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Effects of olive mill wastewater addition in composting of agroindustrial and urban wastes

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Abstract

In order to study the suitability of olive mill wastewater (OMW) for composting, this liquid waste was added to two different mixtures of agroindustrial and urban wastes and the composting process was compared with two other piles of similar composition, but without OMW. These four piles were studied in a pilot plant using the Rutgers static pile system. The addition of OMW produced a greater proportion of degradable organic matter or a higher degradation rate, higher electrical conductivity values, greater losses of total N and lower nitrification than in piles without OMW. Its addition also restricted the increase of the cation exchange capacity and provoked the appearance of phytotoxicity or a longer persistence of phytotoxicity. However, in general, all the composts showed increases in the cation exchange capacity, the percentage of humic acid-like carbon, the polymerisation ratio of these humic substances (which revealed that the organic matter had been humified during composting) and the germination index, the latter indicating the reduction of phytotoxicity during the process.

Introduction

Olive mill wastewater (OMW) is the main waste produced by the olive oil industry via the three phase extraction system and contains olive pulp, mucilage, pectin, oil, the tissue water of the fruit and the water used in different steps of the industrial process. This liquid waste is produced in great amounts in Mediterranean countries, where its treatment and disposal are becoming a serious environmental problem, mainly due to its very high organic COD load. This waste has also a high potassium concentration and notable levels of nitrogen, phosphorus, calcium, magnesium and iron (Paredes et al. 1999), all of which are important factors in soil fertility. OMW also has a low pH and high C/N ratio and is resistant to degradation, mainly due to its high content of phenolic compounds, which are antimicrobial (Ramos-Cormenzana et al. 1995).

Several methods have been proposed for OMW disposal, based on evaporation ponds, thermal concentration and different physico-chemical and biological treatments, as well as its direct application to agricultural soils as an organic fertiliser (Martínez Nieto & Garrido Hoyos 1994). However, most methods are generally very expensive and unable to completely solve the problem because of the need to dispose of sludge or other by-products deriving from the process. Also, phytotoxic effects and negative effects on soil properties have been observed when this waste is used directly as an organic fertiliser (Tomati & Galli 1992).

Composting is a widely used treatment for organic waste, which is very well developed for city refuse and this compost has been widely used in recent years. During the process the simple organic carbon compounds are easily decomposed by microorganisms, which also mineralise proteins, amino acids and peptides to produce ammonia. The humification process takes place during stabilisation of organic matter and is a consequence of the combination of biological, microbiological and chemical processes. During such processes humic-like substances are formed from polymerisation of aromatic substances synthesised by microorganisms during decomposition, and/or via the condensation of simple molecules resulting from the degradation of organic matter. Also, humic-like substances may already exist in the composting substrates (De Nobili et al. 1995). One of the most frequently used composting systems is the Rutgers static pile system, which maintains a temperature ceiling in the pile, providing a high decomposition rate through the on-demand removal of heat by ventilation, since high temperatures inhibit and slow down decomposition due to the reduction of microbial activity. This system, compared with the turning approach currently in widespread use, decomposes a higher amount of waste in less time and the final product is drier and contains a more stabilised organic matter (Finstein et al. 1985).

The composting of OMW to obtain organic fertilisers represents an economically and ecologically acceptable way to dispose of it. Composting experiments with OMW have been performed by Tomati et al. (1995) and Galli et al. (1997), who observed that during composting of OMW with wheat straw the phytotoxicity was eliminated and there was a high organic matter degradation, a great evaporation of OMW water and an increase of microbial growth and biological activities during the thermophilic phase. The final product had significant amounts of macronutrients, an absence of heavy metals and a high level of organic matter humification. Also, Paredes et al. (1996b) studied the mineralisation and humification of the organic matter, the N-losses and the biological N fixation during composting of OMW sludge with maize straw or cotton waste and found that composts with a high level of humification of the organic matter and without phytotoxic effects could be obtained. However, not enough data are currently available on OMW composting to evaluate the requirements of process for obtaining an adequate product stabilisation. Therefore, the aim of the present work is to study the effects of the OMW addition on the composting of agroindustrial and urban wastes.

