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Composting of wastes produced by low water consuming olive mill technology

E. MADEJON [1], E. GALLI [2] and U. TOMATI [2]
[1] Instituto de Recursos Naturales y Agrobiologia de Sevilla - CSIC - Sevilla, Spain
[2] Istituto di Biochimica ed Ecofisiologia Vegetali - C.N.R. - Monterotondo Scalo (Roma) Italy

INTRODUCTION. — The problem of the disposal of olive mill industry waste nowadays concerns mainly the mediterranean area, but it will grow greatly in the near future since many other countries, i.e. Argentina, Australia, South Africa, New Zealand are promoting intensive olive tree cultivation. Therefore, in a policy of environmental protection, there is a need for guidelines to manage waste disposal through technologies which minimize waste production and improve its environmental acceptability and/or reuse as energy or fertilizer.

Low water consuming technologies (LWCT) have been recently proposed for the olive mill industry aimed at reducing the amount of water needed for processing and consequently reducing the volume of the waste produced.

The LWCT, which totally or partially eliminates the water required for oil extraction, produces a semisolid residue called olive mill pomace (OMP). At present, two main alternatives have been proposed for its utilization: combustion for energy production or use as a fertilizer.

Combustion of solid or semisolid wastes reduces the volume by up to 90%; it also offers the possibility of recovering energy in the form of steam or electricity. Besides these facilities which, however, require suitable and sometimes expensive plants, combustion requires high costs for the control of air emission and the management of residual ashes. The use of OMP for energy production is widely applied in Spain in a policy aimed at transforming traditional mills into LWCT.

Recycling wastes as fertilizers not only reduces the volume of water but also conserves a natural resource. Composted organic wastes are increasingly pointed out as an alternative to chemical fertilizers for crop production. Since compost quality closely reflects the composition of the refuses which they derive

TABLE 1. — *Comparison between OMP and OMW characteristics. The results are the average of the analyses of 25 samples for each product.*

		OMP*			OMW**		
		min	max	mean	min	max	mean
Moisture	% f.w.	56.2	74.5	63.6	90.4	96.5	93.2
Organic Matter	% f.w.	22.4	41.5	32.6	2.6	8.0	5.2
pH		4.7	6.5	5.6	4.7	5.5	5.4
EC	mS cm^{-1}	1.5	5.9	3.8			
N-Kjeldalh	% f.w.	0.6	0.9	0.8	0.2	0.4	0.3
C/N		36.3	46.1	41.0	13.0	20.0	17.3

* Analyses on OMP were performed by Centro Edafologia y Biologia Aplicada del Segura, CSIC, Spain.

** Analyses on OMW from Pacifico A. (1989) Agricoltura e Innovazione, luglio-settembre 1989, 33-73.

from, particular attention must be paid to the starting material; from this standpoint, olive mill industry wastes are particularly safe and suitable for transformation into amendants.

Although the existing laws in Italy permit the direct use of the raw waste in agriculture, this poses some problems due to the polluting load and phytotoxicity (Estaun *et al.,* 1985).

Several studies have already demonstrated the feasibility of three-phase waste composting (Amirante *et al.,* 1991; Tomati *et al.,* 1995). The process results in a product which can be used in the field and in indoor agriculture, forestry and land reclamations. Very little information is instead available about OMP composting and use. However, since olive mill wastewaters (OMW) and OMP differ mainly in water content and the presence of lignocellulose compounds (Table 1), no difficulty should arise for bioremediation. According to the philosophy "to return to soil that which came from soil", an agronomical use seems to be the most suitable for OMP recycle, also keeping in mind that organic soil amendants improve soil properties, and consequently crop quality.

The aim of this study is to provide information about the feasibility of OMP composting, through the changes in physical, chemical and biological characteristics which occur during the process and about the composition of the end product.

Materials and Methods. — A mixture of 5,000 kg of OMP and 500 kg of wheat straw was composted in a static pile (7.5 x 2.5 x 1.2 m) with forced aeration. 2% urea (46% of N) was added to reach a C/N ratio of about 35-40. The air required was provided by a blower (0.5 m^3 min^{-1}) connected to a series of perforated pipes laid on a slighty sloping concrete slab. The temperature was monitored using a system of thermistors placed at different depths in the pile. The core temperature was determined by a thermistor connected to a temperature controller set with an adjustable temperature set point (60°C).

