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Composting olive mill pomace and other residues from rural southeastern Spain

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Abstract

The costly disposal of the semisolid residual pomace generated in the two phase extraction used in modern olive mills is causing serious problems to the small oil producers of rural southeastern Spain. Composting may be a viable alternative since complementary residues are usually available in these areas to prepare an adequate starting mixture. In this work, four different combinations of residues (pomace + rabbit manure, pomace + sheep manure, pomace + rabbit manure + rice straw, pomace + rabbit manure + almond shells) were composted in 3 ton piles aerated by turnings, using technology available to any small community of oil producers. During the four long processes (9–10 months), a steady decrease of organic matter and increases in the concentrations of nutrient and humic substances were observed, together with large increases in pH and salinity which may reduce the agronomic value of the final products.

1. Introduction

Production of olive oil has a very significant socio-economic impact in the rural areas of Mediterranean areas of Spain, most particularly in those lacking other possibilities of development such as tourism. Aiming for a reduction in water needs, the extraction process has undergone extensive changes from the traditional press mill to the modern two phase continuous extraction. Unfortunately, this substitution of methodology has led to an inconvenient change in the residues generated since the two phase extraction yields a semisolid pomace including both vegetal liquids and solid residues from the olives, contrary to the traditional techniques in which the solid and liquid residual fractions are separated and can be more easily managed. This pomace is rich in easily degradable organic matter, polyphenolics, unextracted oil and organic acids, and therefore cannot be safely land-applied on a regular basis. In areas where production concentrates, the residual oil is extracted and the residue incinerated in large power plants, but in areas with dispersed production, transportation costs make this option economically inviable.

Since costs of disposal are dramatically reducing profitability of small producers, simpler and cheaper alternatives must be sought if the economic activity of these depressed areas is not to be jeopardized. Composting is a very promising option in these locations, given its low technical and economical requirements. The potentially harmful substances in the pomace are biologically degraded during the process, allowing the safe use of the elaborated compost in agricultural fields. Although physical and chemical properties of olive pomace are rather unsuitable for composting (very low porosity, high moisture and low contents of N and P), many complementary residues are usually generated in these areas, such as animal manures (source of N and P), olive leaves, cereal straw, almond shells or pruning wastes (bulking agents). Composting could therefore be an attractive alternative that would recycle large amounts of a wide range of the residues produced in these communities, resulting in an organic amendment suitable to be applied in their own fields, saving fertilization expenses, and improving their typically poor and erosion endangered soils.

Given the relative novelty of the extraction methodology, and probably because composting may not be the best

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management alternative for the very large amounts of pomace generated in the areas where oil production concentrates, there are not many studies published on composting of two phase olive mill residue. Together with different pile dimensions and aeration methodologies, a wide range of complementary residues have been evaluated: wheat (*Triticum* spp.) straw (Madejón et al., 1998), poplar (*Populus alba*) sawdust and bark chips (Filippi et al., 2002), cotton (*Gossypium* spp.) waste and maize (*Zea mays*) straw (Paredes et al., 2002), poultry manure (Hachicha et al., 2003), sheep litter (Cayuela et al., 2004), and cotton waste, grape (*Vitis vinifera*) marc, olive leaves and fresh cow manure (Cegarra et al., 2004). The pomace concentration in the initial mixture ranged from 40% (Cayuela et al., 2004) to 94.6% (Cegarra et al., 2004). Although the different experimental designs make the results of these investigations hardly comparable, all of them concur that compostability of olive mill pomace is achievable if adequate conditions and complementary residues are provided.

The main objectives of this investigation were to evaluate composting as a recycling solution for the wide range of organic residues typically generated in the areas of small olive oil production in Mediterranean areas of Spain, to study the conditions leading to a fast and efficient process using simple and affordable equipment and methodologies, and to characterize the final product with regard to use in their own agricultural soils.

Table 1
Analytical characteristics of the residues used in the experiment

	Olive mill residue	Rabbit manure	Sheep manure	Rice straw	Almond shells
Moisture (w/w)	56.0	61.0	63.0	20.0	0.0
pH (1:25)	6.15	8.83	8.08	7.87	5.50
EC (1:5, dS/m)	5.95	17.3	11.3	1.84	0.31
Cl^- (1:5, mg/l)	402	2940	1380	1200	26.0
Organic C (%)	59.5	45.3	28.8	49.2	55.8
Water-soluble C (%)	2.68	1.93	2.63	0.617	0.983
Volatile matter (%)	96.2	80.3	58.0	86.5	99.2
Organic N (%)	1.15	2.00	1.53	0.957	0.140
N-NH_4^+ (mg/kg)	101	345	307	107	<7
N-NO_3 (mg/kg)	123	32.8	32.0	<7	<7
C/N ratio	51.0	22.3	18.6	51.2	399
Na (%)	0.046	0.663	0.294	0.028	0.010
K_2O (%)	1.52	3.42	2.10	0.143	0.363
MgO (%)	0.081	1.40	0.863	0.129	0.033
CaO (%)	0.390	3.78	5.45	0.566	0.098
P_2O_5 (%)	0.197	2.28	1.54	2.48	0.069
Fe (mg/kg)	321	1906	106900	420	49.3
Mn (mg/kg)	3.38	90.7	3130	62.8	2.18
Cu (mg/kg)	13.1	73.0	32.2	3.6	3.65
Zn (mg/kg)	10.3	263	137	18.9	30.9
Cd (mg/kg)	<3	<3	<3	<3	<3
Ni (mg/kg)	8.95	6.12	37.5	8.59	0.870
Pb (mg/kg)	<5	<5	<5	<5	<5
Cr (mg/kg)	5.00	3.37	30.2	6.29	1.03