Material and methods

Composting procedure

Four different piles were prepared with mixtures of sewage sludge (SS), an industrial waste from orange juice extraction (OIW) and a waste from cotton gin (CW). Two of them were watered with two freshly collected OMW (piles 1 and 3) and the other two only with water (piles 2 and 4). The analyses of the starting materials are shown in Table 1. SS came from a treatment plant of municipal wastewater and its content of potentially toxic heavy metals was below the limits set by the EU for use in agricultural soils (Council of the European Communities 1986) (data not shown). OIW contained pulp, seeds and peel of this fruit. CW had similar hemicellulose and lignin contents (approximately 25% of each) and a high cellulose content (40.4%). The mixtures were prepared in the following proportions, on a fresh weight basis (dry weight basis in brackets):

Pile 1: 33% SS + 67% CW + 0.9 l OMW_1 kg^{-1} (9:88:3)
Pile 2: 39% SS + 61% CW (12:88)
Pile 3: 78% OIW + 22% CW + 2.1 l OMW_2 kg^{-1} (31:49:20)
Pile 4: 78% OIW + 22% CW (39:61)

The moisture of the piles was controlled weekly by adding the necessary amount of water to obtain a moisture content not less than 40%. Excess water leached from the piles was collected and added again to the piles. In pile 3, 1.1 l OMW_2 per kg was added on the first day, and the remaining volume, up to 2.1 l kg^{-1}, was added gradually up to 52 days of composting. In pile 1 the OMW was added only on the first day.

The mixtures (about 2000 kg each) were composted in a pilot plant, in trapezoidal piles (1.5 m high with a 2 × 3 m base). It was very difficult to prepare piles 1 and 2 with exactly the same proportions of all the components, taking into account that the pile 1 came from a mixture of three wastes. Also, the surface of the sewage sludge may be drier than the material below, which adds an extra-problem with respect to achieving the same composition for piles 1 and 2. However, the difference in the SS:CW ratio between the two piles cannot be considered high enough to be relevant for the composting process. The Rutgers static pile composting system was used, the air being blown from the base of the pile through holes in the walls of three PVC tubes of 3 m length and 12 cm diameter. The timer was set for 30 seconds ventilation every 15 minutes, and the ceiling temperature for continuous air blowing was 55 °C. The temperature increased quickly at the beginning of the process to thermophilic values, reaching the ceiling level (Figure 1a and b). When the temperature started to decrease, the piles were turned in order to improve both the homogeneity of the material and the fermentation process. The thermophilic phase lasted approximately 56, 33, 52 and 49 days for mixtures 1, 2, 3 and 4, re-

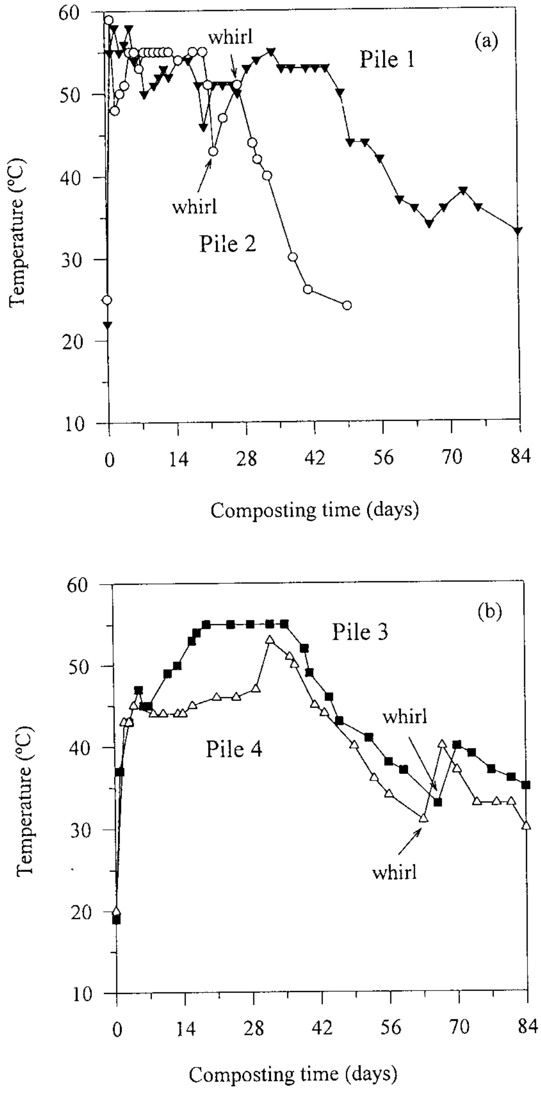

Figure 1. Temperature development during composting of piles 1[sewage sludge (SS) + cotton waste (CW) + olive mill wastewater (OMW)], 2 (SS + CW) (a) 3 [orange industrial waste (OIW) + CW + OMW] and 4 (OIW + CW) (b).

spectively. The bio-oxidative phase of composting was considered finished when the temperature of the piles was stable and close to that of the atmosphere. This occurred after 49 days in pile 2 and after 84 days for the rest of the piles. The air-blowing was then stopped to allow the composts to mature over a period of two months. The mixtures were sampled every two weeks during the bio-oxidative phase and after the maturation period. The samples were taken by mixing six subsamples from six sites of the pile and from the whole profile (from the top to bottom of the pile). Each sample was divided into two parts, one of which was immediately frozen and kept for NH_4^+–N and NO_3^-–N analysis, while the other was air-dried and ground to 0.5 mm for analysis.

