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Post-fire evolution of water repellency and aggregate stability in Mediterranean calcareous soils: A 6-year study

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ABSTRACT

Water repellency (WR) and aggregate stability (AS) are two soil properties generally modified after burning which show several hydrological and soil functioning consequences and may be used as indices for assessing burn severity. Both properties are strongly related and have major impacts on soil functioning and post-fire hydrologic and geomorphological processes. In many cases, the impact of fire on these properties has been analyzed in the short term. However, it is also necessary to investigate the magnitude of these changes and their implications for longer periods under specific conditions. In this work, we have investigated [1] the fire-induced changes on soil WR and AS in the medium term (6-year period after burning) and its distribution within aggregate size fractions (1–2, 0.5–1 and 0.25–0.5 mm), [2] the relations between post-fire AS and WR, and [3] the interactions between AS, WR and different factors (site, time since burning, lithology and vegetation type) in Mediterranean calcareous soils. Five areas burned during the summer 2006 in southern Spain were selected for this study. The study sites were characterized by wettable or slightly water-repellent calcareous soils with loam to clayey texture under herbaceous vegetation and shrubs. Soils were characterized chemically and physically, while the WR and AS of the fine earth and aggregate sieve fractions were determined annually between 2006 and 2011. Results show that soil WR was induced in previously wettable or enhanced in slightly or moderately water-repellent calcareous soils after moderate severity burning. Severity of WR from finer aggregates (0.5–1 and 0.25–0.5 mm) varied or remained stable but did not contribute to general soil WR assessed in the fine earth fraction. AS was slightly increased in some cases, and both properties returned progressively to pre-fire conditions during the study period. Soil resilience to low-moderate severity burning in the study area was very high.

1. Introduction

Water repellency (WR) is a characteristic of some soils, which reduces the affinity of soil for water (Doerr et al., 2000; Jordán et al., 2013). According to Doerr and Moody (2004), soil WR has more than one temporal scale, and infiltration is inhibited in water-repellent soils during periods of time ranging from a few seconds to hours or months (Doerr and Moody, 2004; Doerr et al., 2000). When the infiltration rate is inhibited or reduced, time for runoff generation is shortened and overland flow is enhanced, thus increasing soil erosion rates (Doerr et al., 2000; García-Moreno et al., 2013; Jordán et al., 2008; Shakesby et al., 2000; Sheridan et al., 2007; Varela et al., 2010). Soil WR also contributes to the development of preferential flow paths (de Rooij, 2000; Granged et al., 2011a; Jordán et al., 2009; Zavala et al., 2009a,b) and macropore flow (Burch et al., 1989; Doerr et al., 2006; Nyman et al., 2010). Some important consequences of these irregular wetting patterns are accelerated leaching of nutrients and increased contamination risk (Leighton-Boyce et al., 2005; Ritsema and Dekker, 1994), reduced soil fertility (Blackwell, 2000) and alterations of the run-off–runon patterns between vegetated and bare soil patches due to the existence of biological crusts (Contreras et al., 2008; Lichner et al., 2012).

Soil WR has been reported from a variety of soils under different vegetation types and climates (Doerr et al., 2009a; Jordán et al., 2009; Martínez-Zavala and Jordán-López, 2009; Mirbabaei et al., 2013; Neris et al., 2013), but sometimes fire is considered as a triggering factor (Bodí et al., 2013; Mataix-Solera et al., 2013). Depending on factors such as soil temperatures during burning (DeBano et al., 1976), time of heating (Doerr et al., 2004), soil properties (texture, structure or organic matter content, among other), and quantity and type of fuel, soil WR may be induced, enhanced, destroyed (Arcenegui et al., 2007,

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2008; Doerr et al., 2004; Granged et al., 2011a; Jordán et al., 2011; Tessler et al., 2008) or stay unaffected in the short- (Cerdà and Doerr, 2005; Fernández et al., 2008; Granged et al., 2011b; Jordán et al., 2010a) or in the long-term (Doerr et al., 2009a). Besides other soil properties (such as texture or AS), spatial distribution, intensity and persistence of soil WR are key factors controlling runoff/infiltration patterns and water availability in burned soils.

Soil structure is an important factor controlling hydrological processes, water availability and soil erosion risk. Soil structure results from the arrangement of soil pores and aggregates, which are formed as a consequence of the interaction of soil mineral and organic solid particles (Amézketa, 1999). Aggregate stability (AS) may vary as a result of changes in the concentration of cementing agents (clay, organic matter, calcium carbonates, Ca, Fe and Al oxides) or external forces resulting from wetting/drying, raindrop impacts, dispersion/swelling of clay or mechanical pressure (Mataix-Solera et al., 2011). Destruction or degradation of aggregates by burning has been reported as a cause of increased post-fire soil erosion, but a complex response of soil aggregation to fire has been reported by many authors (Mataix-Solera et al., 2011; Shakesby, 2011). In the short-term, some authors have reported decreased AS after intense wildfire or severe laboratory heating (Giovannini et al., 1988; Sanroque et al., 1985; Úbeda et al., 1990) or increased AS (Díaz-Fierros et al., 1987; Giovannini and Sequi, 1976; Ibáñez et al., 1983). Other studies have not found significant changes in AS after fire (for example: Arcenegui et al., 2008; Jordán et al., 2011; Llovet et al., 2008; Mataix-Solera et al., 2002). According to Mataix-Solera et al. (2011), AS from soils with a high clay content, calcium carbonate, Fe and Al oxides as a principal cementing substance increases with fire severity, while AS from highly water-repellent sandy soils with organic matter as main cementing agent usually decreases with fire severity. As a third pattern, AS from wettable or slightly water-repellent soils, with organic matter as the main binding agent, increases after medium severity fires and sharply decreases after high severity fires.