During the composting process 4 samples of about 0.5 kg were randomly collected in different horizons of the heap and carefully mixed. 3 subsamples of 0.1 kg were dried at 105°C for 24 h and then ground to pass through a 1 mm sieve.

The moisture content, pH, electrical conductivity (EC), total organic carbon (TOC), total extractable carbon (TEC), humic (HA) and fulvic acids (FA), humin (NH) and nitrogen were determined according to Hesse (1971). Phytotoxycity, expressed as germination index (GI), was assayed by the *Lepidium sativum* test according to Zucconi *et al.* (1981). Oxygen consumption was assayed at 28°C (oxygen monitor YSI mod. 240/B) on a 3 ml sample of a suspension obtained by stirring 5 g fresh weight of compost for 30 min in 50 ml of 0.9% NaCl solution. Lignin and lipid content were determined by a modified Klason procedure (Moore and Johnson, 1967). The phenols were extracted and determined according to Balice e*t al.* (1965). Mineral elements (Na, K, Ca, Mg, Fe, Mn, Cu, Zn, Ni, Cr, Pb) were determined after mineralization by atomic absorption spectrophotometry and P by colorimetric determination using the phosphovanadomolybdic complex (Hesse, 1971).

Urease and Casein-hydrolysing protease activities were tested on fresh compost according to Galli *et al.* (1997).

Results and discussion. — Among the methods proposed for waste bioremediation, the aerated static pile has been chosen since it allows a great control of the process and a fast rate of decomposition, while remaining relatively inexpensive (Finstein et *al.*, 1988; Stentiford, 1993).

OMP is characterized by a lower content of water compared with OMW (Table 1), so it is richer both in salts and organic matter. Apart from water content, the greatest difference between the two wastes is that OMP contains a very large amount of low degradable lignocellulose compounds due to the presence of the chopped stones (Table 2).

Because of the high initial C/N of the mixture (about 47), urea was added to ensure a C/N ratio of about 35-40. This treatment enabled the immediate start of the process, as indicated by both respiration and temperature profiles (Figure 1). They exhibited the typical succession of mesophilic, thermophilic and ma-