EC: electrical conductivity. All data, except moisture, pH, EC and Cl^-, expressed in dry weight basis.

Table 2
Initial composition and calculated characteristics of the composting mixtures

	Pile I	Pile II	Pile III	Pile IV
Olive mill residue (kg)	1740	1340	1570	1920
Rabbit manure (kg)	1260	1340	1130	–
Sheep manure (kg)	–	–	–	1080
Almond shells (kg)	–	–	300	–
Rice straw (kg)	–	330	–	–
Moisture (w/w)	58.1	54.3	58.1	58.5
Organic C (%)	53.9	52.1	54.0	49.6
Water-soluble C (%)	2.39	2.00	2.39	2.67
Volatile matter (%)	90.0	88.3	90.0	83.9
Organic N (%)	1.48	1.44	1.48	1.27
N-NH_4^+ (mg/kg)	196	194	196	167
N-NO_3 (mg/kg)	88	66	88	94
C/N ratio	36.4	36.3	36.4	39.0
Na (%)	0.287	0.277	0.286	0.126
K_2O (%)	2.26	1.98	2.26	1.71
MgO (%)	0.597	0.591	0.595	0.332
CaO (%)	1.72	1.71	1.71	2.02
P_2O_5 (%)	1.01	1.43	1.01	0.63
Fe (mg/kg)	941	942	938	34500
Mn (mg/kg)	37.5	47.9	37.4	1010
Cu (mg/kg)	37	34	36	19
Zn (mg/kg)	109	108	109	51
Cd (mg/kg)	<3	<3	<3	<3
Ni (mg/kg)	7.8	7.8	7.8	18.1
Pb (mg/kg)	<5	<5	<5	<5
Cr (mg/kg)	4.4	4.6	4.4	13.1

EC: electrical conductivity. Almond shells were not included in the calculations for pile III, since they act as bulking agent and do not decompose during composting. Weight of organic residues is expressed in wet basis; analytical data is expressed in dry weight basis, except moisture, pH, EC and Cl^-.

2. Materials and methods

2.1. Experimental design

In a plot within the experimental farm of the Instituto Valenciano de Investigaciones Agrarias (IVIA), four composting experiments were initiated using olive mill pomace as main residue and other local residues (sheep and rabbit manures, rice (*Oryza sativa*) straw and almond (*Prunus amygdalus)* shells) as sources of N and P or bulking agents. The analytical characteristics of the residues used in the experiments are shown in Table 1. Table 2 shows the mixing ratios in the piles and the analytical properties of the mixtures, calculated taking into account those from the individual residues and the mixing ratios according to the formula

$$C_m = \sum \frac{C_i \cdot W_i}{W_m}$$

where C_m = total concentration in the mixture, C_i = concentration in the residue, W_i = dry weight of the residue, W_m = total dry weight of the residue.

The composting experiments were conducted within twin-bay enclosures built with concrete blocks on soil pro-

