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Composting of three phase olive mill solid waste using different bulking agents

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ABSTRACT

Pilot-scale experiments were carried out to produce good quality, low-cost composting technology from three phase olive mill solid waste (olive pomace, OP) using rice husk (RH) and olive leaves (OL) as bulking agents. A series of parallel experiments was carried out to examine the effect of: (a) initial moisture content, (b) water addition during the composting process, and (c) material ratios. To monitor the composting process and evaluate compost quality, physicochemical parameters (temperature, moisture content, pH, electrical conductivity, organic matter, volatile solids, total organic carbon, total nitrogen, total phosphorus, potassium, sodium, and water soluble phenols) were measured at different phases of the composting period. Experimental results showed that even after short composting periods, the quality of the final product remained high. To achieve higher quality of the final product, OP should be used in higher quantities than the other two materials (OL and RH). A full-scale compost unit was designed based on the experimental results. For a typical small-sized olive mill, processing 30 tonnes of olives per day for a 90 days operation period, a total area of about 500 m^2 is needed to compost the mill's entire waste production.

1. Introduction

The olive oil extraction industry represents a substantial share of the economies of Mediterranean countries but leads to serious environmental problems by producing huge amount of wastes (by-products) within a short production period. These by-products are olive pomace (OP) and olive mill wastewater (OMW) (for three-phase systems, 3P), and two phase olive mill waste (TPOMW) (for two-phase systems, 2P) (Roig et al., 2006). 3P olive mills separate oil from by-products (e.g. OP and OMW) using a three-phase centrifuge (decanter) and 2P olive mills separate oil from TPOMW, which is a mixture of wastewater and OP, using a two-phase centrifuge. 2P olive mills require smaller amounts of water for oil separation, thus producing smaller quantities of wastes compared to 3P systems. The production rate of olive oil is about 1.4–1.8 million tonnes per year in the Mediterranean resulting in 30 million tonnes of by-products (Barbera et al., 2013). A small portion of these wastes can be used as raw materials in different industries as they contain valuable natural resources. Greece has about 2300 small-scale, rural, agro-industrial units that extract olive oil (Michailides et al., 2011). These are generally 3P systems and their by-products include olive mill residual solids (olive pomace and leaves) and OMW. Olive mills produce significant quantities of solid wastes with outputs of 0.35 tonnes of olive pomace and 0.05 tonnes of leaves per tonne of olives (Niaounakis and Halvadakis, 2004). The huge quantities of OP and OL produced within the short oil extraction season cause serious management problems in terms of volume and space.

The soils of most Mediterranean countries have low organic matter content (<1%) which has negative impacts on agriculture (Alburquerque et al., 2007). Frequent application of composted organic residues increases soil fertility, mainly by improving aggregate stability and decreasing soil bulk density. Organic amendments play a positive role in climate change abatement by soil carbon sequestration. Recurrent use of composted materials enhances soil organic nitrogen content by up to 90% (Diacono and Montmurro, 2010). According to Toscano et al. (2013), composted

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olive mill by-products applied to olive groves increased olive production by 9% and olive oil production by 166–180 kg ha^{-1}. To replenish soil organic matter content and benefit eco-friendly crop production the application of OP compost could be a good solution. Several experiments have been carried out on composting olive mill by-products using OMW from 3P mills and olive humid husk (OHH) from 2P mills and adding other agricultural by-products as bulking agents. These agents include wool waste, wheat straw, olive leaves, wood chips, by-products from rice harvesting, sesame bark, sewage sludge, poultry manure, and sheep manure (Muktadirul Bari Chowdhury et al., 2013). Previous studies produced mature compost with C/N ratios ranging from 11.5 (Sellami et al., 2008) to 53.5 (Alfano et al., 2008) depending on initial carbon and nitrogen content of the materials. Compost maturity is evaluated using the germination index (GI) method. GI experiments were introduced by Zucconi et al. (1981) and include the quantification of seed germination and growth when a solution of compost extract is applied to growth media (Komilis and Tziouvaras, 2009). *Lepidium sativum* (salad cress) seeds are most commonly used for this experiment. Previous research has recorded GI values ranging from 45% (Alfano et al., 2008) to 195% (Michailides et al., 2011).

Rice husk (RH) is an agro-industrial by-product with significant production in Greece and especially in western Greece. While rice husk is highly resistant to biodegradation, it could be used to improve compost porosity.