Analytical methods

Electrical conductivity (EC) and pH were analysed in a 1:10 (w/v) water-soluble extract, the dry matter content was assessed by drying at 105 °C for 12 h and organic matter (OM) by determining the loss-on ignition at 430 °C for 24 h (Navarro et al. 1993). Total nitrogen (N_T) and organic carbon (C_{org}) were determined by automatic microanalysis (Navarro et al. 1991), as were the water soluble organic carbon (C_W), the 0.1 M NaOH-extractable organic carbon (C_{EX}) and fulvic acid-like carbon (C_{FA}), the latter after precipitation of the humic acid-like carbon (C_{HA}) at pH 2.0 (Sánchez-Monedero et al. 1996). The C_{HA} was calculated by subtracting the C_{FA} from the C_{EX}. Concentrations of lignin and cellulose were determined according to the American National Standards Institute and American Society for Testing and Materials (1977a and b) and holocellulose according to the Browning (1967) method. Hemicellulose content was calculated as the difference between holocellulose and cellulose concentrations. NH_4^+–N was extracted with 2 M KCl from the frozen subsample and determined by a colourimetric method based on Berthelot's reaction (Sommer et al. 1992), adding sodium citrate to complex divalent cations. NO_3^-–N was determined by ion chromatography in a 1:20 (w/v) water extract. Organic-N (N_{org}) was calculated as the difference between N_T and inorganic-N (sum of NH_4^+–N and NO_3^-–N, NO_2^-–N was not detected). After $HNO_3/HClO_4$ digestion, P was determined colourimetrically as molybdovanadate phosphoric acid and K by flame photometry. The cation exchange capacity (CEC) was determined with $BaCl_2$-triethanolamine (Lax et al. 1986). The germination index (GI) was calculated using seeds of *Lepidium sativum* L. (Zucconi et al. 1981). Losses of OM and N_T were calculated from the initial (X_1) and final (X_2) ash contents and the initial (N_1) and final (N_2) N_T concentrations, according to the equations of Viel et al. (1987) and Paredes et al. (1996a), respectively.

$$\text{OM-loss}\,(\%) = 100 - 100\,[X_1(100 - X_2)]/[X_2(100 - X_1)]$$

$$N_T\text{-loss}\,(\%) = 100 - 100\,[(X_1 N_2)/(X_2 N_1)]$$

Table 1. Analysis of the starting materials, two different olive mill wastewaters (OMW_1 and OMW_2), sewage sludge (SS), orange industrial waste (OIW) and cotton waste (CW) (dry weight basis)

	OMW_1 [1]	OMW_2 [1]	SS	OIW	CW
Dry matter (%)	1.9	4.0	19.3	16.3	91.5
pH	5.5	5.2	6.8	3.6	7.1
EC ($S\ m^{-1}$)	0.53	0.66	0.42	0.25	0.41
OM (%)	1.3	2.5	67.3	94.1	82.8
C_{org} ($g\ kg^{-1}$)	9.2	17.2	354.0	451.4	422.8
N_T ($g\ kg^{-1}$)	0.2	0.4	65.9	19.6	21.0
C/N	46.0	43.0	5.4	23.0	20.1
NH_4^+–N ($mg\ kg^{-1}$)	n.d.	n.d.	7980	709	530
P ($g\ kg^{-1}$)	0.1	0.1	38.7	1.5	1.8
K ($g\ kg^{-1}$)	1.2	4.1	9.5	18.7	17.4

[1] Data of OMW on fresh weight basis, w/v ($g\ l^{-1}$).

EC: Electrical conductivity, OM: Organic matter, C_{org}: Organic C, N_T: Total N, n.d.: Not determined.

Results and discussion

Evolution of organic matter

The initial OM concentrations were approximately equal in piles of similar composition (1 and 2, 3 and 4) (Table 2). The values decreased during the process from 80.7, 81.5, 85.1 and 84.1% to 56.4, 64.8, 64.4 and 66.8% in piles 1, 2, 3 and 4, respectively, showing the degradation process. This led to substantial total OM losses by the end of the process in all piles (69.1, 58.2, 68.2 and 61.9% for piles 1, 2, 3 and 4, respectively) (Figure 2a and b), OM degradation always being greater in the mixtures with OMW, which may be due to the longer period at maximum temperatures for the OMW piles (Figure 1a and b). This can be attributed to the higher content of easily degradable organic compounds provided by OMW. OM mineralisation was low during the maturation phase (0, 0.1, 3.1 and 8.8% for mixtures 1, 2, 3 and 4, respectively), which indicated the relative stability reached by the products after the bio-oxidative stage.