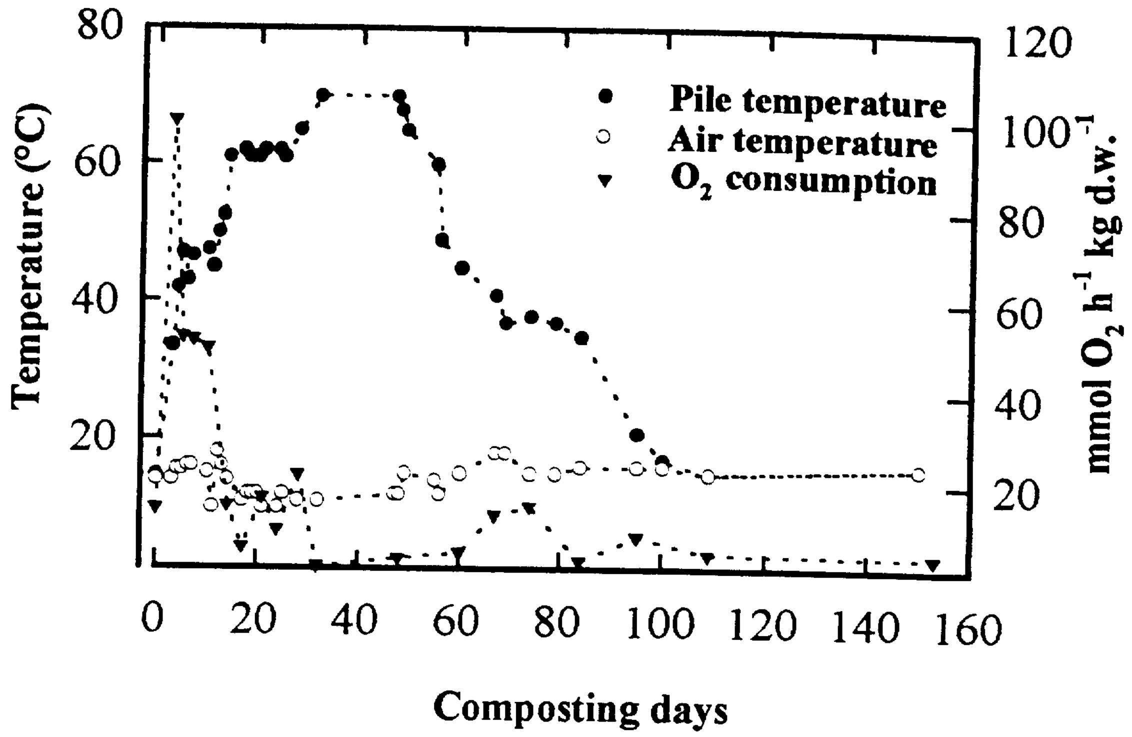

Fig. 1. — Temperature and oxygen consumption rate profiles during composting. Temperatures are the average of the values recorded by 10 thermistors placed at different depths in the heap.

TABLE 2. — *Chemical characteristics of olive mill pomaces (OMP) used for the composting process. The results are the average of the analyses of 5 samples.*

Moisture	%	71.4
Organic matter	% d.w.	94.5
Lipids	% d.w.	8.6
Lignin	% d.w.	35.0
Ashes	% d.w.	5.50
pH		5.19
EC	mS cm^{-1}	2.85
Kjeldahl-N	% d.w.	0.97
C/N		46.6
P_2O_5	% d.w.	0.35
K_2O	% d.w.	2.06
Ca	% d.w.	0.40
Mg	% d.w.	0.05
Na	% d.w.	0.10
Fe	mg kg^{-1} d.w.	1030
Mn	mg kg^{-1} d.w.	13
Cu	mg kg^{-1} d.w.	138
Zn	mg kg^{-1} d.w.	22
Cd, Co, Pb,Cr, Hg	mg kg^{-1} d.w.	< 1

turation phases usually recorded for the aerated static pile process. Due to the intense hydrolytic activity of the mesophylic microflora, oxygen consumption rapidly increased reaching its maximum value (99 mmol O_2 h^{-1} kg^{-1} d.w.) in 5 days, and then it strongly decreased as microbial species characterized by slower metabolism, i.e. fungi, prevailed during the thermophylic phase. As a consequence of the rapid warming of the heap, the tempe-

