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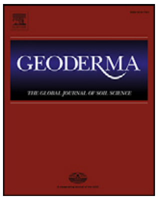

Formation of soil–water repellency in olive orchards and its influence on infiltration pattern

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ABSTRACT

Water-repellent (hydrophobic) soils do not wet instantaneously, but only after some time (a few seconds to hours) of soil-particle contact with water. Some plant species can render soils hydrophobic but in this respect, olive trees have scarcely been examined. Measurements of water repellency in olive orchards of different ages in different locations in Israel using the water drop penetration time (WDPT) test have shown that soils tend to become hydrophobic, regardless of texture and structure. A comprehensive study was then performed for an irrigated young and mature olive grove and nearby uncultivated bare soil in the southern part of Israel. The study included intensive WDPT measurements, initial (repellency intensity) and rate of decrease (repellency persistence) for sessile drops placed on the soil surface, cumulative infiltration using tension disc infiltrometer, and monitoring flow in a transparent flow chamber packed with soils from the different plots. The soil from the mature olive plot was noticeably more water repellent than the young plot's soil, and both differed from the uncultivated soil that was fully wettable. The contact angle of a drop placed on the surface of a single layer of soil particles decreased exponentially with time, with a lower decay rate for the mature orchard soil. Cumulative infiltration had a convex pattern for wettable soils and a concave pattern for water-repellent ones. The difference in infiltration pattern was attributed to water/pressure buildup behind the wetting front as a result of the dynamic contact-angle-induced pore resistivity to wetting. The supplemental pressure, also known as dynamic water-entry pressure, increases the infiltration rate beyond that obtained by the capillary pressure per se. The significant correlation between soil sorptivity and the asymptotic infiltration rate, both calculated from the cumulative infiltration curves, and the WDPT substantiates the dependence of pressure overshoot and the rate at which the contact angle decreases prior to pore wetting. The considerable differences in plume shape, size, and internal saturation distribution between the wettable and water-repellent soils, indicating unstable flow in the latter, were also explained by the wettability-dependent water-entry pressure. The outcome of this study indirectly supports the findings that higher surface runoff and erosion are associated with no-till farming in olive orchards, due to the combination of no-till cropping and the near-surface accumulation of hydrophobic organic carbon compounds.

1. Introduction

Olive groves are an important land use in the Mediterranean region. The main areas of olive oil production are in Spain (2.4 million ha), Italy (1.4 million ha), Greece (1 million ha) and Portugal (0.5 million ha) (Beaufoy, 2001). The present total area of olive plantings in Israel is about 20,000 ha, of which 18,500 ha are trees for oil production. The fact that olive groves are often found on slopes seems to have led to the widespread belief that soil erosion is rife there. Many scientists argue that erosion is the major problem associated with olive cultivation (Beaufoy, 2001; Chisci and Boschi, 1988; Guzmán Álvarez, 1999; Tombesi et al., 1996). Soil erosion has various environmental impacts, notably loss of productive capacity, leading to the need for increased external inputs, and ultimately, desertification, and the downstream effects of runoff, as topsoil, fertilizer and herbicides are washed into water courses and water bodies (Beaufoy, 2001). Nevertheless, tillage management is known as another key factor associated with the rainfall–runoff relationship. It is widely accepted that conventional (clean) tillage increases erosion on most soils, and that soil losses are cut when tillage is reduced (de Graaff and Eppink, 1999). In contrast to the common presumption, Fleskens and Stroosnijder (2007) concluded from field research in three areas (northeastern Portugal, southern Spain and southern Italy) that tillage is not inevitably an adverse soil-management strategy. Many studies indicate that tillage-management practices influence the soil's physical properties, especially its hydraulic characteristics and water capacity, as well as soil hydrophobicity (Hallett et al., 2001; Harper et al., 2000; González-Penaloza et al., 2012). In cases where SOM compounds that render soils hydrophobic exist, reduced tillage increases the content of these compounds

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in the upper soil layer. No-till cropping generally induces 1.5 to 40 times more SWR than conventional tillage, depending on soil type (Blanco-Canqui, 2011). This may result from near-surface accumulation of hydrophobic organic carbon compounds derived from crop residues, microbial activity and reduced soil disturbance. Simon et al. (2009) observed higher soil hydrophobicity in three conservation-tillage treatments compared to ploughing, due to the significantly higher content of hydrophobic organic components. In his recent review paper, Blanco-Canqui (2011) stated that although several land-use systems have been shown to induce water repellency in soils, the specific effects of no-till cropping on SWR are poorly understood. A key question in the relationship between surface runoff and erosion and tillage in olive groves is whether olive trees render soil water repellent, how it depends on soil type and trees age, and how it affects the water infiltration pattern and water distribution in the soil profile.

Water-repellent soils are soils that do not readily wet; soil is proclaimed water repellent when the contact time before a water drop that is placed on their surface penetrates exceeds 5 s. The existence of water-repellent soils has been known for many years and there are indications that under certain conditions, most soils show some degree of soil water repellency (SWR) (Hallett et al., 2001; Doerr et al., 2000, 2006; de Jonge et al., 2009). The phenomenon has been primarily ascribed to sandy soils, but it has also been observed in loam, clay, peat and volcanic ash soils (Jaramillo et al., 2000; Mataix-Solera and Doerr, 2004; Ritsema et al., 1997; Wallis and Horne, 1992).