The main objective of this work was to perform comparative pilot-scale experiments for composting OP, OL and RH, and define the best material ratios, optimum humidity and minimum composting duration. Furthermore, optimum experimental results were scaled up in order to design a full-scale composting unit for an olive mill receiving 30 m^3 of olives per day, which is the typical capacity of small olive mill units in Greece. To observe the composting process, physicochemical parameters (i.e., temperature, moisture content, pH, electrical conductivity, organic matter, total C, total N, total P, K, Na, and water soluble phenols) were assessed at different stages of the experiments. To ascertain the quality of the end product, phytotoxicity tests were carried out using *L. sativum* seeds.

2. Materials and methods

2.1. Composting materials and process

Olive pomace (OP), olive leaves (OL), rice husk (RH), water and OMW were used for this study. The OP, OL and OMW were collected from a three-phase olive mill located in Amfilochia, western Greece. To improve the physical condition of olive pomace for composting, olive leaves and rice husk were added as bulking agents. Water and olive mill wastewater were used as humidifying agents during the composting period. In this study, six trapezoidal bins with dimensions 1.26 m long, 0.68 m wide and 0.73 m deep and a total volume of 0.62 m^3 were employed. The study was carried out at the facilities of the Department of Environmental and Natural Resources Management, University of Patras, Agrinio, in a closed area to maintain controlled temperature conditions. Three experiments were performed with different experimental set-ups (Table 1). The three experiments were conducted in different time periods using six parallel composting bins for each experiment. In each experiment different composting materials were used to determine optimal mixing ratios, and two of the six bins had the same contents to examine the effect of other operational parameters. The main objectives of the first experiment were to: (a) examine the effects of different OP and OL ratios on compost quality, (b) examine the effect of ambient temperature and compare data with a previous industrial-scale experiment (Michailides et al., 2011), and (c) control total composting duration using the compost cooling process. The second experiment was performed to examine the optimum mixing ratio of RH, while compost duration was again controlled as in the first experiment. Finally, the third experiment was performed to examine the effect of prolonged composting (not controlled by cooling) on final compost quality. In the first experiment, two identical series were set-up: Bins 1–3 and 4–6 were filled with OP and OL using different ratios (Table 1). In this experiment water was applied as a wetting agent. In the second and third experiments one bin (Bin 7 and Bin 13 respectively) was used as reference to the first experiment, while bins 8, 10, 14 and 16 were used to examine the effect of OMW as a wetting agent. Bins 9–12 and 15–18 were used to examine the effect of RH as a bulking agent.

In all experiments aeration was achieved by mechanical turning which took place daily for the first three days, once every four days during the thermophillic phase, and once a week during the maturation phase. In the first two experiments compost moisture content was kept constant at about 60–65%, whereas in the third experiment compost moisture content was above 45%. According to Gajalakshmi and Abbasi (2008), moisture contents between 45 and 60% are ideal for the composting process. In the first two experiments the compost mixture was kept in the bins for 60 days. It was then removed from the bins and stored in a covered place to

Table 1
Description of experimental set-ups.

	Bin	Composting materials ratios (per volume)			Moistening agent	Initial mass (kg)	Initial vol. (L)	Final mass (kg)	Final vol. (L)
		Olive pomace	Olive leaves	Rice husk					
1st exp	Bin1	2	1	0	Water	154.19	294	132.73	210
	Bin2	1	1	0	Water	163.92	294	130.96	238
	Bin3	1	2	0	Water	162.50	294	106.68	238
	Bin4	2	1	0	Water	168.80	294	140.00	208
	Bin5	1	1	0	Water	158.60	294	125.00	239
	Bin6	1	2	0	Water	145.30	294	102.00	242
2nd exp	Bin7	2	1	0	Water	93.53	252	122.97	210
	Bin8	2	1	0	OMW	91.13	252	122.67	210
	Bin9	1	1	1	Water	69.92	252	91.16	176
	Bin10	1	1	1	OMW	62.55	252	88.32	176
	Bin11	1.5	1	0.5	Water	74.51	252	101.76	196
	Bin12	0.5	1	1.5	Water	49.25	252	73.50	198
3rd exp	Bin13	2	1	0	Water	214.82	406	111.32	195
	Bin14	2	1	0	OMW	218.08	406	115.80	195
	Bin15	1	1	1	Water	179.77	406	82.24	173
	Bin16	1	1	1	OMW	172.08	406	81.73	172
	Bin17	1.5	1	0.5	Water	193.90	406	93.88	177
	Bin18	0.5	1	1.5	Water	151.94	406	69.09	160