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The sustainable reuse of compost from a new type of olive mill pomace in replacing peat for potted olive tree

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Abstract. The attention for the replacement of peat in growing substrates is increasing due to its environmental and economic advantages. The aim of the present work was to evaluate the impact of peat substitution by new type olive mill pomace and its compost on the vegetative activity of potted olive trees. A new type of humid pomace (hP) derived from an innovative two phase extraction system and its derived compost (C-hP) are used as total or partial (50% vol/vol) replacement of peat in olive growing substrate. The main chemical characteristics (moisture, water extractable organic carbon, total nitrogen, C/N ratio and electrical conductivity) of the hP and C-hP were measured. In order to evaluate the effects of the peat substitution on the plants vegetative activity, measurements of mortality, plant height, leaf net photosynthesis and plant growth (through final destructive measurements) were carried out. The use of hP resulted in a significant increase of the salinity of the substrate. The water extractable organic carbon concentration was higher in all substrates where peat was ewplaced and in particular when C-hP was used. The total replacement of peat with hP caused 100% mortality of the plants while C-hP can substitute peat up to 50% without causing a significative reduction of the final plant growth.

Key words: compost, olive pomace, olive tree, peat replacement.

INTRODUCTION

The olive oil extraction industry produces in a short period of time large amounts of oil mill waste (OMW), i.e. solid by-products (pomace) and olive mill water, whose gradual accumulation or incorrect disposal may cause serious environmental issues (Morillo et al., 2009; Regni et al., 2016). In the last decade, the composition and volumes of OMW has changed, as a result of innovative technologies used for olive oil extraction aiming at reducing water use during the various stages of the oil extraction. In fact, the traditional three-phase centrifugation system that generates olive oil, pomace and vegetation water is being gradually phased out in favor of a two-phase system that generates pomace having a very high water content as the only waste (TPOMW) (Alfano et al., 2008; Gigliotti et al., 2012). TPOMW, is a semi-solid lignocellulosic material with an abundance of potentially phytotoxic substances such as phenols, organic acids and salts (Cayuela et al., 2008). Several approaches for OMW disposal have been proposed for its valorization, such as direct land spreading, residual oil extraction, energy and biogas production, recovery of useful chemicals (Peri & Proietti, 2014; Proietti et al., 2015; Innangi et al., 2017; Regni et al., 2017). Since many of these approaches may be too costly for olive-oil producers worldwide, at present time, recycling solid OMW as soil amendment, either fresh or composted, represents the most convenient approach (Niaounakis & Halvadakis, 2006; Lopez-Pineiro et al., 2007; Rodrìguez-Lucena et al., 2010; Nasini et al., 2013; Ameziane et al., 2019). Co-composting of solid OMW, particularly TPOMW, with lignocellulosic bulking materials, such as pruning, strawor wool waste, is of particular interest for its operational simplicity and ability to transform this waste into a high-quality soil amendment characterized by loss of phytotoxicity and abundance of stabilized organic matter and nutrients for plants (Cayuela et al., 2010; Del Buono et al., 2011; Nasini et al., 2016; Ameziane et al., 2020). Among other uses, the TPOMWderived compost can be used as a cheap organic ingredient for growing substrate of potted plants that are now generally based on the rather expensive peat mixed with inorganic materials (Papafotiou et al., 2005). This valorisation strategy is particularly interesting considering that the rapid depletion of peat lands and the consequent environmental concern haveled the producing countries to limit the exploitation of this natural resource (Alexander et al., 2008). Indeed modern peat extraction methods can remove up to 22.5 cm of peat per annum but peat forms at only ca. 1 mm per annum resource (Alexander et al., 2008). Regarding the annual peat consumption of substrates, in Italy, it is around 5 million m^3, consisting largely of peat imported from abroad (Pinamonti & Cementero, 1997).

Furthermore, the European Commission in 2001 has excluded the issuance of the European 'Eco-label' for plants produced with growing substrates containing peat or derivatives. However, the use of TPOMW, especially if not-composted, as plant nursery substrate component may present problems due to their high organic load and mineral salt content, low pH and presence of phytotoxic compounds (Canet et al., 2008; Del Buono et al., 2011; Gigliotti et al., 2012). To the best of our knowledge, the effects of this new type TPOMW, composted or not-composted, on olive plant growth in nursery is not known.