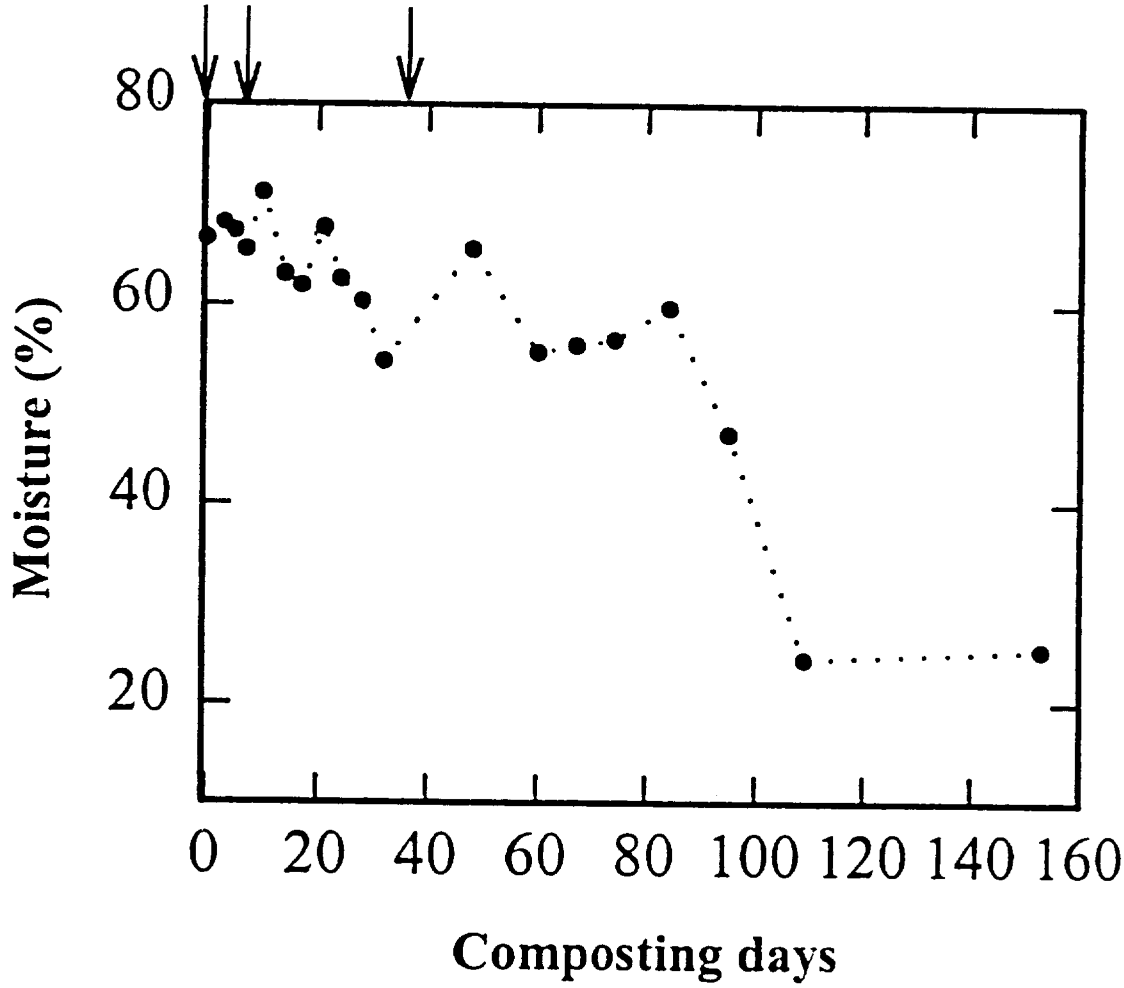

Fig. 2. — Moisture content of the heap during composting. The arrows indicate the addition of water.

rature increased to about 50°C in ten days, then slowly reached values of about 70°C at the top of the heap. This value was maintained for one month. The end of the thermophylic phase usually occurs when readily biodegradable compounds have been consumed or when inhibitory conditions, i.e. moisture decrease, hamper microbial activities. Moisture content in the heap began to decrease after two months from the beginning of the process and then dropped quickly to 25% (Figure 2).

The decrease of TOC and the contemporary increase of TEC indicated the start of the humification process, the efficiency of which is shown by C/N ratio (Figure 3), humification index, degree of humification and humification rate (Table 3). On the average, about 10% of total carbon was degraded at the end of the composting process (Table 3).

The C/N ratio and its evolution during the composting process is closely related to biodegradable carbon compounds (Figure 3). Due to the type of oil extraction process, OMP contains a high fraction (about 35% d.w.) of lignin compounds, relatively low degradable, mainly due to chopped stones which present a very reduced surface for microbial attack. When the total carbon was considered, the initial C/N ratio of the mixture was about 43. At the end of the process a value of 31 was reached. As reported for other wastes rich in low degradable organic matter (Sesay *et al.*, 1997), if the lignin component due to chopped stones was excluded, the initial C/N ratio fell to 29 that is inside a range of 20-35 usually considered optimum for composting (Miller, 1992). At the end of the process a value of 19 was recorded. The results showed that only a low fraction of lignin- about 20%- was degraded during OMP bioremediation (Table 4).

Although no univocal parameter is yet available to assess acceptable levels of compost stability and humification, several tests have been proposed. Among these, widely used are the humification index (HI), which reaches values of less than 0.5 for humified substrates (Sequi e*t al.*, 1986), the degree of humification (DH) and the humification rate (HR) which both tend to increase as organic matter stabilization proceeds (Ciavatta *et al.*,

TABLE 3. — *Organic matter evolution during composting.*

Days	TOC % d.w.	TEC % d.w.	HA % d.w.	FA % d.w.	NH % d.w.	HI	DH %	HR %
5	47.74	2.48	—	1.57	0.91	0.58	63.3	3.29
10	47.63	2.77	—	2.37	0.40	0.17	85.5	4.97
21	47.19	3.75	1.85	1.45	0.45	0.14	88.0	7.00
48	44.20	5.42	3.16	1.08	1.18	0.28	78.2	9.60
67	44.02	6.32	3.77	1.32	1.23	0.24	80.5	11.6
84	44.18	6.50	4.05	1.03	1.42	0.28	78.2	11.5
95	43.70	6.60	4.16	1.62	0.82	0.14	87.6	13.2
109	42.50	6.82	4.48	1.15	1.19	0:21	82.3	13.3
153	42.99	7.21	4.73	1.70	0.78	0.12	89.3	15.0

TOC, total organic carbon; TEC, total extractable carbon; HA, humic acid; FA, fulvic acid; NH, humin; HI, humification index; DH, degree of humification; HR, humification rate; d.w., dry weight.

