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Natural soil water repellency in different types of Mediterranean woodlands

Lorena M. Zavala [a], Jorge García-Moreno [a], Ángel J. Gordillo-Rivero [a], Antonio Jordán [a,*], Jorge Mataix-Solera [b]

[a] MED_Soil Research Group, Department of Crystallography, Mineralogy and Agrochemistry, University of Seville, C/Profesor García González, 1, 41012 Seville, Spain
[b] GEA (Environmental Soil Science Group), Department of Agrochemistry and Environment, University Miguel Hernández, Avenida de la Universidad, s/n, 03202 Elche, Alicante, Spain

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ABSTRACT

Water repellency (WR) is a property of some soils that reduces infiltration rates, enhances runoff generation and increases soil erosion risk. Although wildfires are considered a triggering factor, the characteristics of plant residues and soil properties may contribute to the development of soil WR. Because of its impacts, soil WR must be considered when modeling soil erosion risk and hydrological processes. Although many studies on WR from Mediterranean soils exist, relatively few studies have contributed to the knowledge of the natural baseline of soil WR in wide areas. The objective of this paper is to study the natural background soil WR in Mediterranean soils from south-western Spain under three representative forest types (pines, eucalypts and holm oaks) and its relation with plant cover (trees, shrubs and herbaceous plants) and soil properties. Field sampling was carried out in August 2013 in 15 areas from Huelva (SW Spain) under the studied forest types. Vegetation cover (trees, shrubs and herbaceous plants) was determined using transects at each case. The water drop penetration time test was used for assessing soil WR, and main soil properties were determined (texture, pH, organic C, N, Extractable P, exchangeable base cations – Ca^{2+}, Mg^{2+}, K^+ and Na^+ – and cation exchange capacity). According to results, soil WR was observed in all areas, increasing according to the sequence soils under holm oaks < eucalypts < pines. The severity of soil WR was always higher under the canopy of trees and usually decreased in bare areas, although bare soils under pine forest showed a proportion of slight to strong water-repellent cases. Severity of WR from soils under eucalypts and holm oaks increased with the presence of shrubs and herbaceous plants, but similar levels were not reached out of the tree-covered areas. Soils under vegetation in pine forests were always water-repellent, and wettability was observed only in some bare areas, suggesting a high potential of pines for induction of WR. Soil pH and the proportion of clay showed negative correlations with soil WR. A negative correlation between WR class and the proportion of exchangeable K^+ was found, suggesting that K deficiency for trees and shrubs restricts the input of hydrophobic substances in soil.

1. Introduction

Water repellency (WR) is a natural property of soils that reduces infiltration rates and, in consequence, enhancing runoff flow generation and increasing erosion risk (Doerr et al., 2000; Jordán et al., 2013). Soil WR has been reported in many geographic areas under a range of climatic conditions, vegetation types and soils (Doerr et al., 2000). Although biunique correspondence is difficult to establish (since many biotic and abiotic factors are involved), some plant species seem to be linked to the occurrence of WR in soils (Doerr et al., 1998; Scott, 2000). Plant species most commonly associated with WR are evergreen trees with a considerable amount of resins, waxes or aromatic compounds in their composition, as eucalypts and pines (Arcenegui et al., 2008; Hubbert et al., 2006; Lewis et al., 2006; Martínez-Zavala and Jordán-López, 2009; Mataix-Solera and Doerr, 2004; Mataix-Solera et al., 2007). But WR has been also found in soils under shrub species in temperate areas (Giovannini et al., 1987; Jordán et al., 2008, 2010; Mallik and Rahman, 1985; Martínez-Zavala and Jordán-López, 2009; Zavala et al., 2009a), oaks (Cerdà et al., 1998; Jordán et al., 2008; Mataix-Solera et al., 2007) and deciduous trees (Buczko et al., 2002; Reeder and Jurgensen, 1979).