A better understanding of this issue is therefore necessary. In this respect, the majority of studies have been conducted with olive mill wastewaters and aimed to evaluate their effects as soil amendment in field (Kotsou et al., 2004; Mekki et al., 2006; Di Serio et al., 2008). Meanwhile, the TPOMW used in this study was a humid pomace (hP) (water content between 64 and 78%) without any traces of olive pit obtained from an innovative two-phase extraction system. The high water content of hP made its use for oil extraction or energy production difficult. The two-phase extraction system 'DMF decanter' is rapidly spreading and therefore the production of hP is increasing, with consequent strong problems of disposal for oil exactrion or energy production due to its high levels of humidity. The aim of the present work was to evaluate the use as component of olive growing substrate in nursery of the new type of hP and its derived compost in total or partial (50% vol/vol) replacement of peat. We investigated the possibility to reduce the use of peat aiming at finding, as well, an environmentally friendly disposal of olive mill by-product.

MATERIALS AND METHODS

hP and derived compost (C-hP) characteristics

The hP used in this study was obtained from an innovative two-phase extraction system 'DMF decanter' ('Gruppo Pieralisi- MAIP', Jesi – Ancona, Italy) that does not need water addition and produces two types of by-products: a dehydrated pomace similar to that from a three-phase decanter (water content between 45 and 58%) and a hP (water content between 64 and 78%) without any traces of olive pit. For an appropriate composting of the hP, which had a water content of about 75%, bulking agents have been added in order to improve the bulk density. The C-hP was obtained by co-composting the humid pomace with shredded olive tree prunings (22%) and cereal straw (8%) (w/w) in a cubic pilot bioreactor (1 m^3) equipped with forced aeration (flow rate of 20 L min^{-1} for 10 min per hour). During the active phase (biooxidative phase), the temperature and the moisture were monitored continuously: this phase was considered finished when the mass temperature was similar to the room temperature and the re-heating did not occur (after about 50 d). The following curing phase was conducted in a trapezoidal pile for 80 more days with regular turning and wetting. The chemical characteristics of the hP and C-hP are reported in Table 1 (Gigliotti et al., 2012).

Table 1. Chemical properties of hP and C-hP (w/w of dry material) (Gigliotti et al., 2012)

	hP	C-hP
Moisture (%)	78.1 (3.8)	38.4 (0.8)
TOC (g kg^{-1})	524.3 (9.3)	473 (1.3)
TKN (g kg^{-1})	16.2 (0.6)	29 (0.5)
C/N	32.4	16.3
EC (dS m^{-1})	2.58 (0.08)	3.29 (0.4)

Environmental parameters and plant material

The research was conducted in Perugia–Central Italy (about 400 m a.s.l., 12°23’E longitude, 43°5’N latitude) under a shading structure. The climatic data were reported in Table S1.

In February 2016, one-year-old rooted cuttings of Olea europaea L., cultivar Leccino, obtained in a mist propagation system and then transplanted in pots (100 mL) containing a substrate composed of 60% (w/w) peat and 40% pumice, were individually potted in bigger black plastic pots (2.5 L) containing different substrates. All the substrates were added with the controlled-release fertilizer 'Osmocote' ('Scott Italia' 16:8:12 N:P:K) at the dose of 2 kg m^{-3} of substrate. The potted plants were maintained under the shading structure, on a bench, spaced 30×30 cm between and along the rows (north-south). Plants were regularly irrigated, depending on shading structure temperature and solar radiation, to avoid any symptoms of water stress.

Substrates characteristics

In the experiment, the following potting substrates compositions were used:

- 60% peat + 40% pumice (vol/vol), referred to as 'control';
- 60% hP + 40% pumice (vol/vol), referred to as 'hP60';
- 30% hP + 30% peat + 40% pumice (vol/vol), referred to as 'hP30';
- 60% C-hP + 40% pumice (vol/vol), referred to as 'C-hP60';
- 30% C-hP + 30% peat + 40% pumice + (vol/vol), referred to as 'C-hP30'.

