Geoderma 267 (2016) 185–195

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Long-term effects of olive mill pomace co-compost on wettability and soil quality in olive groves

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ARTICLE INFO

Article history:
Received 7 August 2015
Received in revised form 21 December 2015
Accepted 28 December 2015
Available online 15 January 2016

Keywords:
Organic olive groves
Olive mill pomace
Soil hydrophobicity
Soil water repellency
Surface free energy

ABSTRACT

The importance of soil wettability and its relationship to many soil properties has been studied extensively. However, few studies have addressed it as a result of organic amendment in agricultural soils. Wettability (hydrophilicity) and soil quality in olive groves with olive mill pomace (OMP) compost amendment were compared to conventional groves with only mineral fertilization. In addition to soil management, soil parent material (carbonated vs. siliceous) and soil depth (surface 0–10 cm vs. subsurface 0–20 cm layers) were also studied by means of an unreplicated field experiment on the only appropriate farm available in Southern Spain. The aim of this work was to evaluate the effects of composted OMP on wettability and hydrophobicity of olive grove soils, using the van Oss model for surface free energy components. Other physical, chemical and mineralogical parameters were also analyzed. The electro-donor component γ^- of surface free energy was found to be the most suitable parameter for assessing soil hydrophobicity over other current methods, such as WDPT tests or contact angle. All the soils analyzed were wettable, except the surface horizons of organic siliceous profiles, which were hydrophobic with a mean γ^- of 27.57 mJ m^{-2}. The main factors that significantly increased soil hydrophobicity were depth and parent material. This implies, first, that the effects of compost only affect the soil surface, and second, the lack of carbonates in the siliceous quartzite contributes to further increases in soil hydrophobicity. The variables most correlated with hydrophobicity were organic carbon content (soil organic matter quality was not significantly related to soil hydrophobicity) and cation exchange capacity, but carbonates (the higher the carbonates, the lower hydrophobicity) and soil texture (the more sand, the higher hydrophobicity) also demonstrated their association. It may be concluded that, although moderate soil hydrophobicity seems to alter plant water availability and infiltration under unsaturated conditions, it could be positive for soil structure and soil quality in general.

1. Introduction

Soil wettability and water repellency (hydrophobicity) are important soil characteristics, mainly because they affect soil moisture. Soil water regimes can be profoundly affected by hydrophobicity due to lowered infiltration ratio, hydraulic conductivity and available water (Doerr et al., 2000). In contrast, soil hydrophobicity can improve structural development and stability (Goebel et al., 2005; Plaza et al., 2015) and bulk density and porosity (Doerr et al., 2000). Water repellency has been widely observed in urban (Diehl and Schaumann, 2007), forest (Mataix-Solera and Doerr, 2004) and agricultural soils (Diamantis et al., 2013; Peikert et al., 2015) related to soil organic matter, texture, mineralogy and climate (Doerr et al., 2000; Leelelamanie et al., 2010). Thus further studies relating the dynamics of water repellency to specific soil type and management seem desirable.

Given its significance, a suitable measure of soil water repellency (SWR) is important. There are several techniques for its estimation, from purely empirical to meaningful physical measures. Probably the most common method is the water drop penetration time (WDPT) test, which easily classifies soils into five water repellency classes (Bisdom et al., 1993). However, it has no linear quantitative scale for slight to moderately repellent soil (*e.g.*, <5 s), and could take a long time for repellent soils. Water/ethanol mixtures have been proposed as the liquid for the test, as the molarity of the ethanol droplet method reduces the WDPT test time, but has the same limitations as the WDPT test at low water repellency (Chau et al., 2014). Another widely used measure is the contact angle (CA) (Goebel et al., 2005; Woche et al., 2005; Diehl and Schaumann, 2007), which shows some physical meaning and enables SWR to be studied throughout the soil range (from wettable to extremely repellent). However, all the above tests estimate only the surface properties of solids in water, and do not provide a comprehensive thermodynamic characterization of the solid surface alone. Hence, a complete determination of surface free energy components

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http://dx.doi.org/10.1016/j.geoderma.2015.12.027
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would be recommendable, particularly for mineral soils with low organic matter, where WDPT results are less useful (Hajnos et al., 2013). Few authors have applied this approach to soil wettability. Goebel et al. (2005) followed Fowkes's (1964) description of surface free energy in dispersive and non-dispersive interactions to characterize soil organic matter dynamics. But the van Oss et al. (1988) approach for acid–base and Lifshitz-van der Waals interactions has several advantages, e.g., it can explain mineral surfaces in terms of acid/base components (the electron-donor γ^- and electron-acceptor γ^+). So the γ^- component would delimit soil hydrophobicity better than Fowkes's non-dispersive component, because of the strong monopolarity of the main soil mineral surfaces, which typically show constant but very low γ^+ (Grasso et al., 2002). Hajnos et al. (2013) applied the van Oss model and found no dependencies between soil organic matter and wettability parameters.

