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Composting of a solid olive-mill by-product (“alperujo”) and the potential of the resulting compost for cultivating pepper under commercial conditions

J.A. Alburquerque, J. Gonzálvez, D. García, J. Cegarra *

Department of Soil and Water Conservation and Organic Waste Management, Centro de Edafología y Biología Aplicada del Segura, CSIC, P.O. Box 164, 30100 Murcia, Spain

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Abstract

A pollutant solid material called “alperujo” (AL), which is the main by-product from the Spanish olive oil industry, was composted with a cotton waste as bulking agent, and the compost obtained (ALC) was compared with a cattle manure (CM) and a sewage sludge compost (SSC) for use as organic amendment on a calcareous soil. The experiment was conducted with a commercial pepper crop in a greenhouse using fertigation.

Composting AL involved a relatively low level of organic matter biodegradation, an increase in pH and clear decreases in the C/N and the fat, water-soluble organic carbon and phenol contents. The resulting compost, which was rich in organic matter and free of phytotoxicity, had a high potassium and organic nitrogen content but was low in phosphorus and micronutrients. The marketable yields of pepper obtained with all three organic amendments were similar, thus confirming the composting performance of the raw AL. When CM and SSC were used for soil amendment, the soil organic matter content was significantly reduced after cultivation, while it remained almost unchanged in the ALC-amended plots.

1. Introduction

The industrial olive oil sector generates large quantities of solid and liquid wastes and by-products in many Mediterranean countries during a short period of time (November–February). The gradual accumulation or incorrect disposal of these wastes may cause environmental problems. These materials must be treated or re-used if their environmental impact is to be reduced, enabling at the same time some of their primary components to be recovered (organic matter, nutrients, etc.).

The two-phase centrifugation system for olive oil extraction was introduced in Spain at the beginning of the 1990s. It produces a new by-product called “alperujo” (AL), a solid material of low consistency, whose main agrochemical characteristics have been extensively reported (Alburquerque et al., 2004). Due to the rapid and generalised implementation of the two-phase system, the yearly production of AL in Spain may exceed 4 million tons. Composting as a method for preparing organic fertilisers and amendments is economically and ecologically sound and may well represent an acceptable solution for disposing of AL, at the same time increasing its value. Composting AL, prior to its application in the field, should improve the soil’s agronomic quality and reduce or avoid some of the adverse effects that have been recorded when olive-mill residues are directly supplied to the soil. Some of these effects have been related to its phytotoxic and antimicrobial properties due to their phenolic and lipidic constituents (Paredes et al., 1987; Pérez et al., 1992; Linares et al., 2003), while damage to the soil’s

* Corresponding author. Tel.: +34 968 396 313; fax: +34 968 396 213.
E-mail address: jcegarra@cebas.csic.es (J. Cegarra).

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structural stability has also been described (Tejada et al., 1997).

Several composting experiments (Madejón et al., 1998; Rosa et al., 2001; Filippi et al., 2002) have demonstrated the effectiveness of composting to transform AL into suitable soil organic fertilisers or amendments. However, there has been very little, if any, research into the possible use of AL compost for crop production.

In the present work, we study the suitability of AL for composting as a way of transforming the by-product into a non-toxic organic amendment, as well as the potential of the AL compost for growing pepper under commercial conditions.

2. Materials and methods

2.1. Composting performance

The compost was obtained by co-composting AL and a cotton waste (CW), the latter acting as a bulking agent to increase AL porosity and improve oxygen supply during the process. A pile of about 2700 kg was prepared by mixing on a fresh weight basis (dry weight basis in parentheses) 92.6% AL + 7.4% CW (80/20). AL was provided by "Cooperativas Agrícolas Albacetenses" from Cuenca (Spain) and CW by "SAT 1371" from Torre-Pacheco (Murcia, Spain). The collected AL was very rich in organic matter (OM), mainly composed of lignin, cellulose and hemicellulose; it had a high moisture content and carbon-to-nitrogen ratio (C/N), an acid pH and low electrical conductivity (EC). It also had a considerable proportion of fats, water-soluble phenols and nutrients, mainly potassium and nitrogen (Table 1). CW had a neutral pH, a slightly higher EC value than the AL, a high OM content (mainly composed of cellulose) and a low moisture content and C/N. It also showed a good water-retaining capacity.