The peat had organic C and N contents of 40 and 0.2% (DW), respectively, and a pH of 4.7. The pumice had a porosity of 65% and a pH of 7.0. Water-extractable organic carbon (WEOC) was obtained as described by Gigliotti et al., 2002. Electrical conductivity and pH were determined in a 1:10 compost:water extract ratio. Every 3 months, five pots per treatment were irrigated with 1 L of water, then the leached water was collected to determine the electrical conductivity (EC), using the conductimeter 'Hanna Instruments- HI 9033', and pH, using the pH-meter 'Radiometer Copenhagen-PHM 82)'.

Plant growth

At transplanting and 120 and 270 days after transplanting (DAT) the height of the plants was determined.

Every week, the number of dead plants in each substrate was determined. At 150 DAT, a pruning operation was carried out in order to remove basal shoots and shoots in competition with the principal axis. The fresh weight (FW) and dry weight (DW) of the pruning material were recorded.

At 270 DAT, nine plants per treatment were extracted from the substrate and the roots were washed. Then, roots, stem, lateral shoots and leaves were separated to determine their DW by oven-drying at 95 °C until constant weight was reached. Moreover, in these plants, the number of leaves, number and length of lateral shoots and stem diameter were measured. The development of root system was also assessed by measuring the number, length and diameter of principal roots.

Leaf net photosynthesis (P_n)

At transplanting, 30, 120 and 210 DAT, Pn was determined on cloudless days on seven well-lit current season leaves randomly selected in the middle part of shoots of seven plants per treatment. Measurements were made in the glasshouse, in the morning (from 9:00 to 10:30 h) at natural incident photosynthetic photon flux density (PPFD) that ranged from 414 µmol m^{-2} s^{-1}(February) to 656 µmol m^{-2} s^{-1} (May). Pn was measured using a portable IRGA (ADC-LCA-3, 'Analytical Development', Hoddesdon, UK) and a Parkinson-type assimilation chamber. Leaves were enclosed in the chamber and exposed to the sun's rays. The flow rate of air passing through the chamber was kept at 5 cm^3 s^{-1}. During gas-exchange measurements, the external CO2 concentration was about 360 cm^3 m^{-3} and the air temperature inside the leaf chamber was 2–3 °C higher than that in the atmosphere, varying from 11.0 °C (February) to 31.5 °C (August). Measurements were taken under steady state conditions (about 30 s). Pn was then expressed on a leaf-area basis.

Statistical analysis

The experiment was designed as a randomized block with nine blocks containing each three pots per treatment, resulting in twenty-seven pots for each experimental potting substrate.

Statistical analysis was performed using analysis of variance (ANOVA). Significant differences between values were determined at $P \leq 0.05$ by the Duncan's test.

RESULTS

Substrates characteristics

Table 2 shows the main chemical properties of substrates used in each tretment of the experiment. The pH was significantly different in substrates where the hP was used. The highest pH values were observed in the substrates prepared with compost, particularly for C-hP60. EC results showed similar values to the control in C-hP substrates. On the contrary, the use of hP resulted in a significant increase of the salinity. The WEOC concentration was higher in all substrates where the hP and C-hP were used. The same behaviour was found for the water soluble phenols, which were all significantly higher with respect to the control (hP60 > hP30 > C-hP60 > C-hP30).

Table 2. pH, EC, WEOC and soluble phenols in the substrates at the beginning of the experiment

	pH	EC	WEOC	Water soluble phenols
		mS cm^{-1}	mg g^{-1}	mg g^{-1}
Control	5.69 b	1.11 c	2.95 c	0.23 d
hP60	4.13 c	3.69 a	37.87 a	5.67 a
hP30	4.88 c	2.34 b	31.30 a	3.05 b
C-hP60	7.19 a	1.78 c	21.12 b	2.15 c
C-hP30	6.31 ab	1.42 c	14.69 b	1.41 c

Mean values followed by different letters are significantly different ($P < 0.05$).