The degradation of organic matter during composting, as determined by OM loss, followed a first-order kinetic equation, which is the most widely observed in C mineralisation studies in soils:

$$\text{OM loss} = A(1 - e^{-kt})$$

where A is the maximum degradation of organic matter (%), k the rate constant ($days^{-1}$) and t the composting time (days).

Curve fitting of the experimental data gave the following parameter values (standard deviation in brackets):

Pile 1: $A = 68.4$ (1.6) $k = 0.0594$ (0.0056) RMS = 13.48 $F = 402.15^{**}$
Pile 2: $A = 59.8$ (2.1) $k = 0.0749$ (0.0092) RMS = 12.20 $F = 261.09^{**}$
Pile 3: $A = 66.5$ (2.2) $k = 0.0377$ (0.0037) RMS = 12.72 $F = 414.16^{**}$
Pile 4: $A = 67.0$ (14.0) $k = 0.0203$ (0.0042) RMS = 33.50 $F = 111.04^{**}$

where RMS is the residual mean square. In pile 4 A was calculated as $A = 100 - C$, for adjustment of the model to obtain a better fit, thus OM loss = $(100 - C)(1 - e^{-kt})$. All equations were significant at $P < 0.01$, although the results of piles 1, 2 and 3 fitted this equation better than the results obtained for pile 4, as shown by the lower F and higher RMS values for the latter. This equation was also used by Bernal et al. (1996) in a composting study of sweet sorghum bagasse, in which the A values were within the range found here.

The OMW addition in pile 1 did not show a clear effect on the OM degradation rate in comparison with pile 2 and only a higher proportion of degradable OM (A factor) was obtained. However, the OMW addition in pile 3 increased the rate of OM degradation in comparison with pile 4, as is demonstrated by the higher values of k and the product of $A \times k$.

OM decomposition brought about an initial increase in pH in all piles (Table 2), as a consequence of the degradation of acid type compounds, such as carboxylic and phenolic groups, and the mineralisation of proteins, amino acids and peptides to ammonia. After this, pH decreased, which, as shall be seen later, was associated with the beginning of the nitrification process. Pile 3 had the highest values of pH during composting. This may be due to the greater decomposition of organic nitrogen compounds, to produce NH_3, which can be protonated to form NH_4^+. However, Tomati et al. (1995) also found a high increase of

Table 2. Evolution of the main parameters during the composting process (dry weight basis)

Composting time (days)	OM (%)	pH	EC (S m^{-1})	C_{org} (g kg^{-1})	C/N	C_W (%)	C_W/N_{org}
Pile 1: sewage sludge + cotton waste + OMW							
0	80.7	7.1	0.44	405.5	21.1	2.35	1.35
14	73.5	7.6	0.49	351.0	14.0	2.86	1.20
28	66.2	7.6	0.57	329.7	11.4	2.47	0.92
42	61.5	7.8	0.60	334.6	11.0	1.88	0.67
56	58.5	8.0	0.66	320.8	10.4	1.62	0.54
70	58.6	7.6	0.70	314.5	10.2	1.46	0.51
84	56.3	7.6	0.73	300.9	10.1	1.40	0.50
mature	56.4	7.8	0.77	293.6	9.4	0.89	0.32
Pile 2: sewage sludge + cotton waste							
0	81.5	7.6	0.39	438.6	18.3	2.27	1.01
14	74.1	7.9	0.45	404.7	13.8	2.25	0.80
28	67.6	8.2	0.45	382.0	11.9	1.98	0.67
42	64.9	8.1	0.51	364.6	11.4	1.74	0.57
49	64.9	8.0	0.50	359.8	11.1	1.26	0.42
mature	64.8	7.3	0.67	355.5	9.8	1.12	0.37
Pile 3: orange industrial waste + cotton waste + OMW							
0	85.1	6.0	0.41	425.5	20.5	7.46	3.75
14	79.7	8.1	0.43	407.9	15.6	4.26	1.76
28	77.1	9.2	0.52	399.7	14.4	5.25	1.98
42	73.5	9.5	0.66	371.4	12.3	5.45	1.87
56	69.2	9.8	0.62	370.9	11.7	4.58	1.50
70	69.6	9.7	0.62	363.6	11.5	4.23	1.37
84	66.5	9.7	0.59	352.6	11.5	3.51	1.18
mature	64.4	9.7	0.64	345.3	10.7	3.31	1.05
Pile 4: orange industrial waste + cotton waste							
0	84.1	6.5	0.36	417.4	17.7	5.63	2.64
14	82.1	7.6	0.36	408.1	15.6	2.58	1.14
28	80.1	7.5	0.35	407.7	13.2	2.31	0.88
42	74.7	8.4	0.35	389.8	11.4	1.36	0.43
56	74.7	8.5	0.33	384.9	12.0	1.52	0.49
70	71.9	8.4	0.34	378.5	11.5	1.03	0.33
84	71.2	8.3	0.37	372.7	12.3	0.97	0.33
mature	66.8	7.8	0.47	331.0	9.7	0.86	0.29