Table 1
Main characteristics of the "alperujo" (AL) and cotton waste (CW) used in the composting experiment (dry weight)

Parameters	AL	CW
Moisture (% f.w.)	71.3	11.5
pH[a]	4.97	6.80
Electrical conductivity[a] (dS m^{-1})	3.01	4.12
Organic matter (g kg^{-1})	952.6	933.0
Lignin (g kg^{-1})	449.0	232.0
Cellulose (g kg^{-1})	207.0	392.3
Hemicellulose (g kg^{-1})	379.3	207.8
Total fats (g kg^{-1})	116.3	21.0
Total organic carbon (g kg^{-1})	539.0	477.0
Total nitrogen (g kg^{-1})	12.2	21.3
C/N	44.2	22.4
P (g kg^{-1})	0.9	1.8
K (g kg^{-1})	15.9	17.4
Ca (g kg^{-1})	4.5	23.0
Mg (g kg^{-1})	1.6	4.2
Fe (mg kg^{-1})	390	1710
Cu (mg kg^{-1})	13	12
Mn (mg kg^{-1})	12	108
Zn (mg kg^{-1})	17	40

[a] Water extract 1:10.

A trapezoidal pile of material, approximately 1.5 m high with a 2 m × 3 m base, was composted in a pilot plant by using forced aeration combined with temperature feedback control (Finstein et al., 1985), the air being blown from the base of the pile through the holes of three PVC pipes (3 m in length and 12 cm in diameter) located at the bottom. The timer was set for 30 s ventilation every 15 min, and the maximum temperature for continuous air blowing was 50 °C. The pile was turned once during the eighth week to improve both the homogeneity of the composting substrate and the oxygen supply. The active phase of composting was considered finished when the pile temperature was stable and close to that of the ambient, which occurred after 26 weeks. Forced aeration was then stopped to allow the substrate to mature over a period of 4 months. The pile's moisture level was controlled weekly and the necessary amount of water was added to maintain a moisture content between 45% and 55%. The excess water that leached from the pile was collected and added to the pile.

The composting substrate was sampled weekly during the bio-oxidative phase and then after the maturation period, taking samples from six random sites around the pile using a cylindrical drill (1.5 m in length and 8 cm in diameter) to bore holes through the whole height of the pile. The collected samples were mixed, homogenised and subdivided into three sub-samples in the laboratory. One of the sub-samples was frozen (−20 °C) and kept for the determination of NH_4^+-N and NO_3^--N, the second was dried in an oven at 105 °C for 24 h to determine its moisture content, while the third sub-sample was freeze-dried and ground to less than 0.5 mm prior to analysis.

2.2. Greenhouse culture

The compost obtained (ALC) was evaluated as an organic amendment for the production of pepper (*Capsicum annuum* cv "Orlando"), comparing it with a cattle manure (CM) and a sewage sludge compost (SSC). The field experiment was carried out under fertigation conditions in a commercial greenhouse situated in San Javier (Murcia, Spain), where pepper plants were grown on a calcareous soil with a clay loam texture (Table 2). The three organic amendments were added manually over the treatment area, tilled into the soil and mixed with a rotary soil tiller to ensure their uniform distribution. One month later, pepper seedlings were transplanted to 1.1 m × 30 m soil plots, the plant population being equivalent to approximately 2.2 plants m^{-2}. Thus, there were three organic treatments: C1 (with ALC), C2

Table 2
Main characteristics of the soil employed for the pepper culture in the greenhouse experiment

Parameters	Soil
pH[a]	7.47
Electrical conductivity[a] (dS m^{-1})	1.42
Organic matter (g kg^{-1})	18.4
Total nitrogen (g kg^{-1})	1.6
C/N	6.7
Available phosphorus (mmol P kg^{-1})	6.8
Available potassium (mmol K kg^{-1})	39.9
Cation exchange capacity (cmol kg^{-1})	14.7
$CaCO_3$ (%)	53.2
Sand (%)	25.6
Silt (%)	38.6
Clay (%)	35.8

[a] Water extract 1:5.