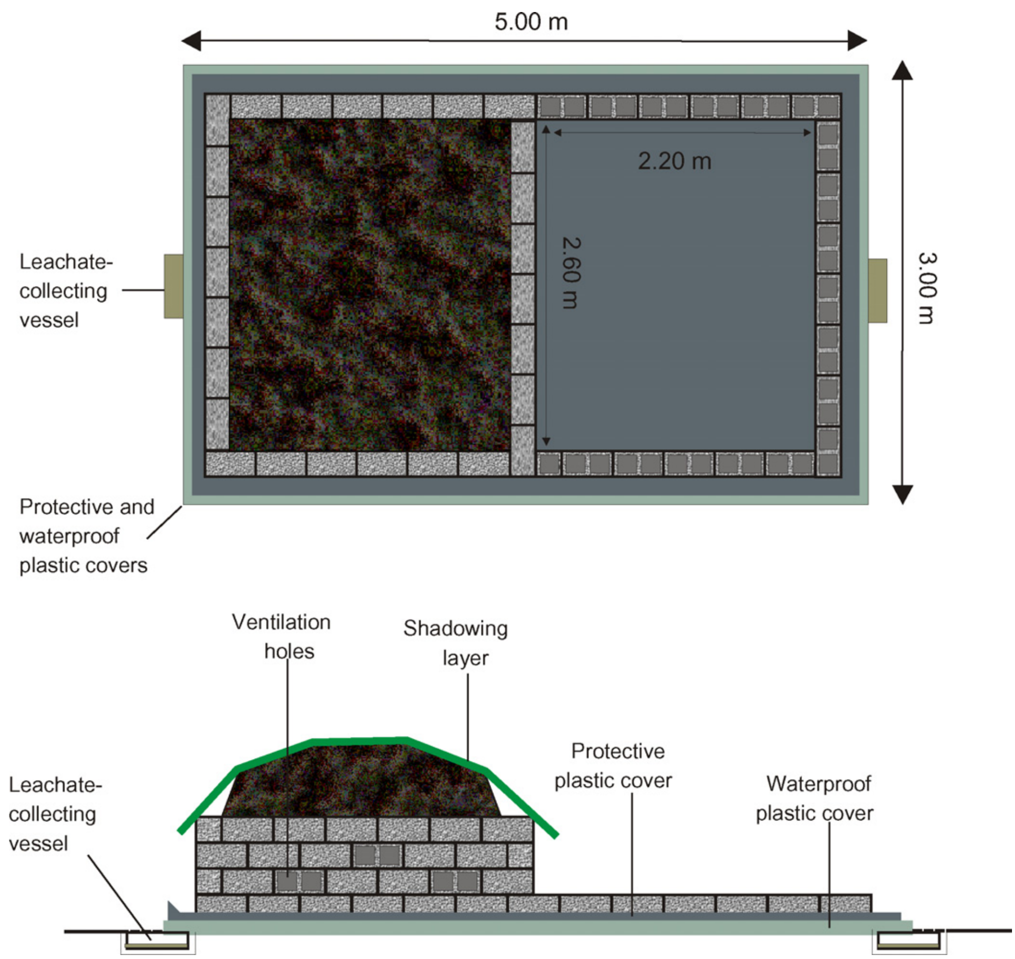

Fig. 1. Aerial and lateral view of the operational design of the composting experiments.

tected and waterproofed with a double plastic layer (Fig. 1). Since blocks were uncemented, the enclosure dimensions could be progressively reduced to compensate for the size reduction of the composting piles as degradation advanced, always keeping a height between 1.2 and 1.5 m. Temperatures were measured daily at ten locations in each pile using an electronic thermometer introduced 1 m at different angles. Cooling and aeration were provided by turning the piles into the empty bays of their respective enclosures with a power shovel. The moisture level of the piles was analyzed weekly and maintained over 40% by manual irrigation.

Meteorological data (temperature and rainfall) during the four composting are displayed in Fig. 2. All the processes started on 30th January.

2.2. Sampling and analytical methods

During each turning, ten subsamples of composting material were taken at random points of each pile and carefully mixed to form a composite sample. All samples thus collected were oven-dried (60 °C), ground and passed through a 0.25 mm mesh. The official methods of the Spanish Ministry of Agriculture (MAPA, 1986) were used for all determinations: moisture (drying at 105 °C to constant weight), pH (1:25 water extract), electrical conductivity (1:5 water extract), Cl^- (1:5 water extract), organic C (oxidization with $K_2Cr_2O_7$), water soluble organic C (1:10 water extract), volatile matter (ashing at 560 °C), organic N (Kjeldahl), mineral N (2 N KCl extract), macronutrients, micronutrients and heavy metals (*aqua regia* digestion), humified substances (extraction with 0.1 N $Na_2P_2O_7 + NaOH$) and humic acids (precipitation of humified substances extract at pH 2). All determinations were made at least three times. Outliers were discarded using the Dixon's test at a 95% level of probability (Gibbons, 1994) and the analysis was repeated.

3. Results and discussion

The temperature changes during the four composting processes are presented in Fig. 3. Once the residues were completely mixed during the first turning, temperatures rose rapidly within the four piles. In piles I, III and IV these steep increases stalled after about ten days probably because of fast depletion of oxygen, but consistent values over 50 °C were reached after the second turning and remained so until the end of the processes between eight