C_W: Water soluble organic C, N_{org}: Organic N; for other abbreviations, see Table 1.

pH during composting of OMW, which they related to the alkaline hydrolysis of K and Na salts from this liquid waste. The EC also increased during composting because of the production of inorganic compounds, as a result of OM degradation, and the increased relative concentration of ions due to the loss of weight of the pile. The higher EC in the piles containing OMW was clear from the beginning of the process, and was probably due to the soluble salts provided from OMW (Table 1).

In addition to reduction of the C_{org} concentration in all piles, an other consequence of the organic matter degradation was that the C/N ratio fell sharply in all the mixtures during the first weeks of the process (Table 2). Then it was steady and after the two months of maturation reached values of between 9.4 and 10.7, which suggested that all the composts had an acceptable degree of maturation, according to the limit value of below 12 accepted for mature compost (Bernal et al. 1998).

The C_W fraction includes the easily degradable organic compounds, such as sugars, amino acids and peptides, and is the most microbiologically active phase. Therefore, the C_W concentration decreased mainly during the bio-oxidative phase (Table 2), although C_W continued to be mineralised during the maturation period. In pile 3, however, this parameter increased from day 14 to 42, which may be due to the

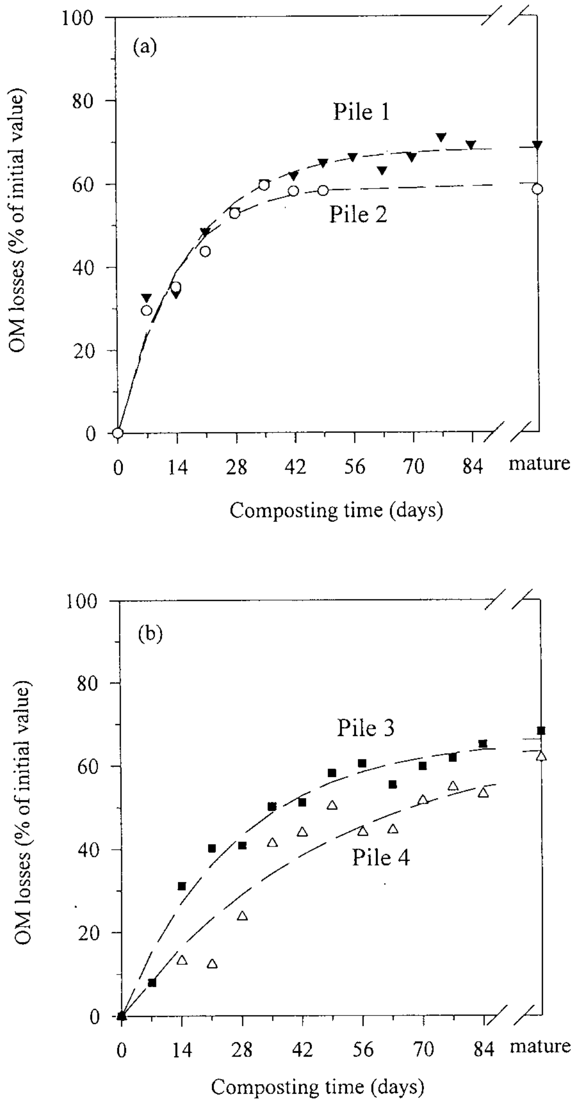

Figure 2. Organic matter (OM) losses during composting of piles 1, 2 (a), 3 and 4 (b); for abbreviations, see Figure 1. (Lines represent curve-fitting).

hydrolysis and solubilisation of complex substances predominating over the mineralisation of the soluble fraction (Saviozzi et al. 1987) and also to the accumulation of water soluble organic compounds from OMW, which was added up to day 52 in this mixture. The C_W level of the piles ranged from 0.86 to 3.31% after the maturation period, so that all composts, except compost 3, could be considered as sufficiently mature according to the threshold value of below 1.7%, suggested by Bernal et al. (1998) as representing a good degree of maturity. The C_W/N_{org} ratio also fell during the composting process to reach in all cases, except again in pile 3, values well below the established limits for mature composts, 0.7 (Hue & Liu 1995) and 0.55 (Bernal et al. 1998). The longer addition period of OMW in pile 3, and the greater water soluble fraction thus provided, could be responsible for the fact that this compost did not reach the limits established for mature composts with respect to the last two parameters. A longer maturation time in compost 3 may improve the values of these maturation indices.