(with CM) and C3 (with SSC) and a non-amended control (C0). Each treatment comprised two replications separated by a border, also of 1.1 m × 30 m. The amendment ratios used for ALC (2.0 kg m^{-2}) and SSC (5.0 kg m^{-2}) were based on the addition of 1.5 kg m^{-2} of organic matter to the soil, as supplied by CM (4.4 kg m^{-2}), which is commonly used as organic amendment in local pepper production.

A basic standard fertigation program was used to supply nitrogen, phosphorus, potassium and micronutrients to all of the treatments, and crop management followed the common practices used in the area. Red and green peppers were harvested according to commercial size and shape criteria determined by the operators of the greenhouse. A comparison of both total production and fruit quality was made between treatments and the macro- and micronutrients in plant leaves were analysed at 59, 149, 190 and 219 days after planting. In addition, the effect of adding the three products as soil organic amendment was evaluated in all the treatments by determining the soil organic carbon content before and after cultivation.

Two representative leaf samples per plot were taken randomly, washed with distilled water, oven dried at 60 °C for 24 h, ground and stored for analysis. For each plot, soil samples were taken at 10 different random sites (0–40 cm depth) and combined to obtain two representative samples, which were air dried and ground to 2 mm prior to analysis.

2.3. Analytical methods

The methods used for analysing the soil and composting the organic materials have been previously described by Caravaca et al. (1999) and Paredes et al. (2002), respectively. The total organic matter (volatile solids) losses were calculated during composting according to Stentiford and Pereira Neto (1985) by taking into account the apparent increase in the ash content resulting from the loss of dry matter weight in order to better reflect the overall changes, as also those of the main components of the organic matter (lignin, cellulose and hemicellulose).

For plant analysis, total nitrogen was determined directly in a Carlo Erba ANA-1500 CNS analyser and the other nutrients were determined after digestion with a mixture of $HNO_3/HClO_4$ according to Abrisqueta and Romero (1969). Thus, phosphorus was measured colorimetrically as molybdovanadate phosphoric acid (Kitson and Mellon, 1944); potassium by flame photometry; and calcium, magnesium, iron, copper, manganese and zinc by atomic absorption spectrophotometry.

2.4. Statistical analyses

Variance and the least significant difference were calculated for the results of the composting samples to determine changes in the parameters with time, whereas the experimental data from the pepper culture were subjected to an analysis of variance, statistical differences between treatments being estimated by Duncan's multiple range test, using the SPSS 11.0 program for Windows.

3. Results and discussion

3.1. Evolution of the composting process

With respect to the temperature profile (Fig. 1), the process exhibited an initial long mesophilic period, which lasted until the eighth week with temperatures of around of 40 °C; a thermophilic step between the eighth and 12th weeks, initiated immediately after turning and coinciding with the better aeration conditions induced as a response to mixing and homogenisation of the composting substrate; and, finally, another mesophilic period, which lasted until the end of the active phase of the process (26th week). Such a long composting period could be related to the low bioavailability of N-compounds existing in AL and the high proportion of biodegradation-resistant components, such as lignin, compared with other wastes currently used for composting (manures, city refuse and sewage sludges).

During the initial phase of the process, the pH progressively increased until the 22nd week due to the degradation of acid compounds and the liberation of ammonia, after which it remained stable at around 9 (Table 3). The EC values, on the other hand, decreased from an initial value of 3.56–2.77 dS m^{-1} during the first four weeks, then values remain still lower until the 16th week of composting, after which it rose to reach a plateau slightly higher than 3 dS m^{-1} (Table 3). A decrease in EC during composting is rather unusual but, when