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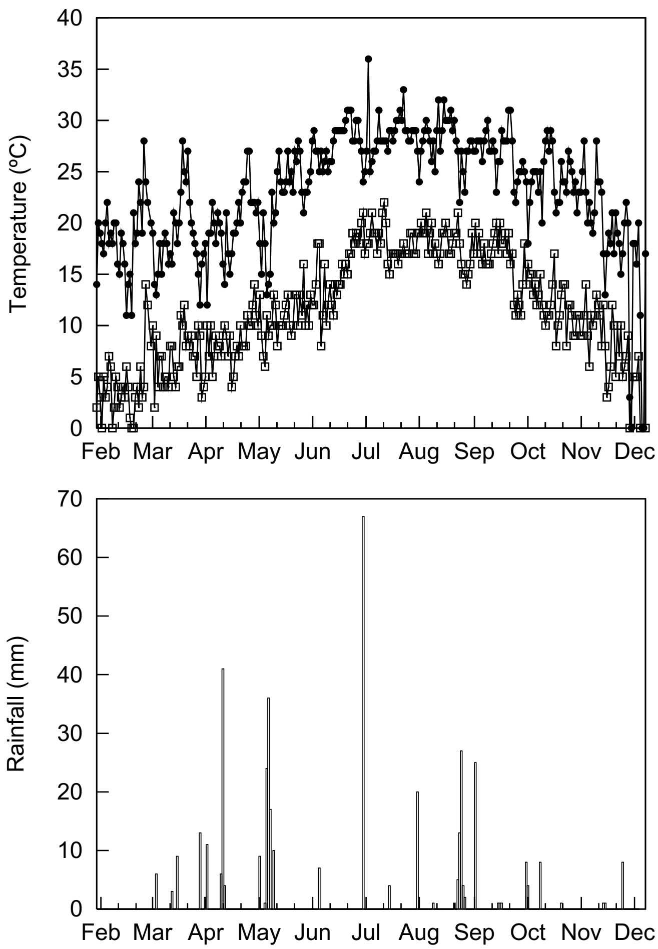

Fig. 2. Temperature (daily highest and lowest values) and rainfall during the composting experiments. The four processes started on 30th January.

to nine months later. The highest temperatures were achieved in pile III, suggesting improved aeration, but as the composting time was not clearly shortened and the final product had to be screened, the use of almond shells as bulking agent became hardly justifiable. Long composting times are typical for olive mill pomace given its high contents of easily degradable materials such as sugars, cellulose, and residual oil. The duration of the processes was close to that reported by Cayuela et al. (2004) in a similar study, but longer than that needed in other studies of composting of olive mill pomace, especially in that by Madejón et al. (1998) .

The wet weight yields of the four processes were 32.3%, 29.0%, 30.1%, and 24.5% for piles I, II, III, and IV, respectively. On a dry weight basis, the yields were 44.7%, 40.6%, 46.0%, 37.6% for piles I, II, III, and IV, respectively, indicating high losses of organic matter rather than of moisture. This was supported with decreases in total and water-soluble organic C during the four compostings (Fig. 4). The extent of changes in total organic C becomes more evident if it is taken into account that more than a third of olive mill pomace dry weight corresponds to crushed olive stones, which degrade slowly. The contents of water-soluble organic C, a usual measurement of easily-available organic matter, remained more or less constant during the first six months of the processes, indicating an equilibrium between the rates of depolymerization of the complex materials and of mineralization of the resultant fractions. The steep drop in this parameter and the consistently low values measured during the last three months indicate the depletion of the most easily degradable organic matter and therefore the end of active composting. Similar trends were observed by Canet and Pomares (1995) and Canet et al. (2005).

The evolution of humified substances and humic acids (Fig. 5) indicates a very active degradation during the first half of the processes, particularly in pile III, followed by a large increase during the second half which indicates the predominance of polymerization over degradation, typical of final stages of composting (Epstein, 1997). The extent of these changes and especially the final values were clearly smaller in pile IV, where sheep manure was used.

N concentrated in all piles as a consequence of organic C mineralization to CO_2, although the increase was lower in pile IV (Fig. 6). This indicates that N losses by volatilization were kept at adequate levels in all cases but the latter (22.4%, 21.4%, 26.3%, and 55.4% of total N was lost in piles I, II, III, and IV, respectively). Given this concentration of N, C/N ratios decreased from 30 (initial target when the mixtures were designed) to values ranging from 14.0 to 17.2, more apropriate for agricultural use, and similar to that obtained by Cayuela et al. (2004). Amounts of mineral forms of N (ammonium or nitrate) were very low and random during the successive samplings, never exceeding 200 mg of N/kg dry sample.

Large increases of pH were observed in all cases, the largest being that in pile IV, close to 3 pH units (Fig. 7). These increments are probably related to the release of ammonia and alkaline cations during organic matter degradation, particularly in pile IV. The final pH values were only slightly higher than those reported by Cayuela et al. (2004), Roig et al. (2004) but clearly higher than those reported by Madejón et al. (1998), Cegarra et al. (2000), Paredes et al. (2000), Filippi et al. (2002), Hachicha et al. (2003). In all piles containing rabbit manure, salinity was increased in the last third of the compostings, probably because of the reduced irrigation corresponding to that stage. The increment was lower in pile III, nevertheless, given that the almond shells used as bulking agent favoured leaching. However, no remarkable change in salinity was observed in pile IV, where sheep manure was used.

