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Do conservative agriculture practices increase soil water repellency? A case study in citrus-cropped soils

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ABSTRACT

Water repellency is a property of soils that inhibits or delays infiltration. Long-term conservation practices as no-tillage, manure addition, application of herbicides may contribute to increase soil organic matter and, hence, soil water repellency. In this research, we have studied the effect of long-term addition of plant residues and organic manure, no-tillage and no chemical fertilization (MNT), annual addition of plant residues and no-tillage (NT), application of conventional herbicides and no-tillage (H), and conventional tillage (CT) on soil water repellency in Mediterranean calcareous citrus-cropped soils (Eastern Spain). Slight water repellency was observed in MNT soils, which may be attributed to the input of hydrophobic organic compounds as a consequence of the addition of plant residues and organic manure such has been demonstrated by the soil organic matter measurements. CT reduced the organic matter content and soils remained wettable. Subcritical water repellency (with water drop penetration times below 5 s) was observed in soils under NT and H treatments.

1. Introduction

Water repellency is a property of soils that reduces the infiltration of water into the soil (Doerr et al., 2000), which has important hydrological and geomorphologic implications (Burch et al., 1989; Witter et al., 1991; Imeson et al., 1992; Jordán et al., 2008, 2009; Zavala et al., 2009a; Malkinson and Wittenberg, 2011). According to Doerr et al. (2000), soil water repellency (SWR) is linked to fungal and microbial activity, vegetation species, organic matter (OM) content and type, soil moisture, wildfires, and soil characteristics (e.g., pH, texture, structure, or mineralogy). Some of the reported consequences of SWR in cropped soils are reduced agricultural production (McKissock et al., 1998), decreased and uneven infiltration of water in soils (Witter et al., 1991; Markus et al., 1994), poor and delayed germination in crops and yields (Abadi Ghadim, 2000), increased runoff and enhanced soil erosion (Doerr et al., 2000; Shakesby et al., 2000), decreased vegetation canopy, leaving soil bare and prone to wind erosion (McKissock et al., 1998), or accelerated leaching of agrochemicals (Ritsema et al., 1997; Dekker and Ritsema, 2000; Taumer et al., 2006). On the other hand, SWR has some positive impacts according to degree of repellency (Blanco-Canqui, 2011), as it has been reported that low levels of SWR may improve soil structure (Eynard et al., 2006; Mataix-Solera and Doerr, 2004; Eynard et al., 2006; Arcenegui et al., 2008; Mataix-Solera et al., 2011), soil C sequestration (Bachmann et al., 2008; Blanco-Canqui and Lal, 2009) and increase protection from crusting (Terry and Shakesby, 1993; Shakesby et al., 2000).

SWR has been reported and studied by many researchers around the world (DeBano, 2000; Doerr et al., 2000), and has often been reported both in soils under natural vegetation.

Plant species most commonly associated with SWR are perennial trees with a considerable concentration of resins, waxes or aromatic oils, as eucalyptus and pines (Mataix-Solera and Doerr, 2004; Hubbert et al., 2006; Lewis et al., 2006; Granged et al., 2011). But hydrophobicity has been reported also in soils under oaks (Cerdà et al., 1998; Sevink et al., 1989; Mataix-Solera et al., 2007; Jordán et al., 2008), deciduous trees (Reeder and Jurgensen, 1979; Buczko et al., 2002), shrubs from temperate areas (Mallik and Rahman, 1985; Giovannini et al., 1987; Cerdà and Doerr, 2007; Jordán et al., 2008, 2010; Zavala et al., 2009b; Kajiura et al., in press), mountain forests (Jordán et al., 2009) or other types of

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vegetation under semi-desert climate (DeBano, 2000). In contrast, there is a short number of studies about water repellency in cultivated soils, as stated by Blanco-Canqui (2011). Pioneer investigations on SWR were carried out in agricultural areas during late 19th and the early 20th century (DeBano, 2000). During the early 20th century, SWR was reported in pastures (Bayliss, 1911; Schantz and Piemeisel, 1917) and some decades later in citrus orchards in Florida (Jamison, 1942, 1945, 1946; Wander, 1949). Since then, the SWR was more a topic of forest soils than agriculture soils, and little has been advanced since then.

Several studies around the world have reported SWR in agricultural soils: orange and olive groves and cereal cropped soils in Spain (Cerdà and Doerr, 2007), pastures in Netherlands (Sonneveld et al., 2003; Sonneveld, 2008), maize and wheat cropped soils and grasslands in Germany (Markus et al., 1994; Urbanek et al., 2007) and others, including soils under mulch and no tillage (Blanco-Canqui and Lal, 2009; Blanco-Canqui, 2011). Soil management practices in cropped areas may influence or induce SWR (Wallach et al., 2005; Urbanek et al., 2007). According to Chan (1992), no-till farming induced slight water repellency in a clay loam soil in Australia. Also, Hallett et al. (2001) observed increased water repellency in a no-till silt loam soil in Scotland in contrast to conventionally tilled soils. Similar results have been reported by Simon et al. (2009), Pikul et al. (2009), and Blanco-Canqui and Lal (2009). Other authors have reported limited or no influence of no-till practices in SWR (Eynard et al., 2004; Blanco-Canqui and Lal, 2009). In a recent paper, Blanco-Canqui and Lal (2009) reported SWR as a common phenomenon in long-term no tilled soils. According to the authors, no-till practices may induce slight and significant water repellency to soils as a consequence of the return of crop residues and reduced soil disturbance. They suggested that intensive research on SWR in long-term no-till soils is necessary to study the impacts of no-till farming in SWR.

