern Spain). This area suffered a wildfire from 28th August 2007 to 7th September 2007. The total affected area covered 7482 ha, of which 476 ha corresponded to forest trees (with dominance of *Pinus halepensis* and in lower extension *Quercus rotundifolia*); 5299 ha were dominated by shrublands and the remainder surface corresponded mainly to agricultural rainfed areas on terraces with almond, olive and carob trees (1707 ha). The area has a dry sub-humid Mediterranean-type climate with a marked dry period from June to September. Mean annual temperature is 15.2 °C and the mean annual precipitation is 567 mm (data from Vilafamés meteorological station).

In this area, a burned zone (739605 West, 4449022 North) of 7 m wide by 16 m long, located at 570 m a.s.l. on a South–South East facing hillslope with 12º slope angle was selected. The soil is a Rendzic Leptosol developed on Cretaceous limestone, with sandy-loam texture, alkaline pH (7.9) and an organic matter content of the Ah horizon of 7.6%. Despite fire, it was possible to identify the presence of two unique shrub species inside the plot: *Q. coccifera* and *R. officinalis*, which are distributed in a patchy mosaic. The upper and central part of the plot is occupied by individuals of *R. officinalis*, separated one from each other at least by 0.5 m. On both sides of the plot, from meter 6 to 16 (Fig. 1), *Q. coccifera* is distributed in two longitudinal stripes, approximately of 2–3 m wide.

Field observations and measurements revealed that fire spread across the shrubland, burning branches of 4–5 mm diameter, and consumed all green leaves of these species. Under *Q. coccifera*, the litter layer was almost completely consumed, the dominant ash colour was grey and white, and the remainder twigs had, generally, a mean of 10 cm height and 2 cm diameter. In *R. officinalis* places, the longest standing twigs had 80 cm height and 2.5 cm diameter on average, the dominant ash colour was grey with some punctual areas with white ashes (mainly close to the stump) (Fig. 2), and the litter layer was partially consumed, remaining some charred leaves, which helped to identify this species.

Out of the burned plot, at its right and left sides, unburned vegetation still stands, dominated by a shrubland of 0.6–1.2 m height, with *Q. coccifera*, *R. officinalis*, *Anthyllis citysoides* and *Brachypodium retusum* as dominant species, and also with some groves of *Q. rotundifolia*. In that unburned zone, some vegetated patches of the same species as above were selected as control microsites (see next epigraph). Unburned *R. officinalis* individuals had a mean height of 90 cm and 60 cm canopy diameter, whereas *Q. coccifera* vegetation patches were 110 cm height and 200 cm wide.

2.2. Soil sampling and analysis

The patchy mosaic distribution of vegetation and the differences on soil surface appearance has been considered when soil sampling and field moisture measurements were made. A total of 44 microsites were selected: 16 at the unburned area (8 with *R. officinalis* and other 8 with *Q. coccifera*) and 28 microsites at the burned zone (20 with *R. officinalis* and 8 dominated by *Q. coccifera*). The distribution of burned microsites is represented in Fig. 1. The selection of unburned microsites was made based on the proximity and similarity to the burned zone.

At burned microsites three weeks after the fire impact, it was possible to distinguish three concentric zones around the charred stumps showing differences on its soil surface appearance (Fig. 2). Zone I corresponds to the soil closest to the burned stump, with a variable diameter between 40 and 60 cm, with grey and white ashes, and where the litter layer was almost completely consumed. Zone II is located between Zones I and III, with variable size from 10 to 30 cm; showing dark grey ashes and litter combustion lower than Zone I. The Zones I and II would correspond to the soil area covered by shrub canopy when unburned. Finally, the Zone III, located all around the previous ones, is the most distant from the stump and corresponds to the bare soil; it is characterised by the absence of ashes and more stones on the soil surface than the other zones. The soil appearance on those different zones indicate a gradient of fire severity, from the highest close to the stumps (Zone I) to the lowest on bare soil (Zone III), according to the classification criteria used by USDA Forest Service (Robichaud et al., 2000).

At each of the selected burned and control microsites, soil sampling and field soil moisture measurements were made. Additional