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Biochemical activity and chemical-structural properties of soil organic matter after 17 years of amendments with olive-mill pomace co-compost

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ABSTRACT

This study evaluates soil fertility, biochemical activity and the soil's ability to stabilize organic matter after application of composted olive-mill pomace. This organic amendment was applied in two different olive groves in southern Spain having different soil typologies (carbonated and silicic). Olive grove soils after 17 years of organic management with application of olive-mill pomace co-compost were of higher quality than those with conventional management where no co-compost had been applied. The main chemical parameters studied (total organic carbon, total nitrogen, available phosphorus, exchangeable bases, cation exchange capacity, total extractable carbon (TEC), and humic-to-fulvic acids ratio), significantly increased in soils treated with the organic amendment. In particular, the more resistant pool of organic matter (TEC) enhanced by about six and eight fold in carbonated and silicic soils, respectively. Moreover, the amended silicic soils showed the most significant increases in enzyme activities linked to C and P cycles (β-glucosidase twenty-five fold higher and phosphatase seven fold higher). Organic management in both soils induced higher organic matter mineralization, as shown by the higher pyrrole/phenol index (increasing 40% and 150% in carbonated and silicic soils, respectively), and lower furfural/pyrrole index (decreasing 27% and 71% in carbonated and silicic soils, respectively). As a result of mineralization, organic matter incorporated was also more stable as suggested by the trend of the aliphatic/aromatic index (decreasing 36% and 30% in carbonated and silicic soils, respectively). Therefore, management system and soil type are key factors in increasing long-term C stability or sequestration in soils. Thus application of olive-oil extraction by-products to soils could lead to important mid-to -long-term agro-environmental benefits, and be a valuable alternative use for one of the most widespread polluting wastes in the Mediterranean region.

1. Introduction

About 80% of Spanish olive crops are concentrated in Andalusia, the largest olive-growing area worldwide, with over 30% of the world's production of olive oil (Spanish Agency for Olive Oil database, 2009). Within Andalusia, the most important olive oil producing areas are in the province of Jaén (southern Spain).

The conventional and intensive agricultural methods used in olive orchards in this area cause soil fertility degradation, erosion and soil compaction, in addition to polluting surface waters (Castro et al., 2008). The main effect of this type of management is loss in organic matter content, which becomes especially significant in originally poor soils such as in the Mediterranean. The role of organic matter and its application to the soil has changed in modern agriculture, where chemical fertilizers are now the major source of nutrients for crops. Deterioration of soil quality in these areas would therefore be related primarily to inappropriate farming techniques (Moreno et al., 2009).

In several studies, the use of environmentally-friendly agricultural practices has proven to be effective in restoring or improving soil quality in olive grove areas in southern Spain by reducing the mechanical disturbance of soil, protecting the soil surface with mulch cover, maintaining vegetative cover, adding organic matter to the soil, etc. (e.g., Castro et al., 2008; Aranda et al., 2011; Calero et al., 2013). The agronomic value of biochar and other emerging technologies, such as hydrothermal carbonization (Poerschmann, 2013), should also be considered in the near future.

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In Andalusia, the extensive olive crop leads to a huge annual production of olive-mill pomace (around four million tons), the main by-product of the two-phase olive oil extraction system (García-Ruiz et al., 2012). Olive-mill pomace is a semi-solid or pasty material with very little porosity, very moist, acidic in reaction, rich in organic matter, potassium and hydrosoluble carbohydrates, which may contain lipid compounds and organic phytotoxic and anti-microbial compounds. The phosphorous content is low as are micronutrients and nitrogen, so the C/N ratio is usually high, with a mean of 48, which is far from the optimum established for composting (25–35) (Alburquerque et al., 2004; Mechri et al., 2011).

Its direct application as an organic amendment in agriculture could cause serious environmental problems in soils or in surface waters, which limits its general use in soil improvement. The stability of organic amendments has been considered of paramount importance in the incorporation of organic matter into soil (Nicolás et al., 2012). Under controlled conditions, composting produces a stabilized organic matter enriched in "humic-like substances" and free of phytotoxic compounds and pathogens. In addition, composting allows longer persistence of the organic carbon from amendments in the soil (Bernal et al., 1998). The composted olive-mill pomace thus acquires acceptable maturity, stability, and detoxification (Alburquerque et al., 2006).

Agricultural practices based on periodic inputs of organic amendments are strongly recommended for Mediterranean agroecosystems. According to García-Ruiz et al. (2012), composted olive-mill pomace contains a large amount of organic matter, and thus might be useful as an amendment to agricultural soils, potentially lowering the need for nitrogen, phosphorus and potassium fertilizers, improving a range of soil properties, and reducing loss of agricultural production. Apart from its positive effect of storing carbon in soil, it would also help prevent problems associated with erosion. Hence, olive-mill pomace compost application could be considered an attractive strategy for soil C sequestration (Sánchez-Monedero et al., 2008).

