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Assessing the impact of agro-industrial olive wastes in soil water retention: Implications for remediation of degraded soils and water availability for plant growth

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ABSTRACT

Olive solid waste (OSW) is a toxic by-product of olive oil production. Disposal of OSW is a major problem in many Mediterranean countries leading to increased interest in its potential as an organic fertiliser. Relatively little is known regarding the impact of augmentation with OSW and olive solid waste compost (OSWC) on soil hydraulic properties. The effect of OSW and OSWC on the hydraulic characteristics of common agricultural soils with high sand but very different silt and clay contents was analysed. Increased organic inputs induced reductions in soil bulk density and increases in air capacity, hydraulic conductivity and the water content available for plant growth (AWC) in the Sandy Clay Loam (SCL) soil. Similar patterns were observed in Loamy Sand (LS) soil augmented with OSW, but OSWC caused reductions in hydraulic conductivity, air capacity and AWC. Nonetheless, over longer timescales OSWC may benefit the hydraulic properties of loamy sand soils as the compost becomes fully incorporated within the soil structure. Augmentation with organic olive waste induced the hydraulic parameters of the sandy clay loam soil to become identical to those loamy sand (LS) with a higher available water capacity; suggesting that soil augmentation with OSW and OSWC may be an effective tool in remediating and improving degraded or organic poor soils. In terms of the improvement of hydraulic parameters, application rates of 6–8% OSW/OSWC were most beneficial for both soil types.

1. Introduction

Soil sustainability is increasingly at risk due to climatic changes, rising populations and inappropriate agricultural practices (Doran and Zeiss, 2000; Richter and Markewitz, 2001; Zalidis et al., 2002). Global prediction models for the end of the current century suggest a 1.4–5.8 °C increase in mean surface temperatures (Randall et al., 2007) and population growth to nine billion people that will necessitate a ~30% increase in food production (FAO, 2013) and 17% improvement in the efficiency of irrigation (WWAP, 2012). Soil health is fundamental to maintaining agricultural productivity and ensuring food security (Grierson et al., 2011). However, the extensive use of unsuitable intensive agricultural practices has resulted in widespread deterioration in soil quality, reductions in soil organic content and diminished soil productivity (Oldeman, 1994; Lal, 2001; Verhulst et al., 2010). This degradation of soils adversely affects soil water retention properties and exacerbates soil weathering and the effects of water deficit on crops (Hueso et al., 2011; Mulcahy et al., 2013). The water retention properties of soils are critical to the ability of a substrate to sustain crop growth (Gupta and Larson, 1979; Silva et al., 1994; Ward et al., 2012); particularly as 80% of crops are currently 'rain-fed' and do not receive supplemental irrigation (FAO, 2003). Augmentation with organic matter may improve the hydraulic properties of soils (Abu-Zreig and Al-Widyan, 2002; Artiola et al., 2012) and assist in soil remediation (Tejada et al., 2006; Altieri and Esposito, 2008; Rigane and Medhioub, 2011; Killi and Kavdır, 2013).

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Mediterranean soils generally possess low organic matter content, making them particularly vulnerable to weathering and degradation (Kosmas et al., 1997; Zalidis et al., 2002). Supplementing degraded Mediterranean soils with organic mulches and composts has great potential in terms of the remediation of these soils and enhancement of soil productivity (Zalidis et al., 2002; Altieri and Esposito, 2008; Kavdir and Killi, 2008; Tang et al., 2013). Despite the potential benefits to soil health, organic fertilisers and composts are relatively expensive and rarely used in comparison to conventional inorganic mineral fertilisers (Celik et al., 2010; Martinez-Blanco et al., 2011; Tortosa et al., 2012). However, the recycling of organic agro-industrial wastes may provide a solution. Olives are one of the characteristic agricultural products of Mediterranean regions, with 20.8 million tonnes produced globally each year (FAO, 2013). Olive oil production results in a large volume of hazardous organic waste material; every 100 kg of olives generates 35–45 kg of olive solid waste (OSW) depending upon the methodology employed in oil extraction (Greco et al., 1999). This OSW contains a number of environmental toxins such as phenols that can pollute water bodies and are harmful to soil microbial communities and plant growth (Alburquerque et al., 2006b; Saadi et al., 2007; Ouzounidoua et al., 2008; Kiril Mert et al., 2010; Asfi et al., 2012; Ilay et al., 2013; Killi and Kavdır, 2013). This led to large volumes of OSW being dumped in landfill sites. However, there has been increasing focus on the possibilities of the re-use and recycling of this material as an agricultural 'green-waste' in the manufacture of organic bulking agents, fertilisers and mulches (Alburquerque et al., 2007; Arvanitoyannis and Kassaveti, 2007; Saadi et al., 2007; Altieri and Esposito, 2010; Del Buono et al., 2011; Martinez-Blanco et al., 2011).

