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Production of organic fertilizer from olive mill wastewater by combining solar greenhouse drying and composting

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ABSTRACT

Olive mill wastewater (OMW) is generated during the production of olive oil. Its disposal is still a major environmental problem in Mediterranean countries, despite the fact that a large number of technologies have been proposed up to date. The present work examines for the first time a novel, simple and low-cost technology for OMW treatment combining solar drying and composting. In the first step, OMW was dried in a chamber inside a solar greenhouse using swine manure as a bulking agent. The mean evaporation rate was found to be 5.2 kg $H_2O/m^2/d$ for a drying period of 6 months (February–August). High phenol (75%) and low nitrogen (15%) and carbon (15%) losses were recorded at the end of the solar drying process. The final product after solar drying was rich in nutrients (N: 27.8 g/kg, P: 7.3 g/kg, K: 81.6 g/kg) but still contained significant quantities of phenols (18.4 g/kg). In order to detoxify the final product, a composting process was applied as a second step with or without the use of grape marc as bulking agent. Results showed that the use of grape marc as a bulking agent at a volume ratio of 1:1 achieved a higher compost temperature profile (60 °C) than 2:1 (solar drying product: grape marc) or no use (solar drying product). The end product after the combination of solar drying and composting had the characteristics of an organic fertilizer (57% organic carbon) rich in nutrients (3.5% N, 1% P, 6.5% K) with quite low phenol content (2.9 g/kg). Finally, the use of this product for the cultivation of pepper plants approved its fertility which was found similar with commercial NPK fertilizers.

1. Introduction

Olives and olive oil production are one of the most successful industries around the Mediterranean basin from antiquity to the present. In the last decade, Mediterranean countries have been produced about 2.5 million tonnes/year of olive oil, which corresponds to 90% of world production (International Olive Oil Council, 2016). Despite the fact that the olive oil industry contributes significantly to the economy of these countries, the management of wastewater from olive mills is still an unsolved problem. The seasonality and characteristics (extremely high organic content, high suspended solids content, low pH and high oil and phenol concentrations) of olive mill wastewater (OMW) makes it difficult to apply a cost-effective treatment method.

Several physical, chemical and biological processes and combinations of these have been reported in the literature (Paraskeva and Diamadopoulos, 2006). Of them all, the evaporation of OMW in ponds and the subsequent discharge of remaining solids in landfill is by far the most realistic method applied for the management of OMW. This process significantly reduces OMW volume but creates significant odour problems in the area. In addition, the organic content and toxicity of OMW is not reduced to acceptable levels. Furthermore, in case of heavy rain the evaporation ponds could fail, resulting in OMW flooding. In the last decade, several filtration processes have been studied for the treatment of OMW, such as microfiltration (Zagklis et al., 2015), ultrafiltration (Stoller et al., 2013), nanofiltration (Sanches et al., 2016) and reverse osmosis (Ochando-Pulido et al., 2014). Using these techniques, it is possible to recover valuable products such as antioxidant substances and phenolic compounds. However, there are still many drawbacks that need to be corrected before the large-scale implementation of these technologies, such as membrane fouling, energy cost and concentrate disposal (Ioannou et al., 2013). Advanced oxidation processes have been extensively studied for OMW treatment, such as ozonation (Beltran-Heredia et al., 2001), photo-Fenton oxidation (Aytar et al., 2013), TiO_2 photocatalysis (Gernjak et al., 2004) and

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wet oxidation (Azabou et al., 2010). The efficiency of these treatment methods was found to be quite high. However, they faced problems related to large-scale feasibility and cost-efficiency, as well as other environmental issues (formation of more toxic compounds). Anaerobic digestion is a biological process recommended for high organic content wastewater. However, in the case of OMW the presence of phenolic compounds inhibits methanogenic bacteria (Eusebio et al., 2007). In order to mitigate the effect of phenols on the anaerobic digestion process, co-digestion with other organic residues has been proposed (Dareioti et al., 2010; Fountoulakis et al., 2008). This technique is very promising but requires centralized treatment and the presence of other feedstocks in the area, such as manure, sewage sludge, cheese whey, etc. It should be mentioned that in most cases olive oil production is the main (or sole) farming activity, resulting in the production of significantly higher quantities of OMW compared to the available quantities of other feedstocks. This means that co-digestion can only be applied to manage a small part of the OMW produced. Storage facilities are also necessary in order to overcome the seasonality of OMW production.