Table 3 reports EC and pH of each treatment leaching water at 0, 90, 120 and 270 DAT. In the substrates containing hP or C-hP, the EC of the leaching water was initially higher than in control. Over time, it decreased in all substrates and the differences with respect to the control were no longer significant starting from 90 DAT. At the beginning of the experiment, pH of leaching water was similar in all the substrates but 120 days later, the substrate with hP30, C-hP30 and C-hP60 showed a pH higher than the control. At 270 DAT, the differences disappeared and the pH values of the leaching water were similar in all substrates.

Table 3. EC and pH in the leaching water of the substrates at 0, 90, 120 and 270 DAT

	EC (mS cm^{-1})			
	0	90	120	270
Control	0.82 c	0.65 a	0.73 a	0.74 a
hP60	3.81 a	-	-	-
hP30	3.90 a	0.95 a	0.88 a	0.82 a
C-hP60	1.54 b	0.54 a	0.77 a	0.71 a
C-hP30	1.22 b	0.62 a	0.55 a	0.53 a
		pH		
	0	90	120	270
Control	6.1 a	6.2 a	6.6 b	7.1 a
hP60	4.2 a	-	-	-
hP30	4.6 a	4.9 a	7.8 a	7.3 a
C-hP60	5.4 a	5.1 a	7.2 a	8.0 a
C-hP30	5.7 a	5.4 a	7.9 a	7.4 a

Mean values followed by different letters are significantly different ($P < 0.05$).

Plant growth

The mortality rate of plants grown with pomace and compost was low and generally slightly higher than in the control. hP60 substrate was the only exception causing the death of all plants after few days from transplanting (Table 4).

At 120 DAT, the control plants showed an increase in height greater than that of the plants grown in the substrates C-hP30 and C-hP60 and especially hP30. At 270 DAT, the plants grown in C-hP30 and C-hP60 showed a similar height to the Control while the height of plants grown in hP30 was significantly lower (Table 5).

Table 4. Mortality rate of the olive trees

	Mortality, %
Control	1 b
hP60	100 a
hP30	5.6 b
C-hP60	4.8 b
C-hP30	4.9 b

Mean values followed by different letters are significantly different ($P < 0.05$).

Table 5. Plant height at 0, 120 and 270 DAT

	Plant height (cm)		
	0	120	270
Control	10.9 a	58.5 a	118.7 a
hP30	12.5 a	23.8 c	64.4 b
C-hP60	12.1 a	49.6 b	98.5 a
C-hP30	11.4 a	41.2 b	113.9 a

Mean values followed by different letters are significantly different ($P < 0.05$).

The FW and DW of pruning material was higher in Control than in the substrates with hP and C-hP regardless the dose used for C-hP (Table 6).

Table 6. FW and DW of pruning material at 150 DAT

	FW	DW
	g	g
Control	95.5 a	33.6 a
hP30	65.5 b	23.4b
C-hP60	55.9 b	18.5 b
C-hP30	61.2 b	20.6 b

Mean values followed by different letters are significantly different ($P < 0.05$).

Table 7. Dry weight (DW) of different parts of olive plants at 270 DAT

	Roots DW, g	Stem+Shoots DW, g	Leaves DW, g
Control	17.35 a	38.86 a	23.95 a
hP30	13.80 a	21.70 b	19.75 a
C-hP60	8.60 b	15.25 c	21.35 a
C-hP30	13.17 a	21.35 b	22.94 a

Mean values followed by different letters are significantly different ($P < 0.05$).

Table 8. Development of aboveground parts

	Leaves n	Lateral shoots n	Mean length of lateral shoots cm	Stem diameter cm
Control	160.60 a	8.33 a	19.10 a	0.58 a
hP30	131.55 a	5.66 b	15.43 ab	0.58 a
C-hP60	91.66 b	4.00 b	9.59 b	0.50 a
C-hP30	116.00 ab	8.66 a	13.63 ab	0.55 a

Mean values followed by different letters are significantly different ($P < 0.05$).

At 270 DAT, the plants of hP30 showed a lower DW of aboveground parts due to a lower height, number and length of lateral shoots compared to the control plants, while C-hP60 plants had a reduced development of the roots system compared to the control plants due to a shorter root lengh. The plants grown in C-hP60 showed the lowest total DW while the Control plants showed the highest total DW. No significant differences were found regarding leaves DW and stem diameter (Tables 7, 8 and 9).

