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Soil water repellency in Mediterranean rangelands under contrasted climatic, slope and patch conditions in southern Spain

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ABSTRACT

This study evaluates the spatial and temporal variability in soil water repellency (SWR) in two Mediterranean rangelands (with similar tree and shrub species) and its relationships to different eco-geomorphologic variables (climate, aspect, soil cover and some soil properties). Every month from October 2008 to May 2009 (rainy season), soil moisture and SWR was measured in field conditions by means of gravimetric method and Water Drop Penetration Test, respectively. Also, disturbed and undisturbed soil samples were taken to analyze some soil properties: bulk density, texture, organic matter, pH and electrical conductivity. The entire tests were performed in north and south aspect hillslopes and beneath shrub and bare soil in every of them. The results indicated that: i) climatic conditions seem to be more transcendent than the vegetal species for explaining the variability in SWR; ii) thus, SWR appears to be controlled by the antecedent rainfall and soil moisture; iii) more severe SWR were observed in patches characterized by sandier soils and/or higher organic matter contents; and iv) the factor 'hillslope aspect' was not found so crucial as it was expected.

1. Introduction

Soil water repellency (SWR) has become an important field of scientific study because of its effects on soil hydrological behavior, including reduced matrix infiltration, development of fingered flow in structural or textural preferential flow paths, irregular wetting fronts, and increased runoff generation and soil erosion (Cerdà and Doerr, 2007; DeBano, 2000; Dekker and Ritsema, 1994; Doerr et al., 2000; Hendrickx et al., 1993). Studies in recent decades have shown that repellent soils are not rare, and can be found in many parts of the world under various climatic and soil conditions (DeBano, 1981; Doerr et al., 1996; Wallis and Horne, 1992).

SWR is caused by a variety of factors. Verheijen and Cammeraat (2007) observed that SWR is caused by either hydrophobic coatings on soil particles or hydrophobic particulate organic matter. Doerr et al. (2000) proposed molecular mechanisms to explain the introduction of repellency into soil by the heating of soil organic matter by fire, by fungal hyphae and plant roots, and by lipids from vegetation. The main factors controlling SWR are soil texture (Bisdom et al., 1993; Harper and Gilkes, 1994), soil moisture content (Bauters et al., 2000; De Jonge et al., 1999; Doerr et al., 2000; King, 1981), wetting–drying history of soil (Doerr and Thomas, 2000), drying temperature (De Jonge et al., 1999; Dekker et al., 1998), ambient relative humidity (Doerr et al., 2002), type of organic matter present and its concentration (Dekker and Ritsema, 1994; Rodríguez-Alleres et al., 2007; Täumer et al., 2005; Wallis et al., 1990), and, particularly in Mediterranean environments: fire (Giovannini and Lucchesi, 1997; Mataix-Solera and Doerr, 2004; Trabaud, 1981) and forests (Cerdà and Doerr, 2007; Moral-García et al., 2005) are particularly important contributors to SWR. In some cases the degree of repellency has been reported to vary with land use or vegetation type. Because of the resins, waxes and other organic substances in their tissues, evergreen trees including eucalypts and conifers are commonly associated with SWR (Mataix-Solera and Doerr, 2004), although SWR has also been found in temperate heathlands (Mallik and Rahman, 1985) and Mediterranean shrublands (Jordán et al., 2008; Martínez-Murillo and Ruiz-Sinoga, 2010; Mataix-Solera et al., 2007).

In Mediterranean regions, where the summer is dominated by dry and warm climatic conditions, soils are expected to be particularly affected by SWR and its hydrological impacts because of the presence of drought resistant and often oil- or wax-rich vegetation types, and the occurrence of prolonged dry periods, which bring soils within the soil moisture range where water repellency occurs (Dekker et al., 2001; Jordán et al., 2010, 2011; Moral-García et al., 2005; Verheijen and Cammeraat, 2007; Zavala et al., 2009). As a consequence of its hydrological and erosive effects, SWR is a key issue in Mediterranean environments, where it shows substantial temporal variability because it is not a static soil property, and its occurrence is affected by short-term and seasonal factors (Doerr and Thomas, 2000). SWR is generally most extreme when soils are dry, and declines and eventually disappears as soils become wet (Bond and Harris, 1964; DeBano, 1971; Ritsema and Dekker, 1994; Witter et al., 1991). Thus, a direct soil moisture/SWR relationship has been proposed, and attempts have been made to identify 'critical soil

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moisture thresholds' that demarcate hydrophilic and hydrophobic conditions (Dekker and Ritsema, 1994; King, 1981; Soto et al., 1994). This threshold appears to be related to the soil texture (Ritsema and Dekker, 1996). In temperate to semi-arid climates, water repellency exhibits seasonal patterns, peaking in the dry periods and declining or disappearing after prolonged rainfall (Buczko et al., 2005; Jungerius and de Jong, 1989; Ritsema and Dekker, 2000).

The research described here was carried out in two Mediterranean rangelands containing similar Mediterranean tree and shrub species but differing in climatic conditions. The aim of the study was to evaluate spatial and temporal changes in SWR in Mediterranean rangelands, and its relationships to eco-geomorphologic variables. The objectives were to: i) assess the effect of similar shrub species under different climatic conditions on SWR; ii) determine whether rainfall and soil water content exert control over SWR; iii) investigate the relationships between SWR and soil properties in soils developed from the same parent material; and iv) assess the effect of aspect on SWR.