Citrus production has triggered intense erosion processes in citrus-cropped soils from Eastern Spain since new plantations were planned on sloping terrain (Cerdà et al., 2007; Cerdá et al., 2009). Citrus production in Spain has grown from sustainable types of management in traditional orchards from alluvial plains and fluvial terraces, to new highly mechanized orchards on slopes. In contrast to conventional tillage, strategies for controlling soil losses include different practices: annual addition of plant residues and organic manure with no-tillage and no chemical fertilization, annual addition of plant residues with no-tillage, and application of conventional herbicides and no-tillage. Previous research has shown that these practices are useful for controlling soil loss and other soil parameters in the area (García-Orenes et al., 2009, 2010), but hydrophobicity has been reported in no-tilled soils due to the increased OM content in the topsoil (Blanco-Canqui and Lal, 2009). In a recent review, Blanco-Canqui (2011) suggested research gaps and future research directions in the study of SWR in the context of no-till farming. Among other research lines, he proposed to assess the positive and negative impacts of the small differences in SWR between no-till and conventionally tilled soils on crop production and analyze the occurrence and impacts of subcritical SWR (water drop penetration time below 5 s). The aim of this paper is to study the impact of different soil management practices on SWR in the long-term.

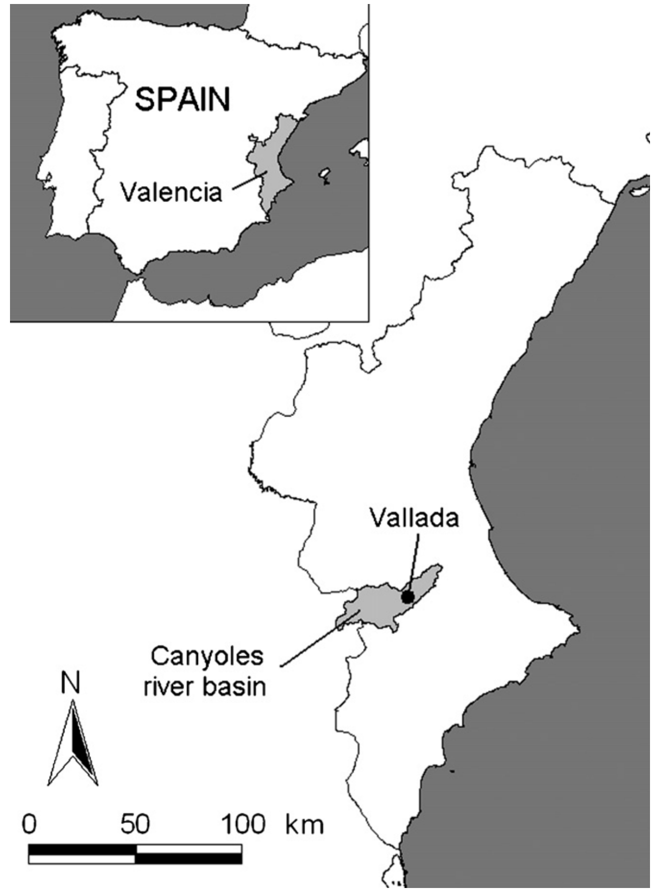

Fig. 1. Study area.

2. Materials and methods

The experiments were conducted in calcareous soils from the Canyoles river basin (Fig. 1). Parent material is Cretaceous limestone. Elevation ranges between 160 and 400 masl, with most slopes between 8 and 14%. The climate is Mediterranean, with warm, dry-hot summers and wet-mild winters. Average annual rainfall varies between 498 and 715 mm, with a dry period in summer (8.7 mm on average in July) and with the wettest period in October–November when intense thunderstorms occur. The mean annual temperature is 16 °C.

Four groups of ten citrus-cropped soil plots were selected under different types of management: conventional tillage (CT), annual addition of plant residues and organic manure with no-tillage and no chemical fertilization (MNT), annual addition of plant residues with no-tillage (NT), and application of conventional herbicides and no-tillage (H) and different periods of treatment. At each plot (total $N = 40$), 100 points were selected along inter-row areas, 10 cm spaced. Periods under each type of management ranged from 2 to 27 (MNT), 1 to 25 (NT), 2 to 27 (H) and 3 to 29 years (CT).

SWR was assessed under field conditions by 1–6 August 2009 after a period of at least 30 days without rainfall. It was determined by the water drop penetration time (WDPT) test (Wessel, 1988). When present, litter was gently brushed off or removed by hand. Five water drops (0.05 mL, 20 °C) were applied using a micropipette onto the soil surface at each point from a height of approximately 5 mm to avoid excess kinetic energy affecting soil–droplet interaction (Doerr, 1998). The time required for each droplet to infiltrate was recorded and the average WDPT was considered as representative for each point. Soils were classified as wettable (WDPT <5 s), slightly water repellent (5–60 s), strongly water repellent (60–600 s), severely water repellent (600–3600 s) and extremely water repellent (>3600 s) (Bisdom et al., 1993).

At each point, a soil sample (0–20 mm) was collected and air dried on paper boxes at room temperature until constant weight. All samples were sieved (2 mm) and coarse material was discarded. Soil organic carbon content analysis, determinate by the Walkley–Black method (Walkley and Black, 1934).