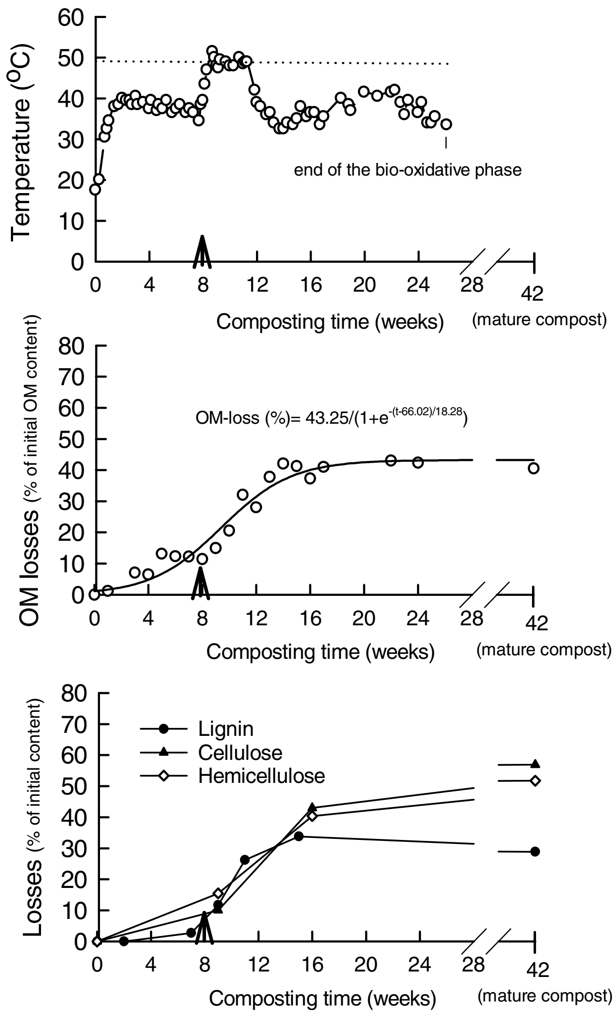

Fig. 1. Temperature profile and losses of OM, lignin, cellulose and hemicellulose during composting. The arrow indicates turning and the line of OM losses represents the curve-fitting to experimental data with a residual mean square of 12.65 and an "F" factor of 200.41 at $P < 0.001$, "t" is composting time in days.

observed (Raviv et al., 1987; Wong et al., 2001), it has been related to a decrease in the soluble nutrient ions fixed during the rapid proliferation of the aerobic microbial population, and to their precipitation as insoluble mineral salts or by ammonia volatilisation. In our experiment, a rather low degree of OM mineralisation occurred, releasing only relatively small amounts of mineral salts, which might rapidly have been removed from the soluble phase, as explained above.

During the whole composting process, the OM content decreased from 938.1 to 900.1 g kg^{-1} (Table 3), leading to a calculated total OM-loss of 40.6% according to Fig. 1, in which experimental data were fitted to a sigmoidal model. Three different phases in OM loss related with the above discussed temperature profile could be discerned in the model: a slight but continuous increase of losses (10–15%) coinciding with the initial mesophilic period (eight weeks), a higher rate of OM degradation, which mostly occurred during the thermophilic phase, and a third step, reflecting a progressive stabilisation in OM loss due to the high lignin concentration existing in the raw material that reduced the bioavailability of the organic substrate (Lynch, 1993; Vikman et al., 2002). It should be added (Fig. 1) that lignin was much less degraded than cellulose and hemicellulose (total losses of 28.9%, 56.9% and 51.8%, respectively).

The low OM degradation rate coinciding with the initial mesophilic step could be related to insufficient substrate aeration, especially with the high initial moisture in the mixture (around 66%). It is well known that important physico-chemical changes occur during composting, affecting the volume, mass, bulk density and water content of the substrate, whose porosity (free air space) greatly influences the aeration efficiency and correct air distribution through the composting mass. When such properties are limited, turning may be an effective operating strategy for encouraging the process

Table 3
Evolution of main analytical parameters during composting (dry weight)