In recent years, OMW has been recognized as a source of organic matter, nutrients and water. Even though the composition varies significantly depending on climatic conditions, fruit variety, extraction process, cultivation techniques and other factors, OMW is rich in organic carbon (>g/L) and potassium (>4 g/L). It also contains lower but significant quantities of nitrogen (~1g/L), phosphorus (0.2 g/L) and magnesium (0.1 g/L) (Karpouzas et al., 2010; Moraetis et al., 2011). It is therefore extensively studied for crop irrigation as is (raw) or after treatment (Chatzistathis and Koutsos, 2017). Contradictory results have been found regarding the effect of irrigation with OMW on soils, plants and environment. Specifically, many studies have shown that this practice improves plant growth (Kapellakis et al., 2015; Belaqziz et al., 2016), crop yield (Mechri et al., 2011; Magdich et al., 2012) and soil fertility (Ben Rouina et al., 2006; Vella et al., 2016). In contrast, other studies have reported phytotoxicity issues (Barbera et al., 2013; Ouzounidou et al., 2010), groundwater contamination (Spandre and Dellomonaco, 1996), decreased soil porosity (Mahmoud et al., 2010) and increased salinity (Lopez-Pineiro et al., 2011). Another issue to be taken into consideration is the fact that OMW is produced during the winter, while the need for crop irrigation is during the summer period.

Solar drying is a cost-effective method applied for biosolids (Mathioudakis et al., 2013). In addition, solar energy was used in order to increase the temperature of a composting reactor with positive results on the quality of final product (Chen et al. 2014). However, little is known about the application of this method to OMW (Potoglou et al., 2004; Sklavos et al., 2015). These previous works examined the efficiency of a solar distiller for OMW drying and the possibility of recovering antioxidants from distillate, with promising results. The physicochemical characteristics of the dried material are still unknown. However, it is expected to be a concentrated OMW rich in nutrients, minerals, phenols and oil, similar to the hazardous dried sludge obtained from the evaporation ponds. A simple method to detoxify this end product may be composting. Composting is a well-established method for the treatment of organic solid waste which is also efficiently tested for the treatment of olive mill wastewater sludge (Hachicha et al., 2009; Hachicha et al., 2012; Plaza et al., 2007). In these cases, different bulking agents were used such as sesame bark; tree cuttings, poultry manure and spent coffee grounds.

This study examined for the first time a novel, simple and relative low-cost technique for the management of OMW which combines greenhouse solar drying and composting. The evaporation ponds used to date for OMW were replaced by solar drying: a more intensive and controlled method. In the next step, the end product of solar drying was detoxified using a composting process in order to make it appropriate for agricultural use. Two other agro-industrial residues were co-treated as bulking agents during the proposed process: swine manure, and grape marc. The use of a bulking agent during composting is a well-known technique (Chang and Chen, 2010). In this study grape marc was used in order to provide air space and to mitigate the toxicity of compostable material. Furthermore, the use of a bulking agent during solar drying was also proposed in order to avoid crusting on the surface of the sludge and to provide sufficient porosity (Shao et al., 2015). In this study, swine manure was used for these purposes.

2. Materials & methods

2.1. Raw materials

Fresh OMW was collected during winter 2015 from a three-phase olive mill located in Stavrakia, Crete. In total, 10 m^3 of OMW were transported to the experimental site and stored in a black plastic tank. Mixing with the help of a submersible pump was conducted in the tank prior to use in solar drying experiment. Swine manure was collected from an industrial farm near Rethymno, Crete, while grape marc was collected from a winery in Heraklion, Crete. The physicochemical characteristics of OMW are presented in Table 1 and those of swine manure and grape marc in Table 2.

2.2. Solar drying

Solar drying was conducted in a concrete chamber (length: 3.0 m, width: 1.4 m, depth: 0.35 m) inside a solar greenhouse situated in Heraklion, Crete, Greece (35°19″N and 25°10″E). The greenhouse was completely covered with a plastic film supported by a metallic structure. On February 2, swine manure was spread in the concrete chamber and the first quantity (150 L) of OMW was added the same day. In total, 4098 L of OMW was gradually added to the chamber over a period of almost 6 months (last addition on August 8) as presented in Fig. 1. The addition of OMW took place when the surface of the dried material was starting to crust. Turnings of dried material were conducted manually, once a month. Fresh and dry weight was measured at the beginning and end of the experiment. Ambient air temperature, humidity and solar radiation were recorded online using a weather station (Vantage Pro2, Davis).

2.3. Composting

The composting experiment was conducted in a commercial composter (BioActor, Helesi). The composter comprises ten stackable frames. Each frame consists of three integrated layers: (a) a perforated inner ventilation wall, (b) an insulating middle wall, and (c) a perforated outer ventilation wall. The final product

Table 1
Characteristics of olive mill wastewater used in the experiment.

Parameter	Olive mill wastewater
pH	4.9
EC (mS/cm)	6.7
COD (g/L)	57.2
TS (g/L)	49.1
TOC (g/L)	34.0
P (g/L)	0.3
N (g/L)	1.6
K (g/L)	4.6
Phenols (g/L)	5.4

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