The contents of organic matter and nutrients in all products were very high (Table 3), whereas the levels of heavy metals were very low, enough to fulfill the requirements needed to be awarded with the European eco-label (European Commission, 2001), with the only exception of compost from pile II which exceeded by 6 mg/kg the maximum level allowed for Cu content. Nevertheless, the high pH of the composts could be problematic for their agricultural use, given the typical high alkalinity of Medi-

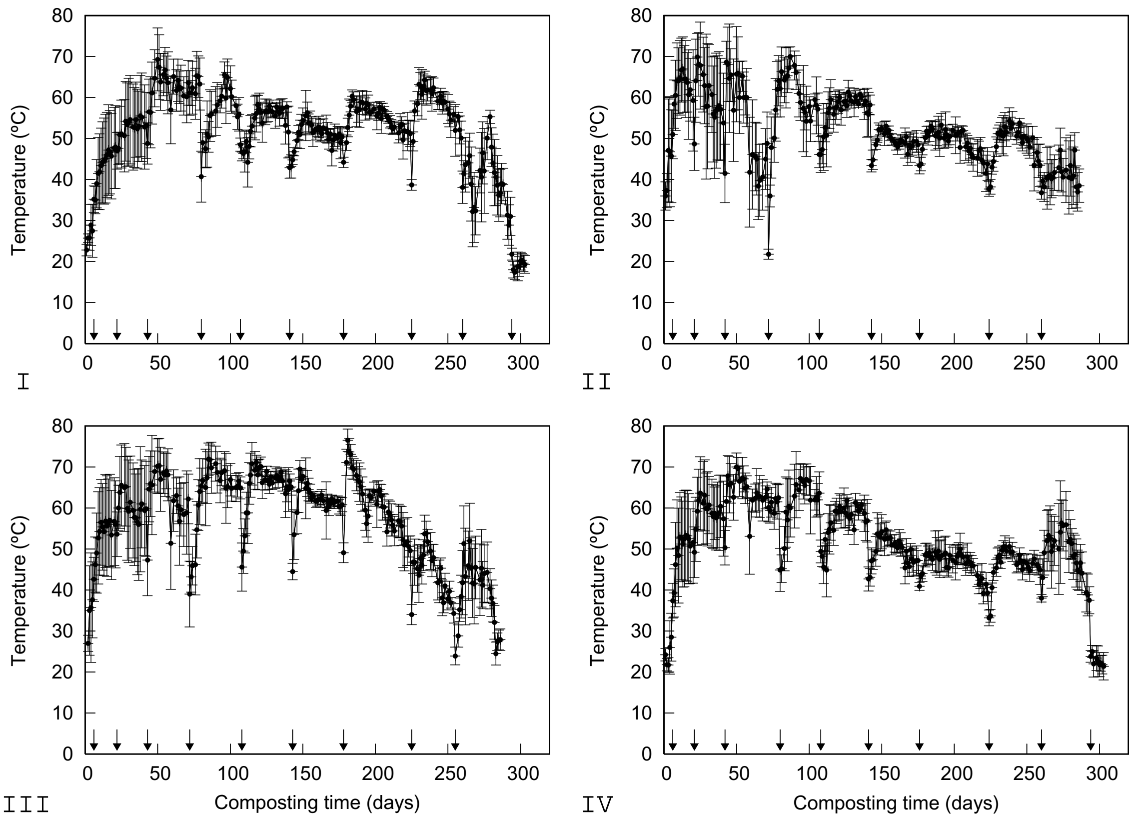

Fig. 3. Evolution of temperatures (mean and standard deviation) during the four compostings. Piles are indicated by roman numbers from I to IV. Small arrows indicate turnings.