Nitrogen dynamics

N_T and N_{org} concentrations increased during the process in all piles (Table 3), probably as a consequence of a concentration effect caused by the reduction in pile weight as has been observed in other composting experiments (Bernal et al. 1996; Paredes et al. 1996a). The concentration of NH_4^+–N increased at the beginning of the process through N_{org} mineralisation, but then diminished, either due to volatilisation losses or nitrate formation. However, only piles 1 and 2 reached a value below 400 NH_4^+–N mg kg^{-1} after the maturation period, which is the maximum recommended value for a mature compost (Zucconi & De Bertoldi 1987). The sharpest decreases in NH_4^+–N occurred after the thermophilic stage had been completed, when the formation of nitrates was permitted. In an experiment with sweet sorghum bagasse composts, Bernal et al. (1996) showed that temperatures above 40 °C and high NH_3 levels inhibit the activity and growth of nitrifiers. Although substantial quantities of nitrate were found in most of the mixtures by the end of the bio-oxidative phase, maximum values were only reached after maturation. Nitrification was clearly lower in piles with OMW (mixtures 1 and 3), which may be related to the higher EC values of these mixtures (Table 2), since it has been observed in soil that the nitrification process is very sensitive to salinity (McClung & Frankenberger 1985). Nitrification was retarded in pile 3 and the concentration of NO_3^-–N was lower than in the other mixtures, because most of the NH_4^+–N was lost through NH_3 volatilisation as a result of the high pH observed from day 14 onwards (Table 2). The NH_4^+/NO_3^- ratio fell during the composting process in all the piles (Table 3), after the maturation period values ranged from 0.08 to 3.37, so that all composts, except compost 3, could be considered sufficiently mature according to the maximum level of 0.16 suggested by Bernal et al. (1998). Therefore, according to the nitrification criterion, compost 3 had lower degree of maturity than the other composts, however the nitrification process could be completed after its application to soil.

N_T losses were substantial during the bio-oxidative stage (Figure 3a and b), but practically non-existent during the maturation stage. Losses of N were mainly due to NH_3-volatilisation (Bishop & Godfrey 1983), since N-losses by denitrification were probably very low because aerobic conditions prevailed in the composting mixtures. Also, leaching was controlled in all piles, so NO_3^--leaching was presumably negligible. The N_T losses by NH_3-volatilisation depend on pH, since the equilibrium between NH_4^+ and NH_3 tends towards NH_3 at high pH values, so initially the N_T losses were low in piles 1 and 4, which had the lowest pH values (Table 2). At the end of the process higher N_T losses occurred in mixtures prepared with OMW (piles 1 and 3) than in those without this waste (piles 2 and 4). The longer period at the maximum temperatures for the OMW piles (Figure 1a and b) may have favoured the NH_3-volatilization process, since longer ventilation periods were required. At the end of the process N_T losses in all the mixtures were below those frequently observed during composting (50% N; Witter & López-Real 1987).

Humification process

The humification ratio (HR), expressed as $(C_{EX}/C_{org}) \times 100$, and the humification index (HI), calculated as $(C_{HA}/C_{org}) \times 100$, in general did not show a clear tendency during the composting process (Table 4). This agrees with the findings of Iglesias-Jiménez & Pérez-García (1992) in a tudy of city refuse composts, who concluded that these parameters could not be considered as good indicators of the humification process.

The humification process was best revealed by the general increases in the percentage of humic acid-like carbon ($P_{HA} = (C_{HA}/C_{EX}) \times 100$), CEC and C_{HA}/C_{FA} and CEC/C_{org} ratios throughout the composting process. Values of CEC > 60 meq 100 g^{-1} (Harada & Inoko 1980) and $CEC/C_{org} > 1.9$ meq g^{-1} (Iglesias-Jiménez & Pérez-García 1992), which are accepted as indicating compost maturity, were exceeded at the beginning of the experiment in all the composts, and therefore they cannot be used here as maturity indicators. Also, the final values of P_{HA} and C_{HA}/C_{FA} ratio depended on the origin of the wastes used. Similar findings were observed by Bernal et al. (1996), in an experiment with composts of sweet sorghum bagasse, and by Bernal et al. (1998), in a study of maturity parameters for composts of different origin. Therefore, definite values of these parameters for mature composts cannot be stated. However, their evolution during composting is a good indicator of the OM humification process. It is interesting to point out that during the maturation period the CEC and CEC/C_{org} ratio increased hardly in piles prepared with OMW (mixtures 1 and 3).