Leaf net photosynthesis (P_n)

At 30 DAT, Pn was higher in the Control plants while the plants of hP30 showed higher level of stress. Starting from 120 DAT, the differences in Pn rates between the different substrates was not significant (Table 10).

Table 9. Development of roots system

	Principal roots n	Mean length of principal roots cm
Control	4 a	29.19 a
hP30	3 a	20.61 b
C-hP60	4 a	10.72 c
C-hP30	3 a	19.95 b

Mean values followed by different letters are significantly different ($P < 0.05$).

Table 10. Leaf net photosynthesis (Pn) at 0, 30, 120 and 210 DAT

	Pn, μmol $(CO_2)m^{-2}s^{-1}$			
	0	30	120	210
Control	1.06 a	1.83 a	12.00 a	5.12 a
hP30	1.27 a	- 0.80 b	8.64 a	5.71 a
C-hP60	1.28 a	1.12 c	9.78 a	4.27 a
C-hP30	1.34 a	1.17 c	10.64 a	3.96 a

Mean values followed by different letters are significantly different ($P < 0.05$).

DISCUSSION

The results obtained indicate that hP especially if composted can be used for the realization of potting substrates without exceeding the 30% (v/v). In fact , after an initial growth reduction of the plants a satisfactory recovery occurred. Meanwhile, 60% (v/v) of hP in substrate composition is a too high dose since the plants died few days after transplant. The substrates obtained by using hP and composted hP showed different characteristics in terms of chemical properties. The low pH of hP substrates was caused by the slightly acidic pH of this type of feedstock (Roig et al., 2006; Gigliotti et al., 2012; Tortosa et al., 2012), which likely affect the mortality of plants. The increase of pH probably was due to the degradation of organic acids, oxidation of phenolic compounds, and the contemporaneous release of ammonium during the composting (Gigliotti et al., 2012). Although the hP substrates showed the highest EC values, the composting of hP did not result in an increase of soluble salts concentration in the respective substrates. The hP substrates showed the highest WEOC concentration, probably due to the degradation of labile, soluble C during the composting process (Said-Pullicino et al., 2007). The same trend was observed for the water soluble phenols, which are commonly found in high concentration in the olive mill wastewaters, causing phytotoxicity (Roig et al., 2006). It is also true that the total phenolic compounds in hP can decrease after its composting (Gigliotti et al., 2012), demonstrating the effectiveness of the aerobic process in their degradation. Moreover, it was found that soil microorganisms lead to a rapid degradation of WEOC and total phenol compounds after the agronomical reuse of the humid olive mill waste (Federici et al., 2017). Based on these considerations, it can be stated that the high mortality observed for hP60 substrate was probably more attributable to the combined effect of soluble phenol and salt concentration of this particular feedstock. These results are in agreement with Papafotiou et al., 2001 who used a pomace compost (moisture 25% w/w) to replace peat and observed that in *Syngonium podophyllum* L. the height was reduced only when 75% (in volume) of the peat was replaced with compost while in Ficus benjamina L. the height was not influenced at all by the amount of compost. The initial stress also evidenced by the decline of Pn can be related to the high CE and soluble phenol content (Papafotiou et al., 2001; Papafotiou et al., 2004; Barbera et al., 2013; Magdich et al., 2016). Successively, due to irrigations and consequent leaching, the EC decreased greatly and at 90 DAT it was similar to that of the control. In this way, considering the fact that olive has a medium resistance to salinity (Mousavi et al., 2019; Regni et al., 2019), the plants could overcome quite rapidly the initial stress.

In addition, the initial low pH in substrate with hP could have negatively affected the plant growth. Afterwards, the pH led to increase in all pots not showing any significant differences with the control. Whereas in the control, the pH behavior can be explained with the supply of carbonates through frequent irrigations, this phenomenon in the substrates with hP and C-hP, already observed in other similar experimentation (Proietti et al., 1995), probably is also a consequence of ammonia production following microbial degradation of organic matter present in the hP and C-hP.Considering that Pn is the integrated and symptomatic result of several processes, giving therefore important information about plant responses to environmental and agronomical factors (Bongi & Loreto, 1989), it is possible to affirm that the C-hP and, above all, the hP are initially the cause of stress. However, at 30 DAT for C-hP the phytotoxicty decreased and plants were able to recover their activity. The stronger negative effect on Pn and plant growth of hP, compared to the C-hP, is in agreement with results reported by Gigliotti et al., 2012 and Del Buono et al., 2011 who found that the composting greatly reduces the phytotoxicty of pomace through the degradation of phenols, lipids and toxic compounds, mainly contained in the water soluble organic matter fraction.

