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Long-term effects of soil management on ecosystem services and soil loss estimation in olive grove top soils

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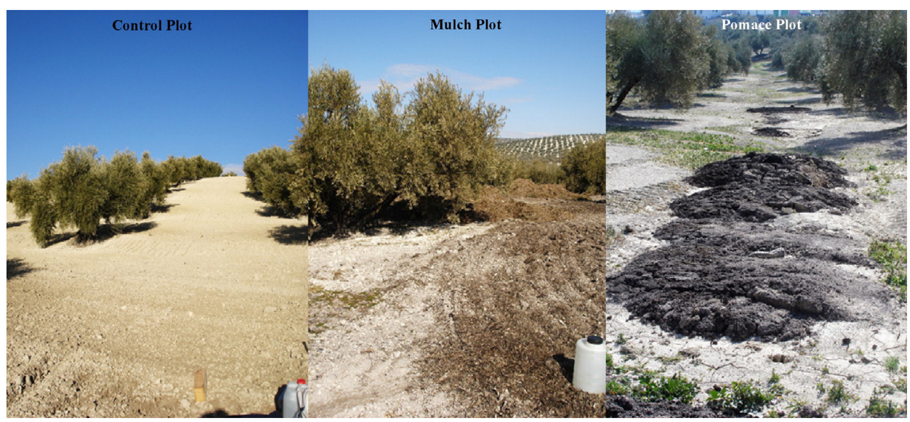
HIGHLIGHTS

- Oil mill wastes application resulted in soil loss reduction.
- The chemical and physical soil properties were improved under the amendments.
- The amendments improved resilience to erosion and enhanced soil functions.

GRAPHICAL ABSTRACT



Model predictions of soil loss for rainfall erosivity-max (R-max). With olive leaves mulch (236 Mg ha^{-1}) and oil mill pomace (270 Mg ha^{-1}) applied yearly from 2003 until 2013.

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ABSTRACT

Soil management has important effects on soil properties, runoff, soil losses and soil quality. Traditional olive grove (OG) management is based on reduced tree density, canopy size shaped by pruning and weed control by ploughing. In addition, over the last several decades, herbicide use has been introduced into conventional OG management. These management strategies cause the soil surface to be almost bare and subsequently high erosion rates take place. To avoid these high erosion rates several soil management strategies can be applied. In this study, three strategies were assessed in OG with conventional tillage in three plots of 1 ha each. Soil properties were measured and soil erosion rates were estimated by means of the RUSLE model. One plot was managed with no amendments (control), and the other two were treated with olive leaves mulch and oil mill pomace applied yearly from 2003 until 2013. The control plot experienced the greatest soil loss while the use of olive leaves as mulch and olive mill pomace as an amendment resulted in a soil loss reduction of 89.4% and 65.4% respectively (assuming a 5% slope). In addition, the chemical and physical soil properties were improved with the amendments. This combined effect will created a higher quality soil over the long term that it is more resilient to erosion and can provide better ecosystem services, as its functions are improved.

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1. Introduction

The International Olive Oil Council (IOOC, 2010) estimates that the cultivated area of olive groves (OG) covers 10 Mha worldwide with 850 million olive trees. In the European Union (EU), OG plantations are the largest agricultural land use, mainly located in Mediterranean areas with over 5 Mha (López-Piñeiro et al., 2011a), and contribute more than 70% of worldwide olive oil production, estimated at about 3×10^6 Mg per year (IOOC, 2010). Spain is the largest producer of olive oil in the world with an average production of 0.9×10^6 Mg per year (AAO, 2010). The OG plantations are located under Mediterranean climatic conditions due to the crop requirements (Kraushaar et al., 2014) and Andalucía has the largest olive plantation concentration in the world (AAO, 2010).

The Mediterranean areas are particularly susceptible to land degradation as a result of environmental and anthropogenic factors; namely land use conflicts that reduce organic matter (OM) in soils (Valera et al., 2016) increasing soil erosion (Pacheco et al., 2014; Valle Junior et al., 2014) and threatened riverine ecosystems (Valle Junior et al., 2015). In this line, water erosion is one of the most important soil threats in southern Europe (Cerdà et al., 2010). It threatens soil functions and ecosystem services such as food production, filtering, biodiversity pool and carbon stock as well as leading to a decrease in soil fertility that can result in reduced agricultural production (Novara et al., 2015; Keesstra et al., 2012; Martínez-Murillo et al., 2013; Brevik et al., 2015).

Due to unsustainable agricultural practices, one third of the world's agricultural lands have been lost to water erosion. According to recent estimates for the EU, the soil lost by water erosion since 2010 averages 2.46 Mg ha^{-1} yr^{-1} (Panagos et al., 2015), while the average rate of soil formation in Europe ranges from 0.3 Mg ha^{-1} yr^{-1} to 1.4 Mg ha^{-1} yr^{-1} (Verheijen et al., 2009). In response, the EU has clearly indicated that soil can be seen as a non-renewable resource and the soil loss creates a loss in soil functions and the ecosystem services that soil provides (Eurostat, 2015).