Olive grove soils are typically Mediterranean, characterized by low organic matter content, by the semiarid climate in which they develop, and degradation by human activities (Nieto et al., 2010). Olive grove soils therefore typically show less than 1% in organic carbon. In this context, increasing soil organic matter becomes imperative. Application of organic amendments that contribute effectively to nutrient supply for plant growth is therefore of interest, and can also improve inherent physical soil properties and preserve soil functions altered by agronomic practices. In the south of Spain, the widely extended olive crop leads to a huge annual production (around four million tons) of OMP, the main byproduct of the two-phase olive oil extraction system (García-Ruiz et al., 2012). OMP recycling by composting and subsequent application returning it to the olive orchard could help to improve soil fertility and reduce the use of inorganic fertilizers in the olive-growing industry. While the implications of the use of untreated and composted OMP on soil fertility (López-Piñeiro et al., 2011; García-Ruiz et al., 2012; Lozano-García and Parras-Alcántara, 2013;) and soil microbiology/enzymatic activities (López-Pieñiro et al., 2011; García-Ruiz et al., 2012) have been reasonably-well studied, their effects on soil physical properties, and especially, on soil water repellency, have not been given much attention, in spite of their relevancy. To the knowledge of the authors, all other studies have been carried out only in olive groves on calcareous soil, which is the most common in the study area, so the effects of OMP compost amendment in siliceous orchards are not well known. Nevertheless, a location where the geology makes possible paired experimental designs for long-term OMP compost applications on calcareous/siliceous soils in replicated field plots is extremely uncommon.

The aim of this work was to evaluate the effects of composted OMP on wettability and hydrophobicity of olive grove soils, applying the van Oss model for surface free energy components. Results of this model are compared to the more widely used measures of water repellency, the WDPT and CA tests. Correlation of surface free energy parameters with soil chemical/physical variables is also analyzed, taking into account the three basic factors of variation in olive grove soils: management (organic vs. conventional), parent material (carbonated vs. siliceous) and soil depth (0–10 cm vs. 0–20 cm layers).

2. Material and methods

2.1. Site description and soil sampling

The olive groves studied are located in Andújar, Jaén Province (southern Spain). The climate is Mediterranean, with cool winters and hot, very dry summers and a mean annual temperature of 17.9 °C. All the olive groves (about 180 ha) under study had a density of 90–110, 35-to-45-year-old trees per hectare distributed regularly with a typical canopy cover of about 30% of the cultivated area. About half of these groves were fertilized with composted OMP (organic management) and the other half with mineral fertilizers (conventional management). Due to the low porosity of OMP, structuring agents, mainly olive tree leaves, are usually employed in composting. Several types of local manure, which act as a source of nitrogen to balance the C/N ratio and avoid nitrogen sequestration after addition to the soil, are also used. In fact, the compost used is considered a co-compost (50% OMP and 50% olive leaves and manure). 6–10 Mg ha^{-1} of this co-compost had been applied annually in autumn to the organic groves for the last 17 years. It was always evenly spread over the soil in the intercanopy and followed by very superficial chisel passes to control plant cover. In the farms where the co-compost was applied, management was organic with no mineral fertilization or pesticides, and was characterized by no-till soils and maintenance of the spontaneous herbaceous cover. Fertilization of the conventional groves, which did not receive co-compost, consisted of the application of 50–70 kg N ha^{-1} as urea or ammonium sulfate under the tree canopy in the early spring. Weeds were controlled by residual herbicides.

Four large homogeneous plots of soil (about 2500 m^2) which were near each other, two with calcareous soils developed over a Miocene calcarenite (with and without co-compost application) and two with siliceous soils over a Triassic quartzite (with and without co-compost application), were sampled. This field experiment was not replicated because no other suitable experimental conditions could be found in the study region (pairs of conventional and OMP-composted olive groves over siliceous and calcareous bedrock). Each plot which received co-compost was comparable to that which received no compost in terms of climate, slope, orientation, soil type, and tree density and age. Sampling in each plot consisted of a random selection of three locations in the intercanopy, and in each location, a soil sample composed of four subsamples (from the surface 0–10 cm layer and subsurface 10–20 cm) was taken at random within a 5-m radius.

2.2. Chemical, physical and mineralogical soil analyses

All analytical soil sample data refer to the fine-earth fraction (<2 mm). The procedures used in soil analyses were as outlined by the American Society of Agronomy and Soil Science Society of America (Page et al., 1982; Klute, 1986). The organic carbon (OC) content was determined by the Tyurin method with dichromate oxidation. Total N was measured with the Kjeldhal method. The pH (1:2.5) was found by potentiometry in distilled water. Electrical conductivity (EC) of water extracts had a soil/water ratio of 1:5, standardized at 25 °C. Equivalent $CaCO_3$ was found by volumetry with a Bernard calcimeter. Extractable phosphorus was extracted with sodium bicarbonate solution and determined by colorimetry (Olsen method). Exchangeable bases and cation exchange capacity (CEC) were found by the ammonium acetate method (pH 7) and the sodium chloride method, and then the concentrations were determined by atomic absorption spectrophotometry. Clay and sand contents were determined by the pipette method after elimination of organic matter with H_2O_2 and dispersion with sodium polyphosphate. Water retention at -33 kPa (field capacity) and -1500 kPa (permanent wilting point) was calculated by the Richards membrane method, and plant available water content (AWC) from the difference between water retention at -33 and -1500 kPa, employing the Cm coefficient for gravelly soils (Soil Conservation Service, 1972). Saturated hydraulic conductivity (Ks, cm h^{-1}) was measured by a constant-head permeameter (Eijkelkamp Agrisearch Equipment, Giesbeek, NL) in laboratory, using unaltered cores taken in the field. Unsaturated hydraulic conductivity was found at -10 kPa employing the pedotransfer functions given by Saxton and Rawls (2006). Soil bulk density was measured using the cylindrical core of known volume method and particle density with a pycnometer. Total porosity was estimated from the particle and bulk density, and macroporosity from total porosity less microporosity, the latter measured as water content at -33 kPa. The soil aggregate stability index (ASI) was determined with the method described by Kemper and Rosenau (1986), using a wet sieving apparatus (Eijkelkamp Agrisearch Equipment, Giesbeek, NL). The water drop penetration time test (WDPT) was performed following Bisdom et al. (1993) and employing