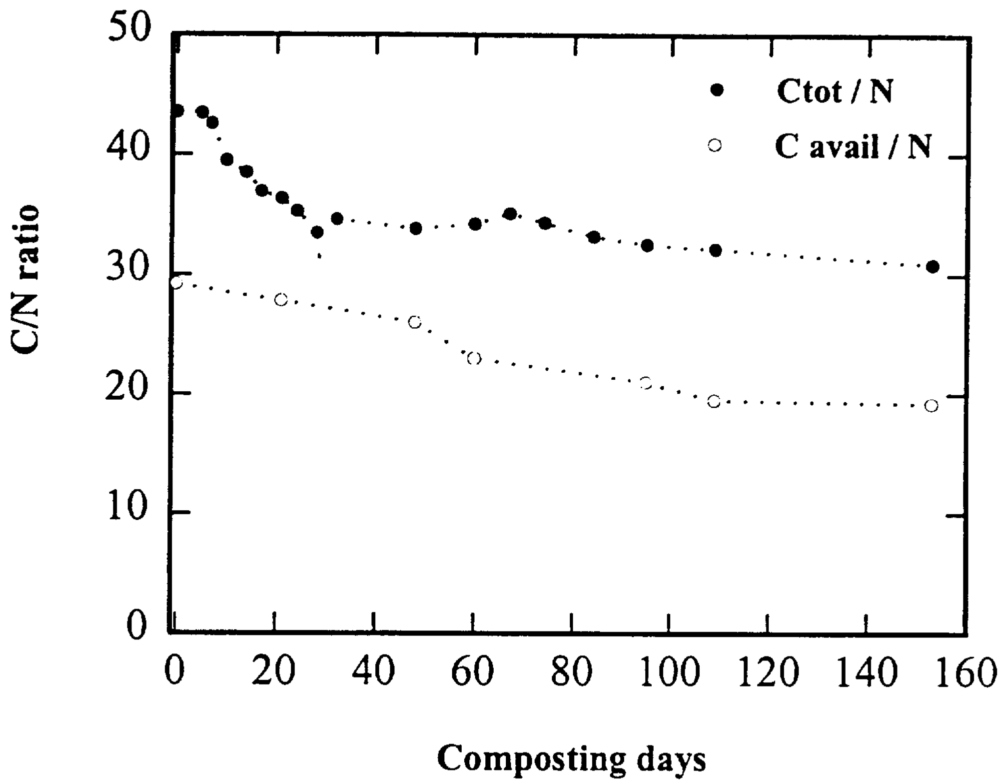

Fig. 3. — C/N ratio of the heap during composting. C_{tot} = Total carbon obtained by ignition. Cavail = Available carbon calculated by difference between total carbon and lignin carbon.

1988). Values of 0.12, 89% and 15% are respectively recorded for HI, DH and HR during the maturation phase (Table 3).

Further information about compost stability can be obtained from the evolution of phytotoxicity, expressed as the germination index (GI) (Table 4). GI increased during the composting process, so it has been proposed as an indirect measure of organic matter stabilization.

A value of $GI_{(10\%)} \geq 70\%$ (Iodice, 1989), and $GI_{(30\%)} \geq 50\%$ (Zucconi *et al.*, 1981), usually assumed as a limit for the absence of phytotoxicity, were reached at the beginning of the maturation phase.

The trend of pH and EC are reported in Fi-

TABLE 4. — *Evolution of phytotoxicity, expressed as germination index (% GI), during composting.*

Days	$\%GI_{(10\%)}$	$\%GI_{(30\%)}$
0	7.50	0
7	34.20	0
21	50.84	2.20
48	50.14	9.91
67	62.30	15.2
74	68.20	49.1
84	72.90	62.8

TABLE 5. — *Evolution of lipids, lignin and phenols during composting.*

Days	Lipids % d.w.	Lignin % d.w.	Phenols % d.w.
0	8.97	36.0	0.23
21	6.70	32.0	0.12
48	3.72	29.5	0
60	4.14	28.0	0
84	2.93	28.0	0
109	2.45	29.0	0
153	2.81	28.0	0

d.w., dry weight.

gure 4. At the beginning of the thermophylic phase, the pH increased from 7.2 to 8.7 and then decreased to 7.8 due to the alkaline hydrolysis of K and Na salts and/or NH_3 evolution. The EC increased from an initial value of 2.30 to 3.75 mS cm^{-1}, due to salt concentration in the composting mixture.