Although wildfires are a major cause of WR, soil properties and the characteristics of the parent material may also condition the severity of WR in soils (Lozano et al., 2013; Mataix-Solera et al., 2013). Soil acidity (Hurrass and Schaumann, 2006; Mataix-Solera et al., 2007; McGhie and Posner, 1981; Zavala et al., 2009b), soil texture (de Jonge et al., 1999; DeBano, 1991; Doerr et al., 1996; González-Peñaloza et al., 2013; Rodríguez-Alleres et al., 2007), aggregates (Doerr et al., 1996; Jordán et al., 2011; Kawamoto et al., 2007; Mataix-Solera and Doerr, 2004) and soil mineralogy (Dlapa et al., 2004; Lichner et al., 2006; Mataix-Solera et al., 2008; McKissock et al., 2000; Ward and Oades, 1993) are also important factors.

* Corresponding author at: MED_Soil Research Group, Departmento de Cristalografía, Mineralogía Química Agrícola (Universidad de Sevilla), C/Professor García González, 1, 41012 Sevilla, Spain. Tel.: +34 954556950; fax: +34 954557140.
E-mail address: ajordan@us.es (A. Jordán).

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Soil WR inhibits or decreases the rate of infiltration, increasing runoff and erosion in forest (Doerr et al., 2000; Jordán et al., 2008; Shakesby et al., 2000) or cropped soils (García-Moreno et al., 2013; González-Peñaloza et al., 2012). Soil WR also induces uneven wetting patterns and the formation of preferential flow paths (de Rooij, 2000; Granged et al., 2011a; Jordán et al., 2009; Zavala et al., 2009a). Some important consequences of uneven wetting are the accelerated leaching of nutrients and increased contamination risk (Leighton-Boyce et al., 2005; Ritsema and Dekker, 1994).

Because of the impacts of soil WR in geomorphological and hydrological processes, information on the natural severity of soil WR is necessary for adequate soil planning and management. Some authors have studied the natural background of soil WR in soils under coniferous forest (*Pinus*, *Picea* and *Pseudotsuga* species) in USA (Doerr et al., 2009; Pierson et al., 2008), in Mexico (Jordán et al., 2009), in Europe (Capriel et al., 1995; Dekker and Ritsema, 1994), in South Africa (Scott, 2000) and in Australia (Blackwell, 2000; Roberts and Carbon, 1972). Background levels of soil WR from Mediterranean areas in Spain have also been reported by Cerdà and Doerr (2007), Cerdà et al. (1998), Jordán et al. (2008, 2009), Mataix-Solera et al. (2007), Rodríguez-Alleres et al. (2012), Schnabel et al. (2013) and Zavala et al. (2009b).

However, the knowledge of soil WR baseline presents some gaps in areas where this is a key property for the understanding of the hydrological and erosional response of soils. The objectives of this research are i) to study the occurrence and severity of WR in the surface of forest soils representative of wide areas in southern Spain (eucalypts, holm oaks and pines), ii) to study the relation between soil WR and tree, shrub and herbaceous cover in these areas and iii) to study the relation existing between soil WR and chemical (pH, organic C, N, P, CO_3Ca and cation exchange capacity) and textural soil properties.

2. Material and methods

2.1. Study area

This research has been carried out during August 2013 in fifteen areas of the province of Huelva (SW Spain), representative of the main types of woodlands in the area: eucalypts (*Eucalyptus globulus* and *Eucalyptus camaldulensis*), pines (*Pinus pinea*) and holm oaks (*Quercus rotundifolia*). Pine woodlands are dominated by *P. pinea* and *Pinus halepensis*. Shrubs under pine and eucalypts are commonly formed by brooms (as *Genista hirsuta*), gorse (*Ulex* sp.), Spanish lavender (*Lavandula stoechas*), flax-leaved daphne (*Daphne gnidium*), dwarf palms (*Chamaerops humilis*) and rock rose (*Cistus ladanifer*, *Cistus salviifolius* or *Cistus crispus*). While eucalypts and pines form woodlands with a dense tree canopy, most holm oaks included in this study are dehesas, a savanna-like agrosylvopastoral system with sparse oaks and used mainly for grazing. Dominant tree species is holm oak (*Q. rotundifolia*), although it can be mixed with cork oaks (*Quercus suber*) in some areas. Shrubs are commonly formed by rockrose (*C. ladanifer*), dwarf palms (*C. humilis*), myrtles (*Myrtus communis*), mastics (*Pistacia lentiscus*), Kermes oaks (*Quercus coccifera*) and buckthorn (*Rhamnus oleoides*).

