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Soil water repellency assessment in olive groves in Southern and Eastern Spain

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ABSTRACT

Soil water repellency (SWR) has been reported under different soils, land uses and regions of the world, particularly in forest land and after wildfires, yet the understanding of this variable in agricultural lands is still rather limited. This study presents the characterization from field-based measurements of SWR in four contrasted olive groves (*Olea europaea* L.) in Spain in terms of different environmental conditions and management: abandoned and commercial farms under permanent cover crop, conventional tillage and herbicide use. The main objectives were [1] to evaluate the potential occurrence, intensity and persistence of soil water repellency in different types of olive groves and [2] to explore its spatio-temporal features as well as the influence of soil properties such as organic matter (OM) and soil moisture. The Water Drop Penetration Time test (WDPT) was used in situ to assess SWR values. Measurements were carried out in two areas for each of the four groves: below and between the tree canopies. A high spatial and seasonal variability was observed. SWR was absent (WDPT = 0 s) for the olive groves under conventional tillage and with the lowest values of OM (OM-mean = 2.04%). The maximum WDPT values were found for cover crop under canopy in summer (WDPT-max = 610 s) and on the lanes in autumn (WDPT-max = 468 s). SWR was developed during the dry season, and to be reduced during the rainfall season as the organic compounds might be reoriented and turned amphiphilic. Strong water repellent values (>60 s) were related with extremely high OM values (>12%) for the cover crop orchard.

1. Introduction

As a man-made landscape, the Mediterranean geomorphological system is highly dependent on the agriculture use and soil management (Cammeraat, 2002; Cammeraat et al., 2010). The hydrological and erosional response, and the properties of soils at pedon, slope and watershed scales in Mediterranean type ecosystems depend on the use and abandonment of soils (Cammeraat, 2004; Parras-Alcántara and Lozano-García, 2014; Bisantino et al., 2015; Hueso-González et al., 2014). Olive is the main crop in the Mediterranean region and it forms, along with wheat and wine, what it is known as the '*Mediterranean triad*'. Mediterranean countries produce over 95% of the world's olive oil, which has a relevant socio-economic importance. The olive and olive oil production is also resulting in environmental impacts. High soil erosion rates and the diffusion of water pollution are serious degradation risks commonly associated with the hydrological processes in olive groves (Gómez-Limón et al., 2011; Gómez et al., 2014; Taguas and Gómez, 2015). The non-sustainable soil erosion rates are mainly related to steep slopes, a high erosivity of rainfall and the lack of vegetation protection to reduce the water competition, which favour runoff generation and sediment transport (Ligonja and Shrestha, 2015; Keesstra et al., 2016). It is in this environment where, traditionally, olives have been cultivated (Taguas et al., 2015; Zema et al., 2015). In addition to the topography and microtopography, spatial patterns derived from the traffic, management and the influence of the distribution in trees and lanes cause variations of soil physical properties, which favour the surface wash initiation, the flow concentration and finally high soil erosion rates (Gómez et al., 1999). Soil erosion in steep olive groves might exhaust the soils and reduces severely its ability to store soil water for the dry season (Gómez et al., 2014), which would be translated into land abandonment due to the low income (Kraaijvanger and Veldkamp, 2015) or the restoration by expensive strategies (Colen et al., 2016). One of the alternatives to this abandonment is to restore the soil with conservation measures based on organic farming and on the application of organic amendments (Parras-Alcántara and Lozano-García, 2014; Moreno et al., 2015; Parras-Alcántara et al., 2015; Yazdanpanah et al., 2016), and the use of olive residues (Moreno et al., 2015; Colen et al., 2016).

Soil water repellency (SWR) is considered a key soil property which can contribute to the understanding of soil hydrology. Some authors demonstrated that the occurrence of SWR over different soils, bedrocks, climate and vegetation types, is well recognized across the Earth (Bisdom et al., 1993; Doerr et al., 2000; Jordán et al., 2008). This is why in the last decade there has been a growing interest to understand

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the origin and causes of SWR (Cerdà et al., 2009; Bodí et al., 2012, 2013; Pereira et al., 2014; Benito et al., 2015; Hewelke et al., 2014; Jiménez Morillo et al., 2015) and its intensity and persistence under different conditions. In the context of varying soil properties, accelerated soil erosion rates and enhanced high runoff rates in olive groves, SWR might have a significant impact as it delays water infiltration which translates into higher values of runoff and flow concentration (Doerr et al., 2000; Shakesby et al., 2000) and at the same time, higher potential erosion (Cerdà and Doerr, 2007). The occurrence of SWR is determined by the type and quantity of hydrophobic substances on the soil, all of them with a biological origin: waxes and resins (DeBano, 1981), root exudates (Doerr et al., 1998), fungi or microorganisms (Savage et al., 1969), or directly from decomposing OM (McGhie and Posner, 1981). Other factors such as vegetation type, soil temperature, soil texture and soil moisture have an effect on its persistence (Bodí et al., 2011). However, few information is available regarding to olive plantations. SWR can affect water infiltration as it reduces the soil matrix infiltration rates, and can increase the macropore flow. This can result in the reduction of the water availability for the vegetation, specially the crop. SWR also have biological, hydrological and geomorphological implications: the reduction of water availability translates into a severe plant water stress, and less vegetation results in high soil erosion rates (Lieskovský and Kenderessy, 2014). Preferential flow is also more feasible if SWR take place (Granged et al., 2011).