CONCLUSIONS

The results of the present study provide positive indications on the potential re-use of the composted humid pomace in replacing peat in growth substrate for potted olive trees. The compost, can be used as a co-substrates with peat, allowing strong reduction of its consumption in horticulture. This appears to be an important point since, in the last years, the use of peat has become a serious environmental and economic issue. Furthermore, the use of composted pomace in professional horticulture can contribute to the disposal of the pomace, a waste that will gradually increase over the next years, in an economic and environmentally friendly way. The utilization of not-composted humid pomace, on the contrary, cannot be recommended, unless used in small doses, since it strongly reduces plant activity causing even mortality.

Further studies would be useful to evaluate the possibility to use this type of compost for other plant species and to verify if its combinations at different percentageswith other components, such as agricultural soil, might allow further reduction of peat content in the substrates.

Supplementary materials

Table S1 Climatic conditions of the experimental site

Month	Average temperature (°C)	Rainfall (mm)
January	7.1	103.6
February	9.3	127.4
March	15.9	36.8
April	22.5	91.2
May	28.1	121.4
June	28.6	194.8
July	29.6	42.4
August	30.4	75.0
September	25.4	137.0
October	18.4	133.6
November	15.3	112.6
December	8.6	3.0

REFERENCES

Alexander, P.D., Bragg, N.C., Meade, R., Padelopoulos, G. & Watts, O. 2008. Peat in horticulture and conservation: the UK response to a changing world. *Mires Peat* **3**, Article 08

Alfano, G., Belli, C., Lustrato, G. & Ranalli G. 2008. Pile composting of two-phase centrifuged olive husk residues: technical solutions and quality of cured compost. *Bioresource Technology* **99**, 4694–4701

Ameziane, H., Nounah, A., Khamar, M. & Zouahri, A. 2019. Use of olive pomace as an amendment to improve physicochemical parameters of soil fertility. *Agronomy research* **17**(6), 2158–2171.

Ameziane, H., Nounah, A., Khamar, M. & Zouahri, A. 2020. Composting olive pomace: evolution of organic matter and compost quality. *Agronomy research* **18** in press https://doi.org/10.15159/ar.20.004

Barbera, A.C., Maucieri, C, Cavallaro, V., Ioppolo, A. & Spagna, G. 2013. Effects of spreading olive mill wastewater on soil properties and crops, a review. *Agricultural Water Management* **119**, 43-53. https://doi.org/10.1016/j.agwat.2012.12.009

Bongi, G. & Loreto, F. 1989. Gas-Exchange Properties of Salt-Stressed Olive (*Olea europea* L.) Leaves. *Plant Physiolog* **90**, 1408–1416

Canet, R., Pomares, F., Cabot, B., Chaves, C., Ferrer, E., Ribo, M. & Albiach, M.R. 2008. Composting olive mill pomace and other residues from rural southeastern Spain. *Waste Management* **28**(12), 2585–2592.

Cayuela, M.L., Millner, P.D., Meyer, S.L.F. & Roig, A. 2008. Potential of olive mill waste and compost as biobased pesticides against weeds, fungi, and nematodes. *Science of Total Environment* **399**, 11–18.

Cayuela, M.L., Sánchez-Monedero, M.A. & Roig, A. 2010. Two-phase olive mill waste composting: enhancement of the composting rate and compost quality by grape stalks addition. *Biodegradation* **21**, 465–473. https://doi.org/10.1007/s10532-009-9316-5

Del Buono, D., Said-Pullicino, D., Proietti, P., Nasini, L. & Gigliotti, G. 2011. Utilization of olive husks as plant growing substrates: phytotoxicity and plant biochemical responses. *Compost Science and Utilization* **19**, 52–60.