When applied directly to soils, unprocessed OSW impairs plant growth and diminishes crop harvests (Alburquerque et al., 2006a; Ouzounidou et al., 2010; Barbera et al., 2013; Killi and Kavdır, 2013). This has led to the exploration of various composting methods where the OSW is combined with other organic materials and then processed to detoxify the OSW (Tortosa et al., 2012). Application of olive solid waste compost (OSWC) to soils has been shown to improve plant growth and crop production (Alburquerque et al., 2006a; Martinez-Blanco et al., 2011; Killi and Kavdır, 2013), suggesting that composting may be a viable alternative to the dumping of this widespread harmful waste material. In addition to the potential disposal and fertiliser benefits, the application of OSWC to soils may enhance their structure and stability (López-Piñeiro et al., 2011; Killi and Kavdır, 2013; Masmoudi et al., 2013). Addition of both OSW and OSWC to typical Mediterranean agricultural soils enhanced soil aggregate stability, carbon to nitrogen ratios, pH and cation exchange capacity. Interestingly, despite the deleterious effects on plant growth, the direct application of unprocessed OSW to soil was most beneficial to soil stability and structure, possibly due to the proportionally higher fibre content of OSW (Killi and Kavdır, 2013).

The impact of augmenting agricultural soils with organic waste derived from olive processing on soil hydraulic properties is less clear. The addition of biochar (charcoalified organic material with high lignin content such as that made from *Miscanthus* spp.) to soils has been shown to increase the water holding capacity of the soil (Karhu et al., 2011; Basso et al., 2012; Ulyett et al., 2014). This increased soil water content might be expected to be beneficial to plant growth in maintaining root mass flow (Wasson et al., 2012) and transpiration (Gilbert et al., 2011) during episodes of drought or high evaporative demand (Haworth et al., 2013; Mulcahy et al., 2013). However, this additional soil water held by organic material added to soils may not be available for uptake by plants in its entirety (Bornemann et al., 2007; Asgarzadeh et al., 2010; Sohi et al., 2010; Karhu et al., 2011; Liu et al., 2012). Nonetheless, the addition of biochar to soils increased water availability and drought tolerance in *Solanum lycopersicum* (Mulcahy et al., 2013), suggesting that the reuse and recycling of olive wastes may be beneficial to soil water retention, plant water relations and the efficiency of irrigation. An additional area of uncertainty associated with the effect of soil augmentation with olive processing residues is the high lipid content and possible hydrophobic properties of these wastes (Abu-Zreig and Al-Widyan, 2002; López-Piñeiro et al., 2011).

The effect of increasing application rates of untreated and composted OSW on the physical soil water characteristics of two typical 'Sandy Clay Loam' (SCL) and 'Loamy Sand' (LS) agricultural soils were analysed. The aims of this study were to investigate the impact of augmentation with OSW or OSWC on: 1) the physical properties of the soils; 2) the water retention capacities of the soils; 3) different soil textures, and to identify those textures most likely to benefit from augmentation with olive processing waste, and; 4) the potential of OSW green-waste products to remediate and improve the hydraulic characteristics of degraded agricultural soils.

2. Materials and methods

2.1. Soils and olive solid waste processing

Olive solid waste was obtained from the three-phase olive oil factory in Ezine, Çanakkale, Turkey. Three-phase centrifuge systems produce less olive solid waste (olive cake) and more olive oil in comparison to two-phase centrifuge systems, and are therefore more commonly used in industrial olive oil production (Alburquerque et al., 2004). This study used OSWC composed of goat manure, straw, alfalfa (*Medicago sativa*) and OSW, mixed and then incubated for one month in Çanakkale Onsekiz Mart University's (ÇOMU) Soil Science laboratory (for production method and compositional analyses see Kavdir and Kavdir, 2009). Samples of typical agricultural loamy sand (LS) and sandy clay loam (SCL) soils were taken from a depth of 0–20 cm at Osnabrueck University of Applied Science facility, Germany, and sieved through a 5 mm sieve. The LS consists of 71% sand, 24.5% silt and 4.5% clay; the SCL had similar amounts of sand (68.4%) but 12.2% silt and 19.4% clay. Despite the similar sand content, the ecological quality of the LS with its high silt content and the SCL with its high clay content was expected to be significantly different. Previous studies involving these soils would indicate that the LS would possess a much higher available water capacity, and the SCL a greater air capacity (Anlauf, 2014 personal communication). Carbon (C) and Nitrogen (N) values of soil types and olive organic waste materials are given in Table 1 (for details of C/N analysis methodology see Killi and Kavdır, 2013). The soil samples were air dried and the residual moisture content was determined (LS: 3.7 v%; SCL: 10.2 v%). Olive solid waste and OSWC were thoroughly mixed with both soil samples at rates of 0, 2, 4, 6, 8 and 10% by weight.

2.2. Soil water retention (pF) curves

As the olive processing waste had to be thoroughly mixed within the soils, it was not possible to use undisturbed soil cores; as is standard practise when conducting soil water retention analyses.

Table 1
Percentage of nitrogen (N) and carbon (C) content of soils and olive waste materials.

Material	C (%)	N (%)
Loamy sand (LS) soil	0.566	0.080
Sandy clay loam (SCL) soil	0.616	0.097
Olive solid waste (OSW)	48.1	1.0
Olive solid waste compost (OSWC)	37.2	1.8