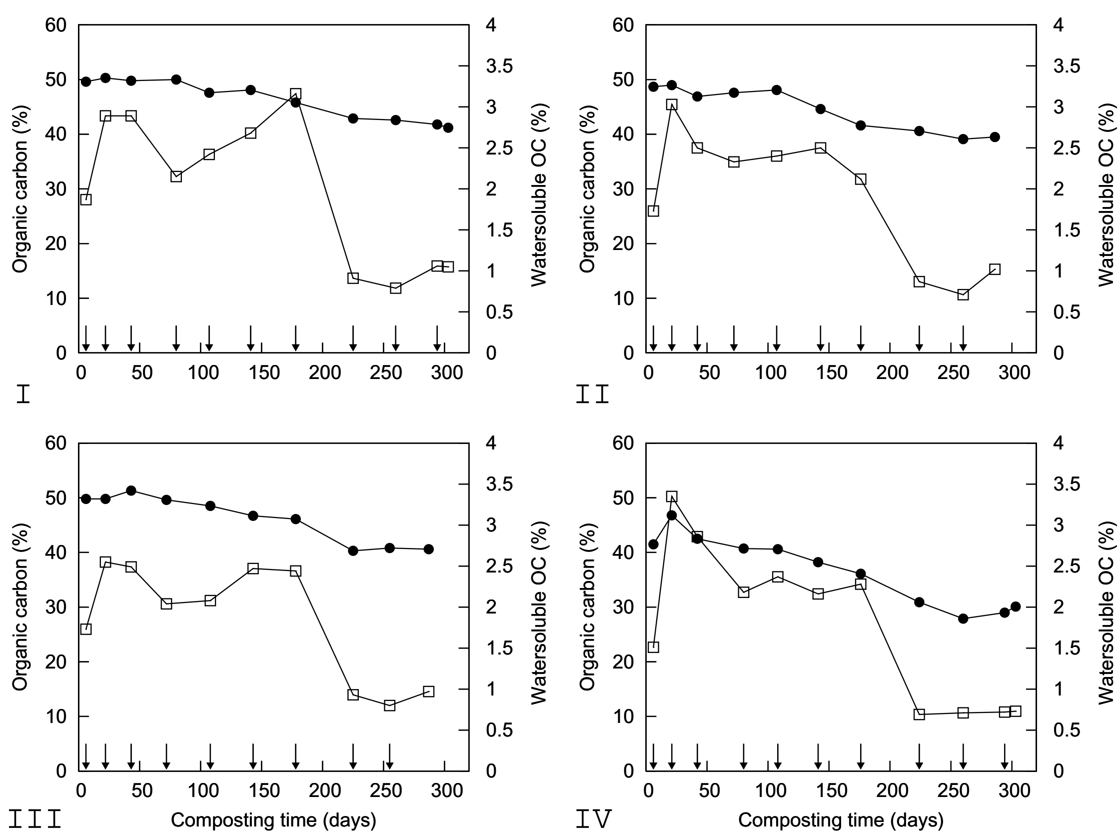

Fig. 4. Evolution of contents of organic carbon (black circles) and water-soluble organic carbon (white squares) during the four compostings. Piles are indicated by roman numbers from I to IV. Small arrows indicate turnings. Data expressed in dry weight basis.

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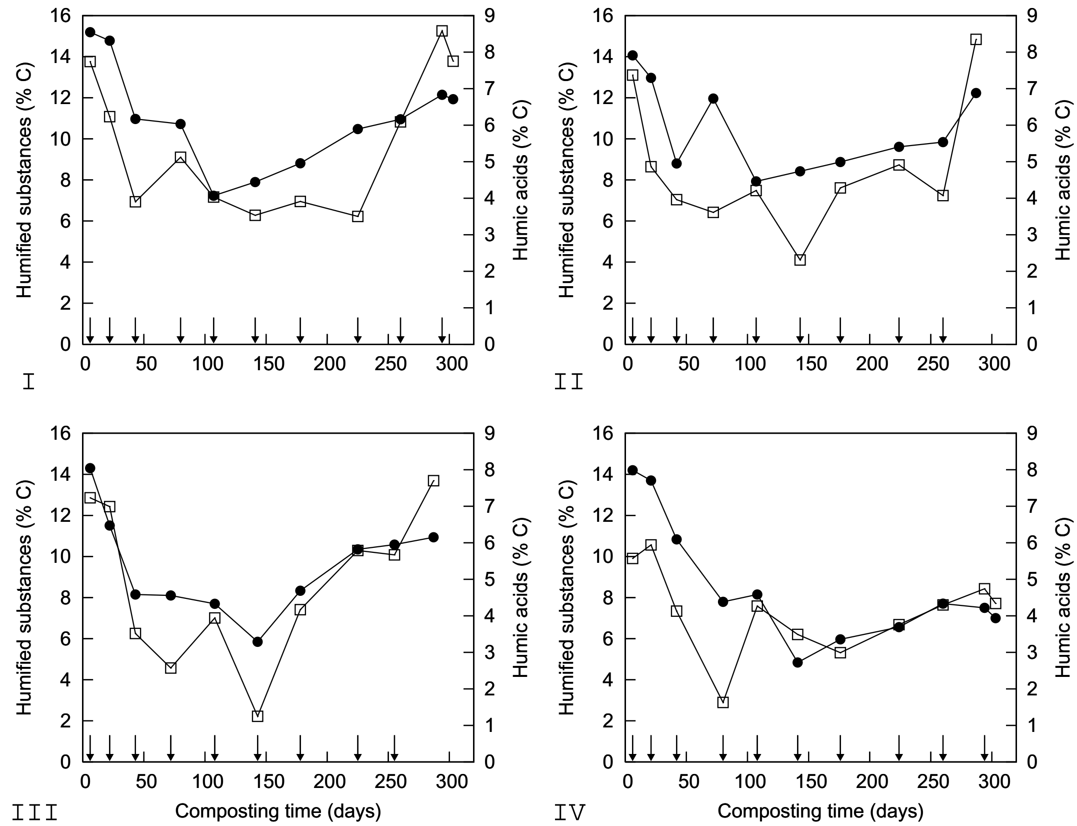

Fig. 5. Evolution of contents of humified substances (black circles) and humic acids (white squares) during the four compostings. Piles are indicated by roman numbers from I to IV. Small arrows indicate turnings. Data expressed in dry weight basis.