Phenols (Table 5), which are a remarkable component of OMP, are strongly reduced during the thermophilic phase. The microbial fungal microflora could be the agent which rapidly metabolizes phenolic com-

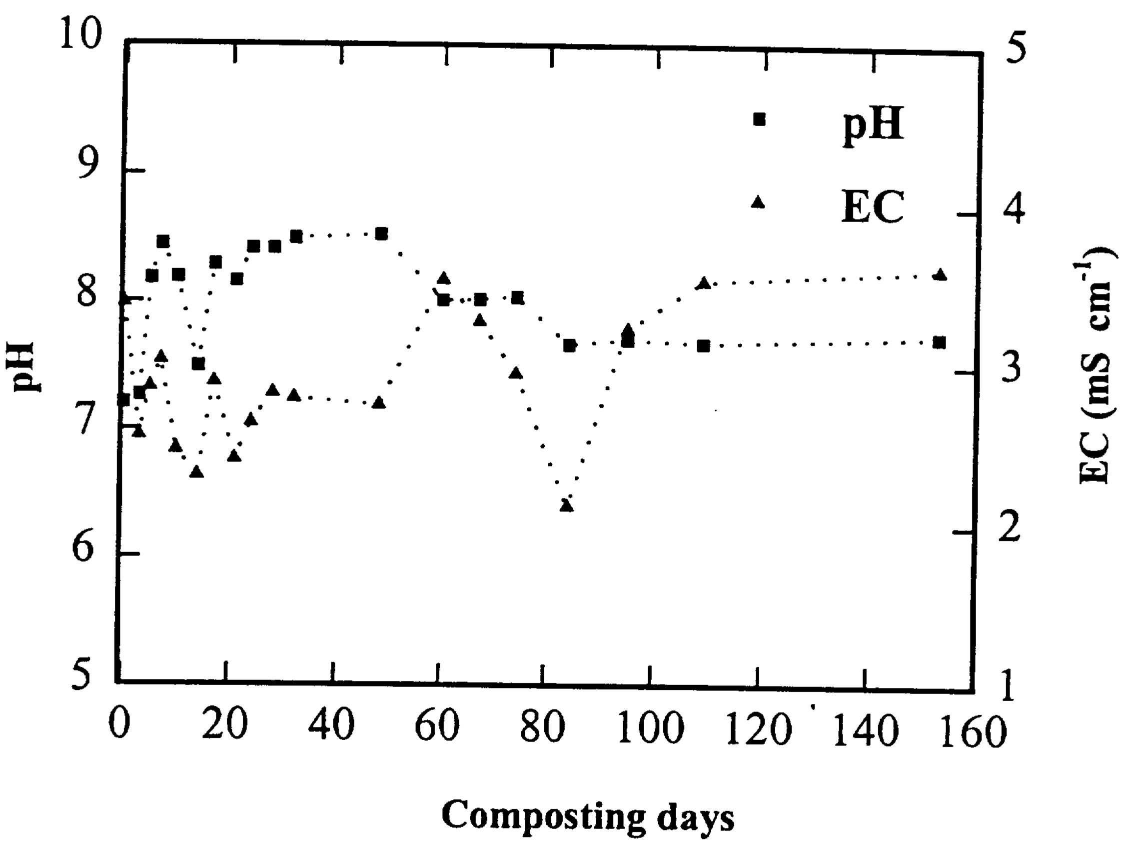

Fig. 4. — pH and Electrical Conductivity of the heap during composting.

pounds through polyphenoloxydases. The phenolic compounds disappeared after 48 days of composting. At this time the high compost phytotoxicity ($\%GI_{(30\%)}$ = 9.9) might be due to the presence of other molecules such as organic acids (Marull *et al.*, 1997) with phytotoxic properties.