In spite of the enormous amounts of waste from olive-oil mills every year, their potential as an organic amendment for environmental remediation of agricultural soils has scarcely been evaluated (Lozano-García and Parras-Alcántara, 2013). Some studies have provided information on the beneficial effects of olive-mill pomace compost on the physical, chemical and biological properties of the soil (Lozano-García and Parras-Alcántara, 2011; García-Ruiz et al., 2012; Lozano-García and Parras-Alcántara, 2013; Gómez-Muñoz et al., 2013), and have demonstrated a general increase in fertility and protection from erosion. However, in-depth studies on the structural evolution of the soil organic matter after application of this compost, and its relationship with soil biochemical activity linked to nutrient cycles continue to be scarce and incomplete.

Therefore, the main goals of this study were to analyze samples of olive grove soil organically amended with olive-mill pomace co-compost by Pyrolysis-GC to find out essential molecular information about the chemical-structural changes in the organic matter, extent of humification to evaluate organic matter quality, and some soil enzyme activities very sensitive to soil management. This study on the application of this organic amendment was carried out on two different soil typologies (carbonated and silicic) in southern Spain, after 17 years of application in the field.

2. Material and methods

2.1. Site description and soil sampling

The studied olive farms were productive private farms located in Andújar, Jaén Province (southern Spain). The average annual rainfall in the area is 480 mm, falling mainly in autumn and spring. The climate is Mediterranean with a mean annual temperature of 17.9 °C, cool winters, and hot, very dry summers.

Olive tree density on the study farms varied between 90 and 100 trees per hectare, trees were 35–45 years old, and distributed in a regular arrangement with a typical canopy cover of about 30% of the farm area. The management practices applied on these farms were those most commonly used in the area. Two of the farms were fertilized with the organic amendment and two with mineral fertilizer.

On the farms with organic management, 6–10 Mg ha^{-1} compost had been applied once every autumn for the last 17 years. The co-compost was about 50% olive-mill pomace, air-dried to less than 20% of its moisture, and 50% olive leaves and manure mixed and heaped in 3-m-high × 6-m-diameter piles, turned regularly every 15 days to prevent anaerobic processes, and matured for seven months. The moisture content was checked periodically and maintained at 40–60% by adding the necessary amount of water and the excess water leached was recirculated.

The co-compost was always evenly spread over the soil in the intercanopy and mowed (very superficial chisel passes to control plant cover). The application period and rate varied depending on co-compost availability, climate conditions, and olive waste production. On 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 plant cover maintenance.

Fertilization of the farms 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. Conventional management was also characterized by no-till soils, and herbicides were used for weed control.

Four farms near each other were sampled, two with calcareous soils (with and without co-compost application) and two with silicic soils (with and without co-compost application). Calcareous and silicic soils were from calcarenitic and quartzitic parent material, respectively. The dominant soils in the calcareous area were Eutric Regosols (FAO, 2006) and in the silicic area Dystric Leptosols (FAO, 2006). Olive farms which received co-compost were comparable to those which received no compost (control soils) in terms of climate, slope, orientation, soil type, and tree density and age. Sampling at each farm consisted of random selection of three intercanopy locations, and taking a random soil sample composed of four subsamples (from the 0–10 cm surface layer) within a 5 m radius in each location. The original co-compost was also kept for further analysis.

2.2. Soil analyses

All analytical soil sample data refer to the fine-earth fraction (<2 mm). The chemical analyses used followed the standard procedures, and were as outlined by the American Society of Agronomy and Soil Science Society of America (Page et al., 1982; Klute, 1986). Organic carbon (OC) content was determined by the Walkley-Black's method with dichromate oxidation (1 N $K_2Cr_2O_7$ and 0.5 N $Fe(NH_4)_2(SO_4)_2$ as titrant for excess $Cr_2O_7^{2-}$). Total N was measured with the Kjeldhal's method, employing a potassium sulfate-catalyst mixture (K_2SO_4–$CuSO_4$–Se), concentrated H_2SO_4 and 10 N NaOH; finally, titration with 0.01 N H_2SO_4. The pH was measured by potentiometry in distilled water (1:2.5, w/v). Electrical conductivity (EC) at 25 °C was determined in water extracts (1:5, w/v). Calcium carbonate equivalent was determined with a Bernard calcimeter, reacting carbonates with hydrochloric acid (10% HCl, w/w). Soil available P was extracted with 0.5 N $NaHCO_3$ (pH 8.5), using a mixed reagent of $(NH_4)_6Mo_7O_{24}$ and K(SbO)$C_4H_4O_6$, and ascorbic acid as color-developing reagent; finally,