Journal of Environmental Management 202 (2017) 94–105

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Thermal destruction of organic waste hydrophobicity for agricultural soils application

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A R T I C L E I N F O

Article history:
Received 16 February 2017
Received in revised form
17 May 2017
Accepted 10 July 2017
Available online 17 July 2017

Keywords:
Soil organic amendments
Water repellency
UV–Vis
ATR-FTIR
TG-SDT
Phytotoxicity

A B S T R A C T

Use of organic amendments is a good strategy for combating the growing problem of soil degradation due to deterioration of organic matter content, particularly severe in semi-arid European Mediterranean regions, while at the same time providing an opportunity for recycling organic wastes. Olive mill pomace (OMP), the main by-product of the olive oil industry, is being used increasingly in olive grove soils for this purpose. Although the positive effects of OMP amendments have been widely studied, they also have some negative effects on soil. One of the most critical is that they increase water repellency (WR) due to the presence of poorly evolved, strongly aliphatic compounds. This detrimental effect has received very little attention, although it may impair plant water availability and infiltration rates, increase erosion and lower long-term soil quality. This study proposed, for the first time, thermal treatment as an effective way of reducing WR in organic amendments (i.e. mixtures of OMP, olive tree pruning, chicken manure and spent coffee grounds) prior to their application to soil. Thermal treatment at 275 °C proved effective in removing WR, while lower temperatures (175 or 225 °C) can even increase it. Changes by thermal treatment in the characteristics of the organic amendments studied with FTIR and UV–Vis spectroscopy and thermogravimetric analysis showed that it strongly reduced the aliphatic compounds mainly responsible for their hydrophobicity, concentrated aromatic compounds and increased thermostability. Heating also reduced phytotoxicity, making all of the organic amendments usable in the field (germination index over 100%). Therefore, heating at 275 °C could be an acceptable option for removing WR from organic amendments, enhancing their quality with more stable evolved characteristics.

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1. Introduction

Olive groves are of enormous importance in the Mediterranean economy. They produce around 2.5 million Mg of olive oil per year, which is over 90% of the world production (COI). Unfortunately, poor agricultural practices have reduced soil organic matter levels, leading to severe soil degradation. One possible solution is to restore organic matter in the soil with the addition of appropriate organic amendments (Pérez-Lomas et al., 2010). As underlined by Almendros et al. (2005) the assessment of the quality of soil organic matter, including the amendment incorporated to the soil, rather than its total concentration, must be considered.

On the other hand, the extensive olive cultivation leads to a huge annual production of olive mill pomace (OMP), the main by-product of the two-phase olive oil extraction system. Due to its high polyphenol, lipid and organic acid concentrations, it is phytotoxic and antimicrobial (Serramiá et al., 2010), and therefore, highly pollutant. This makes OMP a considerable management problem in the olive agro-industry (López-Piñeiro et al., 2007). However, it has interesting possibilities for use as organic amendment after composting, which eliminates the harmful substances. (Fernández-Hernández et al., 2014). The positive effects of the use of composted olive mill pomace (COMP) on soil fertility have been widely studied (García-Ruiz et al., 2012; Lozano-García and Parras-Alcántara, 2013), but there are still some disadvantages like high pH (often above 8). However, the most critical factor is increased soil water repellency (WR) due to hydrophobicity generated by accumulation of hydrophobic compounds from the decomposition of fresh organic matter with little alteration or humification. This affects the soil water regime, reducing the infiltration capacity (Mohawesh et al., 2014), hydraulic conductivity and plant water

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http://dx.doi.org/10.1016/j.jenvman.2017.07.024
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availability (Doerr and Thomas, 2000). It could therefore generate or increase soil surface flow, and consequently, significantly increase risk of erosion (Diamantopoulos et al., 2013), especially at the beginning of the rainy season. This would be amplified on sloping surfaces, for example, by ridges in ploughed agricultural soils (Ahn et al., 2013). WR could induce a preferential flow in soil, causing irregular distribution of water and nutrients, and accelerating pollutant transport to groundwater (Arye et al., 2011). This can affect large areas and thus cause serious problems in agricultural production and plant growth (Vogelmann et al., 2013). Increased WR is also observed in other types of organic amendments (Liyanage and Leelamanie, 2016). In Mediterranean soils, this is a particularly severe problem, because the climate is characterized by very irregular rains and strong seasonal contrasts, which could exacerbate these adverse processes. High WR in Mediterranean agricultural soils has been found to be induced not only by soil type, but also by organic amendments (Aranda et al., 2016).

Study of fire-induced changes in soil properties has revealed that water repellency can be diminished at temperatures above 250 °C, and similar findings have been reported in laboratory simulations with raw organic matter (Mataix-Solera and Doerr, 2004).

High temperature diminishes WR due to thermal degradation or vaporisation of the organic substances responsible for hydrophobicity (Simkovic et al., 2008). These findings suggest that thermal treatment of OMP amendments before application could reduce the aforementioned problems associated with the increase in WR.