In the case of horticultural crops, preliminary research has been carried out in organic peat soils with irrigated potato crop in Sweden under four types of organic soils, founding low SWR values when high soil moisture content (Berglund and Persson, 1996). SWR has been also studied on sandy soils in intensive irrigation potato cultivation in Suffolk, -Great Britain- (Robinson, 1999). In this study, the author found slightly water repellent points with large spatial variability that caused an increase in the deficit irrigation and in the scab infection of the cultivation.

For SWR variations through time and crop-rotation systems, Keizer et al. (2007) found very persistent values in a system of potatoes, maize and fallow in central Portugal. In this case, spatial patterns of the studied phenomena were found in furrows and ridges. In a review of field crops studies, Blanco-Canqui (2011) found that different soil managements orientated towards conservation agriculture (e.g. no-tillage vs. conventional till) increased the soil water repellency, as most of the conventional tillage soils can be classified as 'wettable' whilst the no-tillage ones, which had higher OM content in the top soil, are classified as 'slightly water repellent'.

Considering tree crops, Cerdà and Doerr (2007) evaluated soil water repellency under orange and olive groves, in field surveys in Eastern Spain. In Northeast Greece, Ziogas et al. (2005) measured SWR below olive trees in a sandy soil. Their laboratory results showed that under the olive tree canopies the soil could be extremely water repellent during the winter season. These results seems to be contradictory with several studies on infiltration rates within olive orchards, summarized in Romero et al. (2007), which found higher infiltration rates in the soil below olive canopy projection. Under this context, a better understanding of the SWR spatio-temporal intensity according to different environmental conditions and soil management is fundamental to understand its implication in the overall hydrologic response of olive groves. This is of major importance and it might improve the soil management to reduce soil and water losses.

The aim of this work was to evaluate the occurrence, persistence and spatio-temporal variability of SWR in olive groves under different soil managements and environmental features.

2. Materials and methods

2.1. Study area

This study was carried out in four olive groves in Southern and Eastern Spain. Three were located in the province of Córdoba (Southern Spain), with the following managements (Fig. 1, Table 1): permanent cover crop (CC) periodically mowed in an organic grove (Fig. 1-A), conventional tillage (CT) allowing cover crop in the lanes and bare soil using herbicide under the olive canopy (Fig. 1-B), and weed growing controlled with periodic applications of herbicide (H) (Fig. 1-C). An olive grove abandoned (AB) forty years ago was also surveyed in Valencia province, Eastern Spain (Fig. 1-D). This abandoned olive grove shows the development of the vegetation and soil recovery after the land abandonment.

The parent material in the study sites in the province of Cordoba are marls, and the soil types are Vertisols and Fluvisols. In the study site in Valencia province, the parent materials are limestones the soil is a Regosol (IUSS Working Group WRB, 2006, Table 1).

Average annual rainfall in the CT site is 510 mm, concentrated in the October–March period. On the other hand, average annual rainfall in the H and CC sites is 528 mm and it is also concentrated in the winter period. The average annual temperature is 18.6 °C for CT and 17.4 °C for CC and H (IFAPA, Estación de Alameda del Obispo, 2013). The elevation of the three sites ranges from 90 m.a.s.l (H and CC) to 147 m.a.s.l (CT). At the AB site, the average annual rainfall is 684 mm; mainly concentrated from October to December, with an average annual temperature of 17.2 °C and an elevation of 103 m.a.s.l (SIAR, 2013).

The four sets of olive groves chosen are representative in terms of management of olive orchards in the region (Gómez and Giráldez, 2010). In the sites located in Córdoba, tree-space was 6 × 7 m (CT), 6 × 6 m (H), and 8 × 8 m (CC). In AB, tree spacing was 6 × 7 m. H and CC sites were located on a 1% average slope, while the grove in CT was in an area with an average slope of 8% and AB was in a 4% average terraced hillslope.

2.2. Water Drop Penetration Time (WDTP) measurement

SWR persistence was measured under field conditions 3 times during the hydrological year 2011–2012 (Fig. 2): autumn (20/10/2011 in Cordoba), winter (19/12/2011 in Cordoba and 28/12/2011 in Valencia) and summer (29/7/2012 in Cordoba and 30/7/2012 in Valencia). The methodology used was the Water Drop Penetration Time test (WDPT) (Letey, 1969). WDPT is a measure of the time that the contact angle requires to change from its original value, >90° according to Young's law, to a value approaching 90°, when infiltration occurs (Letey, 2000). It is a test based on placing a water drop (0.05 mL in this case), using a syringe, on a soil surface and recording the time that it takes for the drop to break the surface tension and infiltrate. Three water drops were applied at each transect point from a height of 3 mm from the surface level in order to avoid excess of kinetic energy (Doerr, 1998). The surface organic debris was removed carefully with a brush (or by hand when needed) so the mineral soil was exposed for measurement.

Measurements following this procedure were performed for two trees at the CT (n = 768) and CC (n = 891) sites, and three trees in the H (n = 1116) and AB (n = 810) sites. The difference in the amount of measurements performed varies according to the distance between the trunk and the lane (outside of the canopy projection). At each tree, four transects were performed following the design depicted in Fig. 3, each one from the tree trunk to the olive lane at 10 cm spaced. WDPT values were classified as in Bisdom et al. (1993) (0–5 s wettable, 5–60 s slightly wettable and 60–600 s strongly water repellent).

2.3. Soil sampling: soil moisture and OM content

Soil samples were collected from the top 5 cm of the soil for determining the gravimetric soil moisture content at each survey and grove and the OM content. In the autumn survey, a total of 10 samples from under the canopy (4 samples) and between lanes (6 samples) were taken; whereas 16 were taken during the winter survey (8 under the tree canopy and 8 between lanes) and 18 during the summer study (9 under the tree canopy and 9 in between lanes). For the dry-weight