Di Serio, M.G., Lanza, B., Mucciarella, M.R., Russi, F., Iannucci, E., Marfisi, P. & Madeo, A. 2008. Effects of olive mill wastewater spreading on the physico-chemical and microbiological characteristics of soil. *International biodeterioration & Biodegradation* **62**(4), 403–407.

Federici, E., Massaccesi, L., Pezzolla, D., Fidati, L., Montalbani, E., Proietti, P., Nasini, L., Regni, L. & Gigliotti, G. 2017. Short-term modifications of soil microbial community structure and soluble organic matter chemical composition following amendment with different solid olive mill waste and their derived composts. *Applied Soil Ecology* **119**, 234–241.

Gigliotti, G., Proietti, P., Said-Pullicino, D., Nasini, L., Pezzolla, D., Rosati, L. & Porceddu, P.R. 2012. Co-composting of olive husks with high moisture contents: Organic matter dynamics and compost quality. *International biodeterioration & Biodegradation* **67**, 8–14. https://doi.org/10.1016/j.ibiod.2011.11.009

Gigliotti, G., Kaiser, K., Guggenberger, G. & Haumaier, L. 2002. Differences in the chemical composition of dissolved organic matter from waste materials of different sources. *Biology and Fertility of Soils* **36**, 321–329.

Innangi, M., Niro, E., D'Ascoli, R., Danise, T., Proietti, P., Nasini, L., Regni, L., Castaldi, S. & Fioretto, A. 2017. Effects of olive pomace amendment on soil enzyme activities. *Applied Soil Ecology* **119**, 242–249. https://doi.org/10.1016/j.apsoil.2017.06.015

Kotsou, M., Mari, I., Lasaridi, K., Chatzipavlidis, I., Balis, C. & Kyriacou, A. 2004. The effect of olive oil mill wastewater (OMW) on soil microbial communities and suppressiveness against *Rhizoctonia solani*. *Applied Soil Ecology* **26**, 113–121.

Lopez-Pineiro, A., Murillo, S., Barreto, C., Munoz, A., Rato, J.M., Albarran, A. & Garcia, A. 2007. Changes in organic matter and residual effect of amendment with two-phase olive-mill waste on degraded agricultural soils. *Science of Total Environment* **378**(1–2), 84–89.

Magdich, S., Abid, W., Boukhris, M., Ben Rouina, B. & Ammar, E. 2016. Effects of long-term olive mill wastewater spreading on the physiological and biochemical responses of adult Chemlali olive trees (*Olea europaea* L.). *Ecological Engineering* **9**7, 122–129. https://doi.org/10.1016/j.ecoleng.2016.09.004

Mekki, A., Dhouib, A. & Sayadi, S. 2006. Changes in microbial and soil properties following amendment with treated and untreated olive mill wastewater. *Microbiological Research* **161**(2), 93–101.

Morillo, J.A., Antizar-Ladislao, B., Monteoliva-Sánchez, M., Ramos-Cormenzana, A. & Russell, N.J. 2009. Bioremediation and biovalorisation of olive-mill wastes. *Applied Microbiology and Biotechnology* **82**, 25–39. doi:10.1007/s00253-008-1801-y

Mousavi, S., Regni, L., Bocchini, M., Mariotti, R., Cultrera, N.G.M., Mancuso, S., Googlani, J., Chakerolhosseini, M.R., Guerrero, C., Albertini, E., Baldoni, L. & Proietti, P. 2019. Physiological, epigenetic and genetic regulation in some olive cultivars under salt stress. *Scientific Reports* **9**, 1093. doi: 10.1038/s41598-018-37496-5

Nasini, L., De Luca, G., Ricci, A., Ortolani, F., Caselli, A., Massaccesi, L., Regni, L., Gigliotti, G. & Proietti, P. 2016. Gas emissions during olive mill waste composting under static pile conditions. *International Biodeterioration & Biodegradation* **107**, 70–76 https://doi.org/10.1016/j.ibiod.2015.11.001

Nasini, L., Gigliotti, G., Balduccini, M.A., Federici, E., Cenci, G. & Proietti, P. 2013. Effect of solid olive-mill waste amendment on soil fertility and olive (*Olea europaea* L.) tree activity. *Agriculture Ecosystem and Environment* **164**, 292–297.