Composting time (weeks)	pH	EC (dS m^{-1})	OM (g kg^{-1})	TOC (g kg^{-1})	TN (g kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})
0	6.1	3.56	938.1	518.9	15.1	279	–
2	6.9	3.20	938.9	513.6	16.9	236	–
4	7.1	2.77	934.1	514.6	17.6	310	–
6	7.7	2.64	930.0	511.3	17.5	192	–
8	7.5	2.60	930.7	494.7	16.4	396	–
10	7.8	2.73	923.3	495.8	18.3	459	–
12	8.0	2.61	916.0	486.4	19.7	505	–
14	8.3	2.66	897.7	494.1	23.3	502	–
16	8.3	2.71	904.8	496.0	22.4	417	–
22	8.9	3.05	896.2	492.6	22.3	208	–
24	9.0	3.05	897.2	495.1	22.0	192	50
42	8.9	3.07	900.1	491.5	21.7	90	112
Lsd	0.1	0.16	4.2	6.3	0.8	39	3

–: Not detected.
EC: electrical conductivity, OM: organic matter, TOC: total organic carbon and TN: total nitrogen.
Lsd: least significant difference at $P < 0.05$.

by restoring the air-flow channels or pores, homogenising and re-inoculating the composting substrate, as was demonstrated in our experiment.

With a clear predominance of the organic forms, there was an increase in the total nitrogen concentration (TN) from 15.1 g kg^{-1} at the start of composting until values of around 20 in the 12th week (Table 3), as a result of the OM mineralisation which reduced the weight of the pile. The increase of nitrogen led the C/N to decrease from 34.4 at the beginning to 22.7 at the end of composting, the latter value being rather high compared with other composts made of animal manures and city refuse, but reflecting the substantial proportion of lignin remaining in the mature AL compost. After the start of the thermophilic stage (eighth week), a relative increase in the NH_4^+-N content was detected, values of 400–500 mg kg^{-1}, coinciding with the more intense rate of OM biodegradation (until the 16th week). Thereafter, the NH_4^+-N content decreased as the composting progressed and reaching the lowest content (90 mg kg^{-1}) at the end of the process, which is well below the maximum limit of 400 mg kg^{-1} established for a mature compost (Zucconi and de Bertoldi, 1987; Bernal et al., 1998). Nitrates, on the other hand, could hardly be detected at the end of the active phase of composting and in the mature compost, when temperature dropped (Table 3). These results agreed with those of Filippi et al. (2002), who did not detect nitrifying bacteria during AL composting.

In the early stages of composting, readily available compounds, such as sugars, starches, fatty acids, lipids and proteins, are degraded by microorganisms as the most suitable carbon and energy source. In our experiment, a decrease in the water-soluble organic carbon (WSC) and carbohydrates (WSCH) was already evident in the fourth week of composting, both parameters reaching values of around 30 and 10 g kg^{-1}, respectively (Table 4), revealing the availability of these OM fractions for microbial metabolism. Other important fractions of the initial composting substrate were total fats (91.8 g kg^{-1}) and water-soluble phenols (WSPH, 5.7 g kg^{-1}), both components being responsible, as in the case of the organic acids, for the antimicrobial and phytotoxic effects currently assigned to olive-mill wastes and by-products (Estaún et al., 1985; Riffaldi et al., 1993; Linares et al., 2003). Until the 10th week of composting, the total fat content decreased to 15.6 g kg^{-1} and WSPH to 4.0 g kg^{-1}, but these values were reduced to 8.8 and 2.2 g kg^{-1}, respectively, in the mature compost. Both decreases contrasted with the increase observed in the germination index (GI), an easy to quantify parameter that predicts the potential phytotoxicity of a compost. Thus, the high initial phytotoxicity tended to disappear during the process, as the decrease in the above mentioned potentially phytotoxic compounds led to the higher GI, which reached a value greater than 70% in the 10th week of composting (Table 4).

The compost obtained (ALC), clearly lacking in phytotoxicity, had considerable greater OM and lignin contents than the other two organic amendments tested (Table 5), lignin being recognised to be both poorly biodegradable and an important precursor of soil humic substances. ALC also had a considerable content of potassium and organic nitrogen, although phosphorus and micronutrients were rather low.