Agriculture is the key to understand some of the environmental issues in Mediterranean ecosystems (Cerdà et al., 2009a; Ligonja and Shrestha, 2015). Farming is the main cause of soil losses and soil erosion is the primary environmental concern for agricultural land in many parts of southern Europe (Gómez et al., 2003; Cerdà et al., 2009a, 2009b; Tarolli et al., 2015). In addition, Mediterranean soils are highly variable (Ibáñez et al., 2015), although they have common properties such as low OM content, low vegetation cover, poor structure and weak aggregate stability that make them susceptible to water erosion (Ping et al., 2015; Cerdà et al., 2016). In agricultural land, the ploughing and herbicide applications used to control weeds increases soil erosion processes (Costantini et al., 2015; Vaudour et al., 2015; Prosdocimi et al., 2016a; Keesstra et al., 2016b). These characteristics lead to surface sealing during rainfall or irrigation, slow water infiltration, ponding and runoff with subsequent soil erosion (Liu et al., 2014). Therefore, studying soil erosion in agricultural catchments is essential for environmental and ecosystem protection, together with adequate information for farmers to improve soil management (Keesstra et al., 2016a).

Soil management in OG has important effects on runoff and soil losses in olive plantations (Lozano-García et al., 2011). It has been shown that runoff rates are high in OG, and that vegetative cover can solve this problem (Taguas et al., 2015). This is not unusual, as other orchards and vineyards have also shown non-sustainable soil erosion rates (Cerdà et al., 2010; Prosdocimi et al., 2016b; Bravo-Espinosa et al., 2014; Li et al., 2014; Keesstra et al., 2016b).

OG vulnerability to soil erosion has been widely documented, and a heterogeneous response based mainly on soil management techniques has been developed. Gómez et al. (2003) found that on slopes up to 20% water erosion could reach 80 Mg ha^{-1} yr^{-1}, Ramos et al. (2008) measured soil profile lowering due to particle detachment of up to 0.2 ± 0.1 m yr^{-1} along slopes ranging from 2 to 45% in an orchard that was conventionally tilled, Fleskens and Stroosnijder (2007) indicated that studies about soil erosion rates have assumed soil losses >-1 Mg ha^{-1} yr^{-1} since 1990, and Gómez et al. (2014) showed that rates higher than 10 Mg ha^{-1} yr^{-1} are often measured in OG.

Besides the soil erosion in OG in Mediterranean areas, another environmental concern is the waste generated by olive oil production. The main waste types generated during the two-phase olive oil extraction method are oil mill pomace and olive leaves. In this regard, Spain generates 5.89×10^6 Mg of oil mill pomace and 0.367×10^6 Mg of olive leaves annually (Moreno, 2009). Both wastes are characterized by high OM contents (Altieri and Esposito, 2008), and the major components of the oil mill pomace organic fraction are: lignin (32–56%), hemicellulose (27–42%), cellulose (14–25%), fats (8–20%), proteins (4–11%), water-soluble carbohydrates (1–16%), and water-soluble phenols (1–2%). The components of olive leaves are small gravels, twigs and olive leaves, which come from the olives being washed prior to milling, while oil mill pomace is composed of the waste products left after oil extraction.

Mediterranean OG soils are characterized by low (<2%) OM content (Trigo et al., 2009), and therefore, there is a need to increase the soil OM content to improve soil quality (Fernández-Romero et al., 2016a). For this reason, addition of the organic wastes generated during olive oil production to agricultural soils could be the answer to increase soil OM, reduce soil erosion, and recycle wastes generated by agricultural activity (Fernández-Romero et al., 2016b). Oil mill wastes application to agricultural soils has already been shown to improve soil structure and increase soil fertility after a short period of time (Lozano-García et al., 2011). However, no research has been done over a longer time scale, and little is known about the impact of the olive leaves and the olive mill pomace on soil losses, properties, and ecosystem services after a decade.

The goals of this study were: (i) to evaluate the long-term (after 11 years) effects of oil mill wastes (oil mill pomace and olive leaves) addition on soil properties; (ii) to estimate and model the oil mill pomace and olive leaves amendments effects on soil losses in OG with conventional tillage; (iii) to compare the soil loss rates predicted using an empirical model (RUSLE) and previous measurements carried out in the research study site by means of rainfall simulation experiments; and (iv) to evaluate the implication of these treatments for ecosystem services and mitigation of soil threats.

2. Materials and methods

2.1. Study area

This study was carried out in Garcíez-Torredelcampo-Jaén, (37°50′ N - 3°52′ W; 441 m.a.s.l.) in rainfed OG (*Olea europaea*) of the Picual variety. The farm was oriented N-NW with slopes below 5% and undulating landscape. The parent materials were Miocene marl and marlaceous lime. The studied soils were Cambisols according to IUSS Working Group (IUSS-ISRIC-FAO, 2006). The climate was Mediterranean with 3–5 months of summer drought, usually from late June to September, and moderately wet cool winters. The annual average temperature was 17 °C, with a maximum air temperature of 40.6 °C in August and a minimum air temperature of −5.2 °C in January. The annual average precipitation was 645.7 mm, and monthly rainfall ranges from 4.7 mm (July) to 87 mm (February).

2.2. Experimental design

The experiment was carried out from 2003 until 2013. In January 2003 three adjacent plots (1 ha each; 100 m × 100 m) were established in an OG planted at a density of 90 trees ha^{-1} (each tree had two or three trunks) that were 35 years old, with a uniform tree spacing (10 m × 10 m) and tree size (3 m high × 5 m in canopy diameter). Two oil mill wastes: oil mill pomace (waste of the two-phase olive oil extraction system) and olive leaves (olive leaves dragged along with