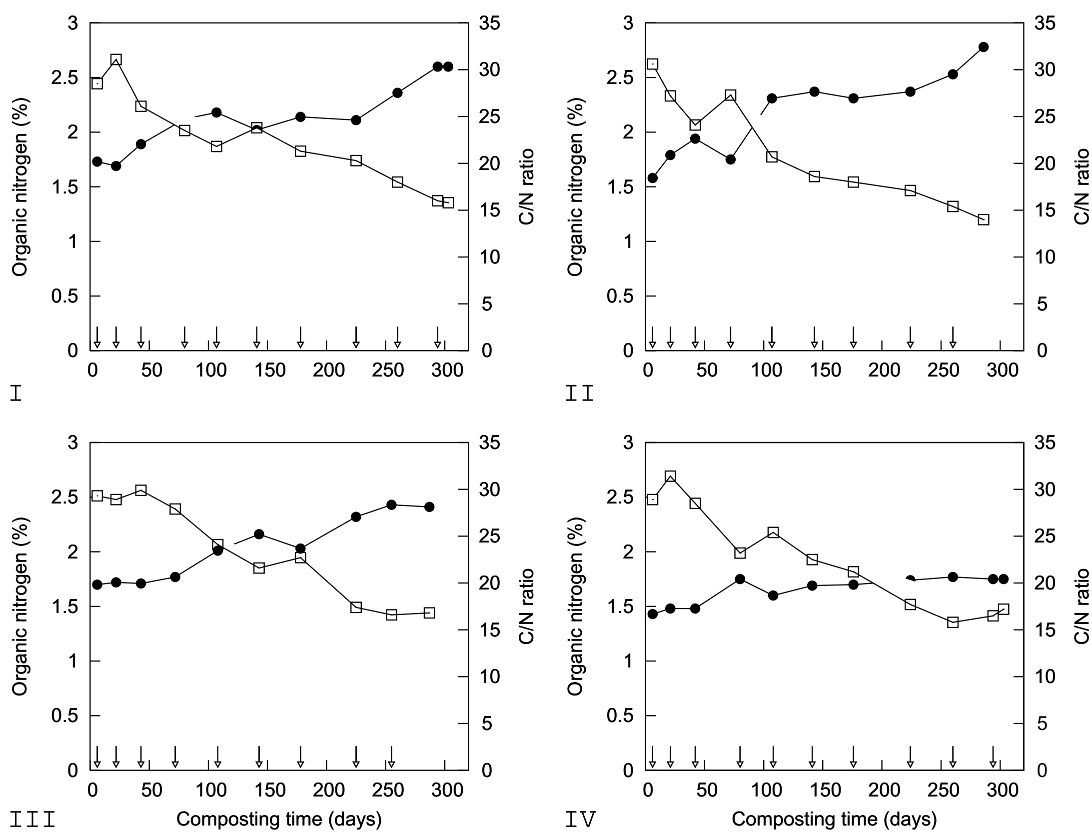

Fig. 6. Evolution of organic nitrogen content (black circles) and C/N (white squares) during the four compostings. Piles are indicated by roman numbers from I to IV. Small arrows indicate turnings. Data expressed in dry weight basis.