Table 4
Evolution of water-soluble organic carbon (WSC), carbohydrates (WSCH) and phenols (WSPH), total fat content and germination index (GI) during composting (dry weight)

Composting time (weeks)	WSC (g kg^{-1})	WSCH (g kg^{-1})	WSPH (g kg^{-1})	Total fats (g kg^{-1})	GI (%)
0	40.7	13.6	5.7	91.8	5.0
4	32.0	11.6	4.0	62.0	52.5
10	31.4	9.0	4.0	15.6	73.0
16	29.7	10.6	2.8	15.0	74.0
42	31.4	12.6	2.2	8.8	78.0
Lsd	1.4	0.7	0.2	3.2	8.7

Lsd: least significant difference at $P < 0.05$.

3.2. Greenhouse experiment

During the experiment, there was no evidence of adverse effects on plant growth or phytotoxicity symptoms in plots treated with ALC. Marketable pepper yields in plots amended with ALC, CM and SSC were similar (99.6, 98.3 and 97.7 t ha^{-1}, respectively) and rather greater than in the control (90.0 t ha^{-1}), although the

Table 5
Main characteristic of the "alperujo" compost (ALC), cattle manure (CM) and sewage sludge compost (SSC) used in the agronomic experiment (dry weight)

Parameters	ALC	CM	SSC
Moisture (% f.w.)	14	41	53
pH[a]	8.88	8.67	7.03
Electrical conductivity[a] (dS m^{-1})	3.07	5.31	4.63
Organic matter (g kg^{-1})	900.1	603.4	649.2
Lignin (g kg^{-1})	410.0	248.3	223.1
Total organic carbon (g kg^{-1})	491.5	332.2	315.2
Total nitrogen (g kg^{-1})	21.7	21.4	23.5
C/N	22.7	15.5	13.4
P (g kg^{-1})	1.5	1.0	16.8
K (g kg^{-1})	24.9	35.3	5.4
Ca (g kg^{-1})	13.4	58.5	37.5
Mg (g kg^{-1})	2.9	7.7	5.1
Na (g kg^{-1})	2.6	6.8	3.1
Fe (g kg^{-1})	0.7	4.3	39.4
Cu (mg kg^{-1})	21	32	203
Mn (mg kg^{-1})	46	252	204
Zn (mg kg^{-1})	41	175	811
Pb (mg kg^{-1})	4	4	78
Cr (mg kg^{-1})	8	9	36
Ni (mg kg^{-1})	8	10	31
Cd (mg kg^{-1})	–	–	1

–: Not detected.
[a] Water extract 1:10.

Table 6
Organic matter content of soil (C0), soil + ALC (C1), soil + CM (C2) and soil + SSC (C3), before (T1) and after (T2) the pepper cultivation

Treatments	Time	Soil organic matter (g kg^{-1})
C0	T1	18.53c
	T2	18.49c
C1	T1	21.41a
	T2	21.28a
C2	T1	20.76a
	T2	19.06bc
C3	T1	21.53a
	T2	19.50b
Treatment	***	
Time	***	
Treatment × time	**	

Values followed by the same letters are not statistically different according to the Duncan's multiple range test at 5% probability level.
** $P < 0.01$.
*** $P < 0.001$.

differences were not statistically significant and did not affect the commercial quality of the fruit, thus confirming the beneficial effect of composting on the starting phytotoxicity of the raw AL. Nutrient leaf concentrations were also generally similar in all treatments due to the efficiency of fertigation in supplying nutrients, although the three organic amendments led to a statistically significant but rather negligible increase in the leaf nitrogen, potassium and copper contents compared with the control (data not shown). After cultivation, the soil organic matter content was significantly reduced in the plots amended with CM and SSC, but remained almost unchanged in the ALC-amended plots (Table 6), demonstrating the considerably greater resistance of the obtained compost to edaphic biodegradation.

4. Conclusions

The AL composting process involved a relatively slow biodegradation rate of organic matter, an increase in pH and decreases in the C/N and the fat, water-soluble organic carbon and phenol contents. The compost obtained was free of toxicity, rich in organic matter (mainly composed of lignin), and had a considerable potassium and organic nitrogen content but was low in phosphorus and micronutrients. It can be used as an efficient organic amendment, as was shown by its comparison with other organic materials for growing pepper. It also demonstrated a considerably greater resistance to edaphic biodegradation in the harsh thermal conditions of the greenhouse.

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