Although fire-induced soil WR dynamics in the post-fire have been rarely studied, it is well established that the severity of fire-induced soil WR depends on burning temperature (DeBano, 1981; Jordán et al., 2011; Robichaud and Hungerford, 2000), vegetation type and land use (Arcenegui et al., 2007; Doerr et al., 2002, 2006; Granged et al., 2011a; Reeder and Jurgensen, 1979; Zavala et al., 2009b) and soil properties (Mataix-Solera et al., 2013). Malkinson and Wittenberg (2011) suggested that in the short-term, fire-induced WR dynamics are controlled by pre-fire vegetation. Bodí et al. (2013) reported increased soil WR immediately after burning and a rapid decrease in the following period, with variations strongly related with soil moisture. In contrast, little is known about the long-term variability of fire-induced soil WR at a decadal time scale (Doerr and Moody, 2004; Malkinson and Wittenberg, 2011). Long-term patterns have been reported, with soil WR decreasing slowly (Dyrness, 1976; Hubbert and Oriol;, 2005; Reeder and Jurgensen, 1979; Tessler et al., 2008), or increasing, which has been attributed to microbial activity, plant species or erosion of the surface wettable layer after deep environmental changes induced by burning (Hallett, 2008; Jordán et al., 2010a; Zavala et al., 2009b).

Independently of fire, both properties, AS and soil WR are related, since hydrophobic organic coatings may retard water entry in aggregates and reduce air entrapment, inhibiting aggregate slaking. This results in increased AS, as it has been reported by many authors (Mataix-Solera et al., 2011; Shakesby, 2011). Soil WR has been reported to occur preferably in coarsely-textured soils with low aggregation (DeBano, 1981; McGhie and Posner, 1981; Roberts and Carbon, 1972), since coarse particles are more likely to develop water repellency for a certain amount of hydrophobic substances because of its lower specific surface (Blackwell, 1993; Giovannini and Lucchesi, 1983; González-Peñaloza et al., 2013) and super-hydrophobicity (González-Peñaloza et al., 2013). However, soils with 25–40% clay have been reported to be extremely water-repellent (Crockford et al., 1991; Dekker and Ritsema, 1996). It has been suggested that aggregation in clayey soils reduces the area that needs to be coated with hydrophobic substances to produce water repellency (Bisdom et al., 1993; Wallis et al., 1991). It may also happen that the size of the particles of hydrophobic organic material is small enough to enhance the severity of repellency fine fractions compared to the coarse ones (de Jonge et al., 1999). In other cases, it has been shown that a certain amount of hydrophobic substances may be sufficient to coat fine particles, plus the mineral particles and coarse aggregates (Doerr et al., 1996). If this happens, a fine-textured soil might also show a high severity of water repellency. Some authors have suggested to include the combined assessment of soil WR and AS in studies of fire-affected soils because of the interaction between both properties, their implications and the complexity of post-fire soil processes (Mataix-Solera et al., 2011; Shakesby, 2011; Shakesby and Doerr, 2006).

In this paper, we study the evolution of soil WR and AS during a 6-year period after a wildfire in Mediterranean calcareous loamy to clayey soils from SW Spain. The objectives of this research are: [1] to study the changes in SWR and AS immediately after fire and in the medium-term (6 years after burning) and its distribution within aggregate size fractions, [2] to assess the relationships between postfire AS and WR, and [3] to investigate interactions between AS and WR and different factors (site, time since burning, lithology and vegetation type) in calcareous Mediterranean soils.

2. Methods

2.1. Study area and fire characteristics

Five areas affected by wildfires between July and September 2006 were selected in the municipalities of Cortes de la Frontera (CF), Jimena de la Frontera (JF), Los Barrios (LB) and Tarifa (T1 and T2), in the provinces of Cádiz and Málaga (southwestern Spain; Fig. 1). The climate is Mediterranean, with cool, humid winters and warm, dry summers. The mean annual rainfall ranges between 971 (Tarifa) and 1922 mm (Cortes de la Frontera). The annual number of days with precipitation over 1 mm is 60. The mean air temperature is mild, 16–18 °C, with a maximum monthly mean air temperature of 22 °C (August) and a minimum monthly mean of 13 °C (January–February). Table 1 shows the location and characteristics of each site, date of fire, burned area and mean annual rainfall. Fire severity was estimated according to the degree of vegetation and ground fuel destruction (Chandler et al., 1983; Moreno and Oechel, 1992). According to terminology proposed by Keeley (2009), fire severity at each study area varied between low (burned herbs; shrubs below 2 m were partly charred but not consumed; scarce deposition of ash; most soil organic layer unaffected) and high (scorched trees; stems thinner than 15 mm were completely consumed; white ash covering part of the soil surface; organic layer completely burned) severity. Only areas affected by moderate fire severity were selected for this study. These areas showed complete consumption of herbs and most shrubs, and soil organic layer largely consumed. When present, sparse trees and larger shrubs were scorched but biomass was not completely burned or consumed, and stems thicker than 8–10 mm were not completely consumed and some of them even survived.

The main vegetation types in unburned areas adjacent to studied burned plots are grassland (dominated by Poaceae and Fabaceae); shrublands dominated by mastic (*Pistacia lentiscus*) and Mediterranean dwarf palms (*Chamaerops humilis*) associated with brooms (*Genista linifolia* and *Calicotome villosa*), and Kermes oak (*Quercus coccifera*). Also sparse olive trees (*Olea europaea*) and holm oak (*Quercus rotundifolia*) were present in some cases (LB and CF sites, respectively).

2.2. Soil sampling and analysis

Ten soil samples (0–15 mm) were collected for soil characterization in unburned areas adjacent to each burned areas during the first week