Soil water repellency is known to affect the soil's physical and hydrological properties. It increases hysteresis of the water-retention curve (Bauters et al., 2000; Ritsema et al., 1998), reduces infiltration capacity relative to wettable soils (e.g., Ritsema et al., 1993; Wang et al., 2000), generates unstable wetting fronts with fingered flow (Hendrickx et al., 1993), and induces greater surface runoff and erosion (Benavides-Solorio and MacDonald, 2001; Burch et al., 1989). Since water repellency depends, among other factors, on water content, rainstorm events that follow prolonged dry periods may produce distinctly more surface runoff than after wet periods (Doerr et al., 2003; Imeson et al., 1992; Jungerius and Dekker, 1990).

It is usually difficult to identify the exact chemical and environmental conditions under which SWR will appear. Often, the development of SWR is related to the type of vegetation that covers it (Doerr et al., 2000 and references therein). It has been agreed upon that the origin of natural water repellency is caused by organic compounds released from different plant species, due to resins, waxes and other organic substances in their tissues. There are a large number of research publications that associate SWR with soil organic matter (SOM) content (Doerr et al., 2000; Graber et al., 2009; Mataix-Solera and Doerr, 2004; Zavala et al., 2009; and references therein). Soil can also become water-repellent as a result of forest fires, as these release large amounts of hydrophobic organic substances all at once that cover the soil particles (DeBano, 2000), and as result of prolonged irrigation with treated waste water (Wallach et al., 2005). It was found that temporal and spatial variability in repellency in soils that rendered water repellent by effluent irrigation was not related to seasonality. The wetting pattern (plume shape, dimensions and internal water content distribution) in these soils by on-surface and subsurface drip irrigation was substantially affected by the degree of water repellency (Wallach and Jortzick, 2008; Wallach, 2010; Xiong et al., 2012). The considerable differences in the plumes' shapes and internal water content distributions, the sharp decrease in moisture content at the plume's edge, and the saturation overshoot behind the wetting front indicate that the flow in these soils turns unstable. The change in flow pattern should be considered in the design of drip irrigation systems that are commonly used for effluent irrigation.

Until recently, little attention has been paid to the effects of orchards (e.g., citrus, olive) on soil wettability, despite their wide presence in Mediterranean climate regions where the soil surface turns often dry between subsequent rainfall and irrigations events, which increase the vulnerability to surface runoff and associated erosion. In a few studies examining the effect of different vegetation covers on SWR, it was evident that olive trees can also cause SWR and consequently increase runoff (Jordan et al., 2008; Ziogas et al., 2005). Ziogas et al. (2005) found that field-moist samples taken from sandy soil at depths of 0–0.19 m were slightly to extremely water repellent, and Jordan et al. (2008) found that soil under cork oaks and olive trees shows a strongly hydrophobic character. In contrast, Cerda and Doerr (2007) and Zavala et al. (2009) found that water repellency is absent or subcritical (water drop penetration time [WDPT] < 5 s) and in the latter study, with poor correlations between SOM and acidity and water repellency.

In the current study, we examined the effect of olive orchards of different ages on SWR and infiltration. The examined orchards grow in different soil types in semiarid to arid regions in Israel and irrigated with water of different qualities. The SWR was evaluated by the WDPT and the rate of contact angle decrease with time. Moreover, the effect of the latter on the infiltration rate and spatial and temporal water distribution in the soil profile was also studied.

2. Materials and methods

2.1. Study sites and sample collection

The work was performed in two stages: a preliminary survey of SWR in six olive orchards in four different locations consisted of different soil types irrigation-water qualities, olive cultivars and tree ages (Table 1). This study was followed by a comprehensive study in one of the olive orchards consisted of different tree's age and a similar soil type. The persistence of the soil water repellency was determined by WDPT test. Drop penetration time was measured in the laboratory for 91 undisturbed soil samples taken along six transects in Revadim grove (RD), 29 samples along two transects in the Karmey Yossef grove (KY), 27 samples along two transects in a Kefar Shmuel freshwater-irrigated grove (KS1) and 28 samples along two transects in a Kefar Shmuel rain-fed grove (KS2). 72 samples from six transects in the young orchard in Revivim (RM1) and 38 samples from three transects in the mature Revivim plot (RM2).

Following the preliminary survey, which showed that olive trees tend to confer a certain extent of SWR, a comprehensive study was performed in Revivim commercial olive grove. The Revivim orchard is located in the northern part of the Negev desert, Israel. The climate is arid with annual rainfall of less than 100 mm and the soil is Aeolian sand having poor SOM content (Table 1). The Revivim orchard is irrigated with saline water (EC = 3.4 dS/m). Two plots, 100 m apart, were chosen: one with 5-year-old trees (RM1), and one with 15-year-old trees (RM2). Samples were also taken from a nearby bare soil area for reference purposes (RM0).

Undisturbed soil samples were taken along transects between two adjacent trees parallel to the drip lateral, and transects perpendicular to these. The sampling points were 40 cm apart. The samples were

Table 1
Information on the six olive orchards that were studied for soil water repellency.

Olive orchard location	Irrigation water quality	Age of trees (years)	Soil type
Revadim (RD) (31°2′39″N 34°43′17″E)	Effluent	7	Heavy-textured vertisol
Karmey Yossef (KY) (31°51′9″N 34°54′20″E)	Fresh water	Not known	Heavy-textured vertisol
Kefar Shmuel (KS1) (31°52′22″N 34°57′4″E)	Fresh water	9	Heavy-textured vertisol
Kefar Shmuel (KS2)	Rain-fed	20	Heavy-textured vertisol
Revivim Young (RM1)	Brackish	5	Aeolian sand
[31°45′23″N 34°48′38″E] Revivim Mature (RM2)	Brackish	15	Aeolian sand