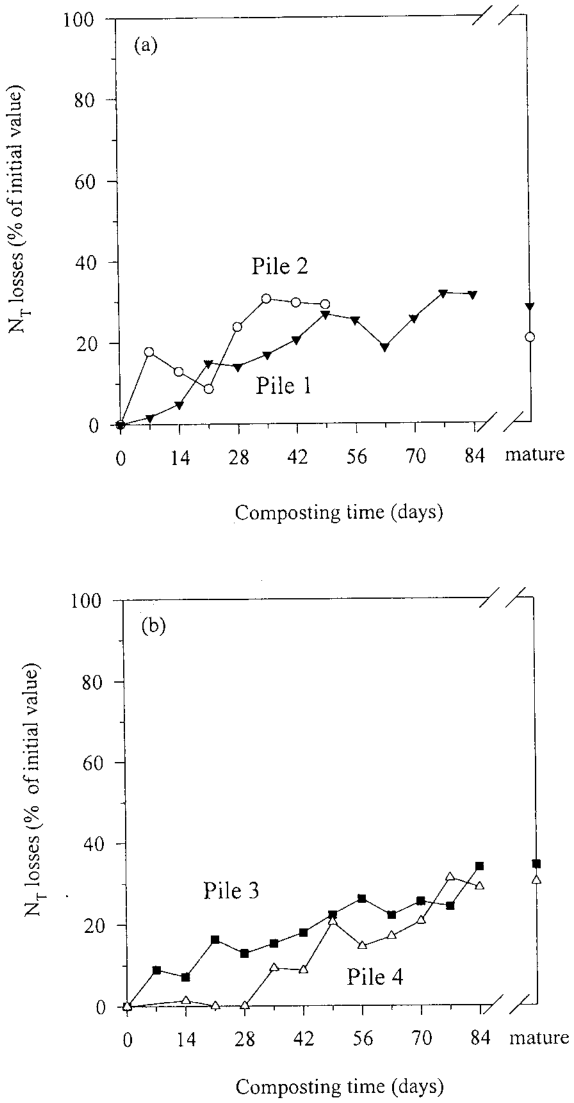

Figure 3. Nitrogen (N_T) losses during composting of piles 1, 2 (a), 3 and 4 (b); for abbreviations, see Figure 1.

The GI values increased in all the mixtures during composting, except in the case of pile 2, where it remained practically constant (Table 4). All composts reached GI values above 50%, which indicated that the

Table 3. Evolution of the nitrogen fractions during the composting process (dry weight basis)

Composting time (days)	N_T (g kg^{-1})	N_{org} (g kg^{-1})	NH_4^+–N (mg kg^{-1})	NO_3^-–N (mg kg^{-1})	NH_4^+/NO_3^+
Pile 1: sewage sludge + cotton waste + OMW					
0	19.2	17.8	1365	<0.4	n.d.
14	25.1	23.8	1270	<0.4	n.d.
28	29.0	26.9	2054	<0.4	n.d.
42	30.4	28.1	2130	173	12.31
56	31.0	30.2	468	370	1.26
70	30.7	28.5	503	1655	0.30
84	29.9	27.9	287	1690	0.17
mature	31.1	28.1	315	2739	0.12
Pile 2: sewage sludge + cotton waste					
0	24.0	22.6	1424	<0.4	n.d.
14	29.3	28.0	1263	<0.4	n.d.
28	32.1	29.5	2530	30	84.33
42	32.1	30.3	807	1000	0.81
49	32.4	30.0	1081	1290	0.84
mature	36.3	30.7	400	5200	0.08
Pile 3: orange industrial waste + cotton waste + OMW					
0	20.8	20.0	846	<0.4	n.d.
14	26.2	24.3	1901	<0.4	n.d.
28	27.8	26.6	1233	<0.4	n.d.
42	30.2	29.3	945	<0.4	n.d.
56	31.6	30.5	1051	<0.4	n.d.
70	31.5	30.8	722	<0.4	n.d.
84	30.7	29.7	928	69	13.45
mature	32.4	31.6	583	173	3.37
Pile 4: orange industrial waste + cotton waste					
0	23.6	21.3	2309	<0.4	n.d.
14	26.2	22.6	3572	<0.4	n.d.
28	30.9	26.2	4667	<0.4	n.d.
42	34.2	31.4	2626	209	12.56
56	32.0	30.9	968	113	8.57
70	32.9	31.6	1134	139	8.16
84	30.3	28.9	966	456	2.12
mature	34.3	29.6	603	4096	0.15

For abbreviations, see Tables 1 and 2.

application to soil of the products obtained would not injure plants (Zucconi et al. 1981). The high phenol and organic acid content of the OMW was probably responsible for the initial phytotoxicity of pile 1 with respect to pile 2, as pile 1 received OMW only on the first day of composting, and also for the phytotoxic effects persisting longer in pile 3 in comparison with pile 4, as OMW was added over 52 days in pile 3.