Table 1 shows the main characteristics of the studied plots, including geographical location, main vegetation type, soil type, lithology, slope, mean annual rainfall and conservation practices (if existing). Lithology includes metamorphic rocks (phyllites and slates) and volcanic rocks (Bellinfante et al., 2005). When present, conservation practices observed included no till and contour plowing.

Elevation of selected plots is variable, ranging between 68 and 500 masl, and slope ranged between 3 and 40%. Annual rainfall data (mean annual rainfall between 1984 and 2009) were extracted from the Andalusian Climate Database (Regional Andalusian Government). Mean annual rainfall increased irregularly with latitude, and varied between 485 and 889 mm.

2.2. Assessment of vegetation cover

During August 2013, plots of 15 m × 15 m were established at each of the fifteen study areas. At each plot, four 7.5 m long east-to-west oriented transects were placed. At each transect, plant cover (tree, shrub or herbaceous cover) was recorded every 2.5 m as 1 (present) or 0 (not present). The final number of observations was 15 plots × 4 transects × 4 points = 240. Tree, shrub and herbaceous cover were expressed as the percentage of 16 observations at each plot. The amount of bare soil was calculated as the percentage of points where no type of cover was recorded at each plot. Bare soil included rock fragments and rocky outcrops.

2.3. Assessment of soil water repellency

Soil WR assessment was carried out under field conditions along vegetation transects every 2.5 m during August 2012, after a period of 40–45 days without rainfall. Persistence of SWR was analyzed by the water drop penetration time (WDPT) test (Wessel, 1988). At each point, litter was gently removed by hand and 10 drops of distilled water were placed on the soil surface and time for complete infiltration was recorded. The average time was considered a representative for each case and soil was classified as wettable (WDPT ≤ 5 s), slightly water repellent (5 s < WDPT ≤ 60 s), strongly water repellent (60 s < WDPT ≤ 600 s), severely water repellent (600 s < WDPT ≤ 3600 s) and extremely water repellent (WDPT > 3600 s). Water drops were applied with an automatic micropipette onto the soil surface from a height of approximately 5 mm to avoid excess kinetic energy affecting soil–droplet interactions.

Table 1
Characteristics of the studied plots: longitude and latitude (decimal degrees), vegetation type, lithology, elevation (masl), slope (%), mean annual rainfall (rainfall, mm) and conservation practices.

Study area	Longitude	Latitude	Vegetation	Lithology	Elevation	Slope	Rainfall	Conservation practices
1	−7.466	37.558	Eucalypts	Slates	260	12	485	Contour plowing
2	−7.382	37.717	Holm oaks	Slates	240	4	526	None till
3	−7.339	37.423	Eucalypts	Slates	68	3	516	Contour plowing
4	−7.331	37.721	Holm oaks	Slates	110	8	543	None
5	−7.234	37.575	Eucalypts	Slates	220	30	564	Contour plowing
6	−7.243	37.837	Pines	Phyllites	252	15	665	None
7	−7.214	37.681	Holm oaks	Slates	255	7	594	None
8	−7.223	37.867	Pines	Phyllites	260	12	691	None
9	−7.208	37.920	Holm oaks	Slates	160	20	763	None
10	−7.099	37.378	Pines	Slates	100	8	489	None
11	−7.108	37.600	Eucalypts	Slates	200	4	585	None
12	−7.110	37.764	Holm oaks	Volcanic rocks	290	5	637	None
13	−7.098	37.824	Pines	Phyllites	500	40	672	None
14	−6.944	37.549	Eucalypts	Slates	70	4	731	None
15	−6.882	37.800	Pines	Volcanic rocks	160	5	889	None