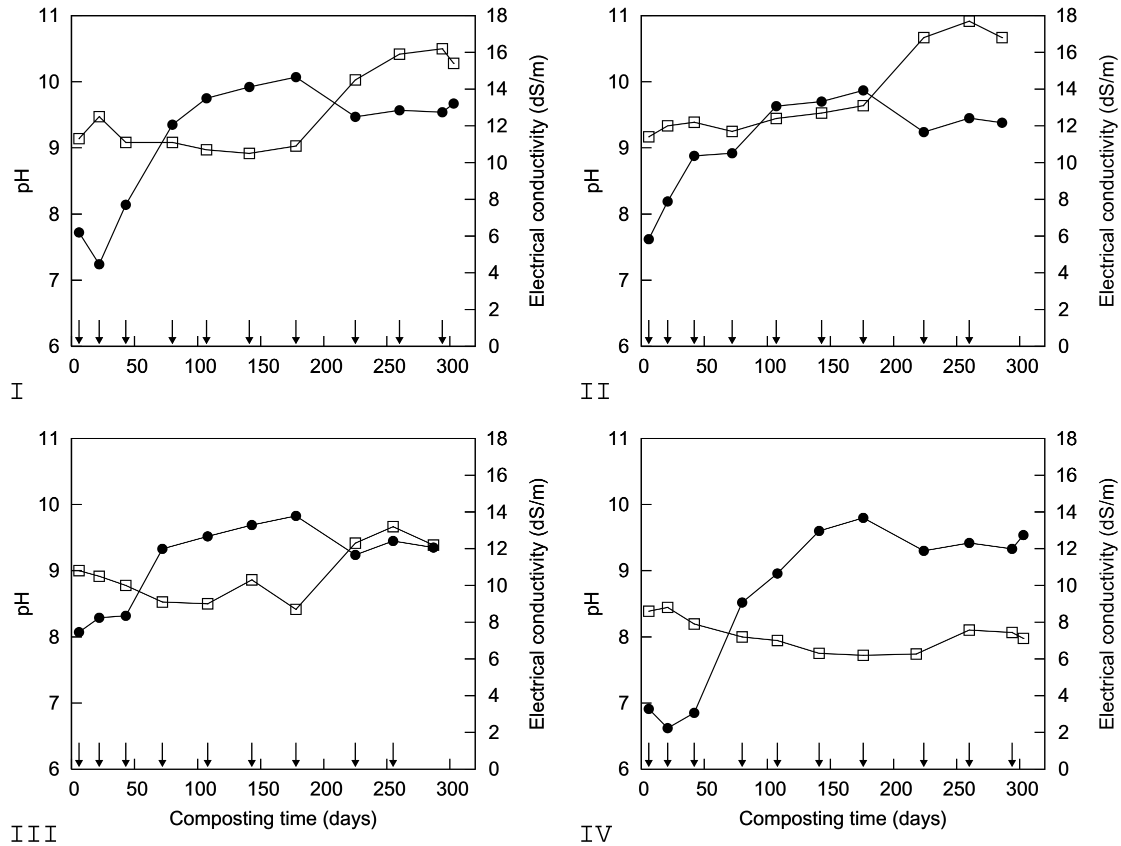

Fig. 7. Evolution of pH (black circles) and electrical conductivity (white squares) during the four compostings. Piles are indicated by roman numbers from I to IV. Small arrows indicate turnings.

Table 3
Final composition of the composted mixtures

	Pile I	Pile II	Pile III	Pile IV
Moisture (w/w)	42.0	54.2	36.0	36.4
pH (1:25)	9.67	9.38	9.35	9.54
EC (1:5, dS/m)	15.4	16.8	12.2	7.12
Cl^- (1:5, mg/l)	2500	3070	1775	940
Organic C (%)	41.2	39.5	40.6	30.1
Water-soluble C (%)	1.05	1.02	0.969	0.731
Volatile matter (%)	77.6	71.2	78.4	57.3
Organic N (%)	2.6	2.78	2.41	1.75
N-NH_4^+ (mg/kg)	24.9	18.4	24.5	12.6
N-NO_3 (mg/kg)	185	447	29.2	27.0
C/N ratio	15.8	14.0	16.8	17.2
Na (%)	0.526	0.595	0.419	0.168
K_2O (%)	4.54	4.76	3.66	2.48
MgO (%)	1.40	1.63	1.32	0.732
CaO (%)	2.92	3.26	3.07	3.26
P_2O_5 (%)	2.04	2.36	2.03	1.22
Fe (mg/kg)	2640	3174	3450	87560
Mn (mg/kg)	230	271	236	5200
Cu (mg/kg)	93	106	83	45
Zn (mg/kg)	196	252	181	80
Cd (mg/kg)	<1	<1	<1	<1
Ni (mg/kg)	15.9	17.9	13.7	45
Pb (mg/kg)	4.21	3.80	<1	<1
Cr (mg/kg)	11.5	12.2	10.1	22.2

EC: electrical conductivity. All data, except moisture, pH, EC and Cl^-, expressed in dry weight basis.

terranean soils. Since the usual procedures to reduce pH of organic products may also increase the rather high salinity of the composts (Roig et al., 2004), it may be advisable to reduce the proportion of manure in the initial mixtures, or to take advantage of the high nutritive content of the composts to reduce the application rate accordingly.

4. Conclusions

The results of this investigation demonstrate the feasibility of composting olive mill pomace and other organic residues from rural Mediterranean areas using simple and affordable techniques and long composting times. Elevated pH and salinity of the final products are the main disadvantages. Nevertheless, even though the process could theoretically be accelerated by improving the aeration, keeping down labour and operational expenses is preferable, since olive mill pomace is generated during November to March and the rest of the year is available for composting. Compost alkalinity could be decreased by adding cheap additives as ammonium sulphate or elemental sulphur as an organic alternative (Roig et al., 2004), or changing the composition of the initial mixtures. However, the low nutritional requirements of olive trees allow for small application rates, largely reducing the significance of the problem. However, the high contents of nutrients and organic matter of the composts, together with the possibility of getting the European eco-label given their very low levels of heavy metals, could make commercialization interesting. In this case it would make economic sense to optimize the process in search of shorter composting times and more adequate control of pH and salinity in the final products.

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