Conclusions

According to the results obtained, it can be concluded that composting can be considered as an alternative for the recycling of OMW, and that it can help to solve the environmental problem of this waste. The quality of the OMW composts obtained was, in general, similar to that of composts produced without this waste. All the composts had higher OM and N_{org} contents than the limits set by the Spanish legislation for compost (BOE, 1991). Also, all the composts lacked phytotoxicity but had a stabilised and humified OM, and, in general, satisfied he limits established for mature composts, with respect to the parameters studied. Compost 3 had a lower degree of maturity than the other composts, not achieving the limits for mature composts with respect to three parameters (C_W, C_W/N_{org} and NH_4^+/NO_3^-). However, this may not limit its use in

Table 4. Evolution of humification indices, cation exchange capacity (CEC) and germination index (GI) during composting process (dry weight basis)

Composting time (days)	HR (%)	HI (%)	P_{HA} (%)	C_{HA}/C_{FA}	CEC^1 (meq 100 g^{-1})	CEC/C_{org} (meq g^{-1})	GI (%)
Pile 1: sewage sludge + cotton waste + OMW							
0	14.27	6.98	48.93	0.96	94.2	1.88	38.6
14	17.99	7.85	43.65	0.78	n.d.	n.d.	n.d.
28	17.50	7.80	44.58	0.81	148.1	3.04	n.d.
42	12.68	5.39	42.43	0.74	260.1	4.76	66.1
56	13.23	6.89	52.07	1.09	n.d.	n.d.	n.d.
70	11.92	5.20	43.52	0.78	n.d.	n.d.	n.d.
84	13.33	6.48	48.59	0.95	235.4	4.41	83.2
mature	10.88	4.62	42.44	0.74	233.2	4.48	94.4
Pile 2: sewage sludge + cotton waste							
0	24.92	16.37	65.69	1.92	115.7	2.15	76.0
14	29.36	19.77	67.34	2.06	n.d.	n.d.	n.d.
28	30.50	20.58	67.47	2.07	169.0	3.03	66.5
42	30.86	21.75	70.49	2.39	216.6	3.75	n.d.
49	30.18	21.54	71.36	2.49	230.0	4.15	71.1
mature	31.48	24.25	77.03	3.35	285.3	5.21	70.3
Pile 3: orange industrial waste + cotton waste + OMW							
0	28.42	7.14	25.13	0.34	99.3	1.99	0.0
14	18.86	7.82	41.40	0.71	n.d.	n.d.	n.d.
28	22.11	12.05	54.51	1.20	127.1	2.48	n.d.
42	21.57	11.59	53.74	1.16	129.7	2.57	40.9
56	17.81	10.48	58.86	1.43	n.d.	n.d.	n.d.
70	16.81	9.69	57.61	1.37	n.d.	n.d.	n.d.
84	11.85	5.86	49.47	0.98	174.3	3.29	62.9
mature	14.49	7.79	53.70	1.16	197.1	3.68	58.9
Pile 4: orange industrial waste + cotton waste							
0	18.60	1.11	5.96	0.06	102.2	2.06	0.0
14	16.10	6.38	39.63	0.66	n.d.	n.d.	n.d.
28	14.22	4.77	33.43	0.51	141.8	2.80	n.d.
42	9.56	4.08	42.60	0.75	158.1	3.04	67.5
56	10.00	4.54	45.20	0.83	n.d.	n.d.	n.d.
70	9.27	3.96	42.68	0.75	n.d.	n.d.	n.d.
84	8.51	3.39	39.80	0.66	173.8	3.32	80.2
mature	9.60	4.09	42.56	0.74	219.1	4.42	77.4

[1] Ash-free material.

HR: Humification ratio, HI: Humification index, P_{HA}: Percentage of humic acid-like C, C_{HA}/C_{FA}: ratio of humic acid-like C/fulvic acid-like C, GI: Germination index; for other abbreviations, see Table 1.

soil, as were acceptable other maturation indices (C/N and GI) and the OM humification.

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