Niaounakis, M. & Halvadakis, C.P. 2006. Olive Processing Waste Management Literature Review and Patent Survey, second ed. *Elsevier Ltd*., Kidlington, Oxford, pp. 65–73.

Papafotiou, M., Chronopoulos, J., Kargas, G., Voreakou, M., Leodaritis, N., Lagogiani, O. & Gazi, S. 2001. Cotton gin trash compost and rice hulls as growing medium components for ornamentals. *The Journal of Horticultural Science and Biotechnol*ogy **76**(4), 431–435.

Papafotiou, M., Phsyhalou, M., Kargas, G., Chatzipavlidis, I. & Chronopoulos, J. 2004. Olive-mill wastes compost as growing medium component for the production of poinsettia. *Scientia Horticulturae* **102**(2), 167–175. https://doi.org/10.1016/j.scienta.2003.11.016

Papafotiou, M., Kargas, G. & Lytra, I. 2005. Olive-mill waste compost as a growth medium component for foliage potted plants. *Horticultural Science* **40**, 1746–1750.

Peri, C. & Proietti, P. 2014. Olive mill waste and by-products. In: The Extra-Virgin Olive Oil Handbook; Peri, C. Ed.; John Wiley & Sons: Oxford, UK, pp. 283–302.

Pinamonti, F. & Centemero, M. 1997. Compost nella preparazione di terricci e substrati colturali. L'Informatore Agrario **44**, pp. 51–55.

Proietti, P., Federici, E., Fidati, L., Scargetta, S., Massaccesi, L., Nasini, L., Regni, L., Ricci, A., Cenci, G. & Gigliotti, G. 2015. Effects of amendment with oil mill waste and its derived-compost on soil chemical and microbiological characteristics and olive (*Olea europaea* L.) productivity. *Agriculture Ecosystem and Environment* **207**, 51–60.

Proietti, P., Palliotti, A., Tombesi, A. & Cenci, G. 1995. Chemical and microbiological modifications of two different cultivated soils induced by olive oil waste water administration. *Agricultura mediterranea* **125**, 160–171.

Regni, L., Del Pino, A.M., Mousavi, S., Palmerini, C.A., Baldoni, L., Mariotti, R., Mairech, H., Gardi, T., D'Amato, R. & Proietti, P. 2019. Behavior of Four Olive Cultivars During Salt Stress. *Frontiers in Plant Science* **10**, 867. doi:10.3389/fpls.2019.00867

Regni, L., Gigliotti, G., Nasini, L. & Proietti, P. 2016. Reuse of olive mill waste as soil amendment. In: Olive Mill Waste: Recent Advances for Sustainable Management; C. M. Galanakis Ed.; Elsevier-Academic Press: Oxford, UK, pp. 97–117.

Regni, L., Nasini L., Ilarioni L., Brunori A., Massaccesi L., Agnelli, A. & Proietti, P. 2017. Long Term Amendment with Fresh and Composted Solid Olive Mill Waste on Olive Grove Affects Carbon Sequestration by Prunings, Fruits, and Soil. *Frontiers in Plant Science* **7**, 2042.

Rodrìguez-Lucena, P., Hernandez, D., Hernandez-Apaolaza, L. & Lucena, J.J. 2010. Revalorization of a two-phase olive mill waste extract into a micronutrient fertilizer. *Journal of Agricultural and Food Chemistry* **58**, 1085–1092.

Roig, A., Cayuela, M.L. & Sanchez-Monedero, M.A. 2006. An overview on olive mill wastes and their valorization methods. *Waste Management* **26**(9), 960–969.

Said-Pullicino, D., Erriquens, F.G. &Gigliotti, G. 2007. Changes in the chemical characteristics of water extractable organic matter during composting and their influence on compost stability and maturity. *Bioresource Technology* **98**, 1822–1831.

Tortosa, G., Alburquerque, J.A., Ait-Baddi, G. & Cegarra, J. 2012. The production of commercial organic amendments and fertilisers by composting of two-phase olive mill waste (“alperujo”). *Journal of Cleaner Production* **26**, 48–55.