Composted OMP for use as an organic amendment can also be improved by adding other organic matter sources, like spent coffee grounds, another waste by-product, which arouses much scientific interest and an industry that produces millions of tonnes worldwide. Part is recycled by processes such as composting, although its use as a soil amendment has not been well studied (Cruz and Marques dos Santos Cordovil, 2015).

This study evaluated the feasibility of using different thermal treatments to increase the quality of several organic amendments based on olive mill pomace by eliminating their hydrophobicity. The functional characterisation and stability of these materials was studied using ATR-FTIR, UV–Vis spectroscopy and thermogravimetric analysis (TG-DTA).

2. Material and methods

2.1. Sample description

Ten samples of compost containing olive mill pomace and other wastes were collected as described below and summarized in Table 1. Samples COMP1 to COMP4 were composted (mixed and heaped in 3-m-high x 6-m-diameter piles) and turned regularly every 15 days to avoid anaerobic processes for a maturation period of seven months. For better composting, olive tree prunings were added to all samples as a bulking agent, and chicken manure was also added to COMP1 to COMP4 to accelerate and improve composting. Sample COMP5 was prepared by mobile stacking, turning every fortnight for the first four months of bio-oxidation and then allowed to stand without turning for a two more months. Samples COMP5-CF1 to COMP5-CF4 were mixtures of sample COMP5 with different proportions of spent coffee grounds.

An additional sample of uncomposted dried olive mill pomace (OMP) and another of spent coffee grounds (CF) were also included. Each compost sample consisted of five subsamples taken from five different positions within the heap in order to ensure representative results of the material.

2.2. Thermal treatment

After desiccation at 65 °C, samples were ground with a ball mill and sieved to 200 μm. Then they were subjected to thermal treatment by placing about 60 g of each in porcelain containers and heating to 175, 225 or 275 °C in a pre-heated oven (Binder FED GmbH) by ramping temperature up on a 5 °C/min gradient and maintaining the temperature for 5 h (Simkovic et al., 2008). A total of 42 thermally treated samples were obtained in this way. It should be noted that OMP samples burned at temperatures above 200 °C, probably due to their high residual olive oil content.

2.3. Chemical characterisation and elemental analysis

Electrical conductivity and pH were measured in a 1:10 water soluble extract (w/v) with a CRISON conductimeter and a CRISON pH-meter respectively. A LECO TruSpec CHN 620-100-400 analyser was used to determine the total organic carbon, total nitrogen and ash content. P, K, Ca and Mg were determined after digesting samples with H_2O_2, HNO_3 and HF in an ETHOS microwave digester, then adding H_3BO_3 for elemental determination in an ICP-OES VARIAN 715-ES.

2.4. Spectroscopy

Mid-IR spectra of the solid samples were recorded using a Varian 660 FTIR spectrometer (Varian, Inc.) equipped with an attenuated total reflection accessory (ATR, Pike Technologies) with a three-reflection diamond crystal. Samples were finely ground in an agate mortar and placed directly on the ATR crystal. Controlled

Table 1
Description of the organic waste samples.

Sample	Composition	Origin
COMP1	50% OMP 25% Olive tree pruning 25% Chicken Manure	OMP produced and composted in Hermejor de la Reina organic oil factory[a] Pile 1.
COMP2	50% OMP 25% Olive tree pruning 25% Chicken Manure	OMP produced and composted in Hermejor de la Reina organic oil factory[a] Pile 2.
COMP3	80% OMP 10% Olive tree pruning 10% Chicken Manure	OMP produced and composted in olive-growing cooperative N. S. Remedios[b]
COMP4	80% OMP 10% Olive tree pruning 10% Chicken Manure	OMP produced and composted in Alcanova S.L. oil factory[c]
COMP5	30% OMP 70% Olive tree pruning	OMP produced and composted in IFAPA[d]
COMP5-CF1	24% OMP 56% Olive tree pruning 20% Spent coffee grounds	Mix of COMP5 with spent coffee grounds
COMP5-CF2	18% OMP 42% Olive tree pruning 40% Spent coffee grounds	Mix of COMP5 with spent coffee grounds
COMP5-CF3	12% OMP 28% Olive tree pruning 60% Spent coffee grounds	Mix of COMP5 with spent coffee grounds
COMP5-CF4	6% OMP 14% Olive tree pruning 80% Spent coffee grounds	Mix of COMP5 with spent coffee grounds
OMP	Dried OMP	OMP produced in Hermejor de la Reina organic oil factory1
CF	Spent coffee grounds	Spent coffee groundsobtained from University cafe

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[b] (Noguerones, Jaén).
[c] (Alcaudete, Jaén).
[d] Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA) (Mengibar, Jaén). COMP: composted olive mill pomace; OMP: olive mill pomace.

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