2. Material and methods

2.1. Experimental sites

The experimental sites were established in two Mediterranean rangeland areas (Gaucín and Almogía) with different climatic conditions in southern Spain. Fig. 1 shows the location of the experimental areas and a general view of the hillslopes where the study was conducted; contrasting hillslopes are present at each site. The Gaucín (GA) and Almogía (AL) experimental areas are located in the so-called Serranía de Ronda and Montes de Málaga, respectively. The mean annual precipitation at GA is 1010 mm y^{-1} and the mean annual temperature is 14.7 °C. The mean annual precipitation at AL is 550 mm y^{-1} and the mean annual temperature is 15.6 °C. Both study sites have steep topography (slope angle > 25%) and metamorphic rock substratum (phyllites and shales), and both experimental sites are affected by grazing that has resulted in less vegetation cover than in adjacent unaffected areas. Because of the natural scrub properties and the grazing effects the vegetation is patchy on the hillslopes, especially the south-facing slopes where water stress contributes to the patchiness of the vegetation cover. This has resulted in a mosaic-type distribution of plants that include *Quercus suber* and *Quercus ilex* (GA also has *Quercus pyrenaica*), and shrub cover of *Cistus monspeliensis* (more abundant on the south-facing slopes) and *Cistus albidus* (more abundant on north-facing slopes).

The GA experimental area is composed of two contrasting over-grazed slopes (N20° and N220°) having mean slope gradients of >20% and a patchy pattern of vegetation cover ranging from 40 to 60% and 50 to 70% on the north- and south-facing hillslopes, respectively. The grazing pressure is especially intense during the high precipitation period (from October to May), when the cover of shrubs increases and annual plants grow in bare soil areas in response to the water supply, especially on slopes with a northerly aspect. Water erosion is the main geomorphic process acting on the hillslopes, and is more intense on those facing south because of their lower vegetation cover. The bare soil areas are usually characterized by crusting and the presence of embedded rock fragments in the soil surface. The north-facing slopes have inter-shrub areas covered with moss and annual plants. Litter (1–3 cm) accumulates beneath the *Cistus* shrubs during summer, as these plants are semideciduous. The soils are eutric Cambisols on south-facing slopes and umbric Cambisols on north-facing slopes according to the FAO (2006). The AL site has similar slope gradients and vegetation cover to the GA site, although the vegetation cover is slightly greater on the north-facing slopes. The bare soil areas on the south-facing slopes are characterized by the absence of crusts and rock fragment

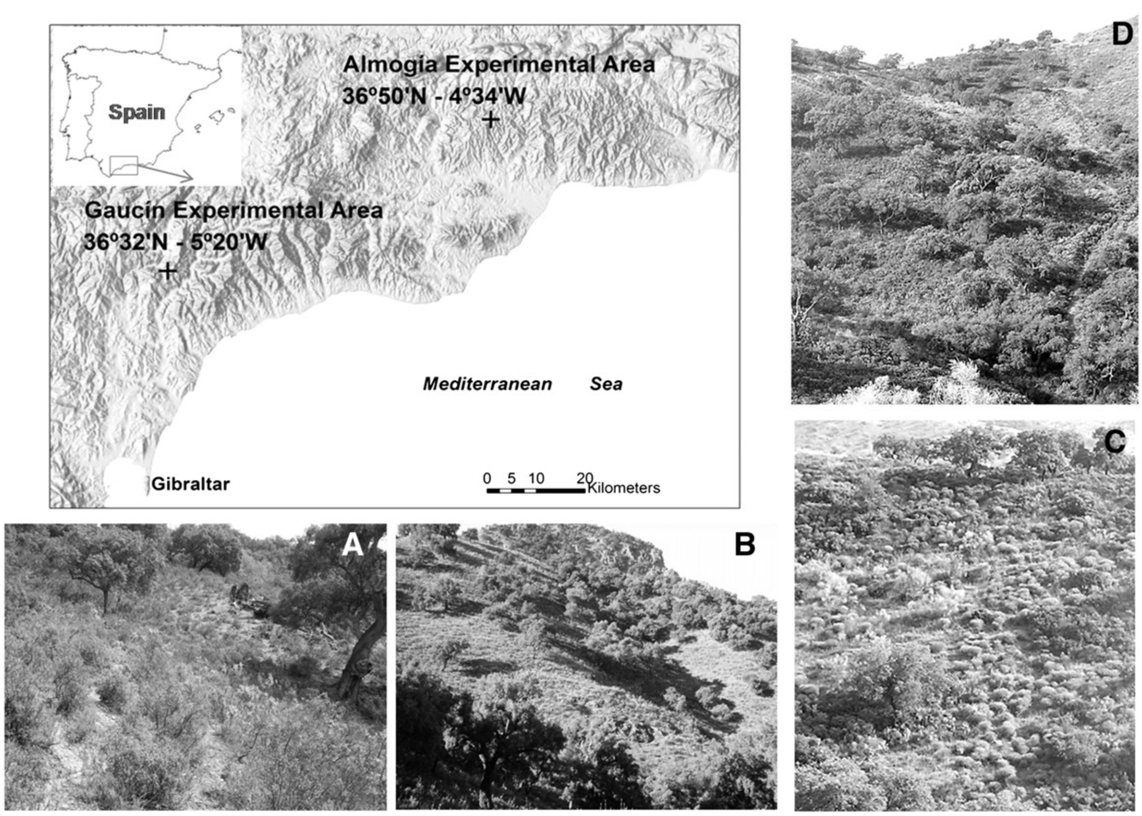

Fig. 1. Location of the experimental field sites and general view of hillslopes where the study was conducted. A and B, south and north-facing hillslopes from the Gaucín site; C and D, south and north-facing hillslopes from the Almogía site.