A remarkable decrease in lipid fraction (70%) was also recorded (Table 5). It is known that these substances are biodegraded during composting (Diner *et al.*, 1996).

Because of the low amounts of nitrogen present in the initial mixture, 2% urea was added, the hydrolysis of which supplied the nitrogen necessary for the growing microbial populations. Urease activity increased at the beginning of the process and then declined during the thermophilic phase (Figure 5). As shown by casein-hydrolysing protease activity, proteins were rapidly hydrolysed. A high value of protease activity was recorded early and declined after a few days. A further increase of this activity was then recorded during the maturation phase, probably due to the hydrolysis of dead microbial cells (Figure 5).

Finally, in order to gather information on the quality and

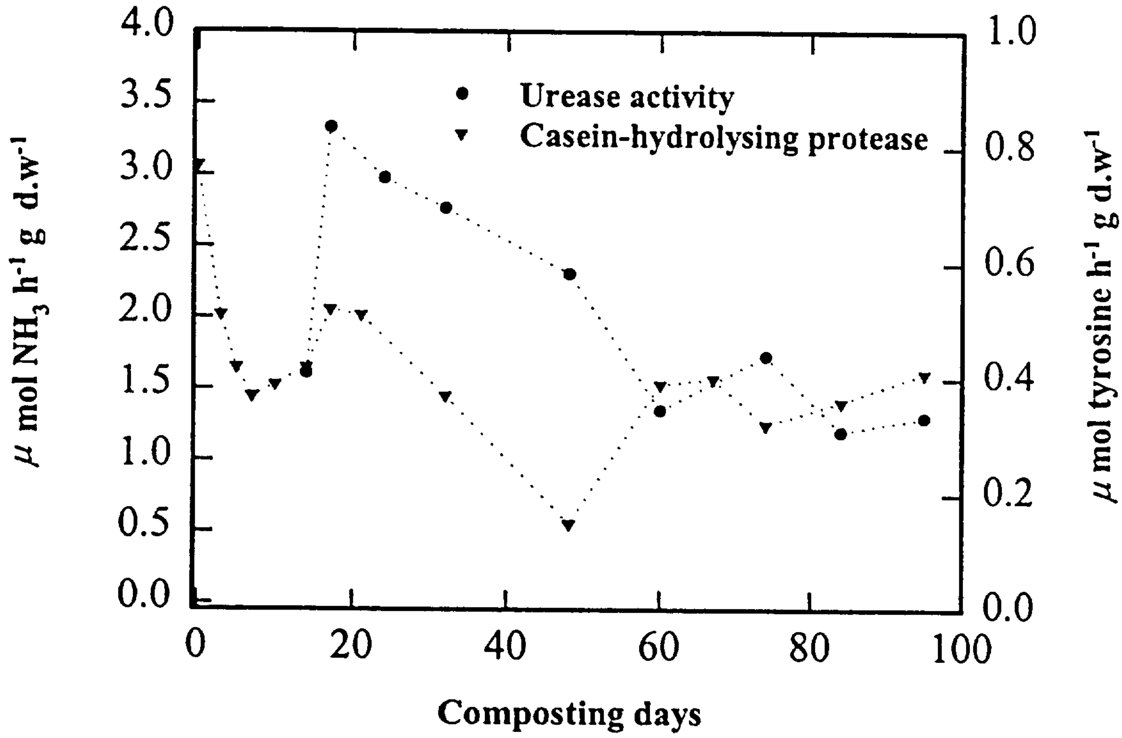

Fig. 5. — Urease and casein-hydrolysing protease activities during composting.

TABLE 6. — *Chemical composition and physical properties of olive mill pomace compost. The results are the average of the analyses of 5 samples of the end-product.*

Moisture	%	23.3
Organic matter	% d.w.	84.4
Ashes	% d.w.	15.6
Specific weight	kg dm^{-3}	0.568
Maximum water capacity	%	121
pH		7.70
EC	mS cm^{-1}	3.75
Kjeldahl-N	% d.w.	1.40
$N-NO_3^-$	mg kg-1 d.w.	78
P_2O_5	% d.w.	0.75
K_2O	% d.w.	2.63
Ca	% d.w.	0.36
Mg	% d.w.	0.07
Na	% d.w.	0.04
Fe	mg kg^{-1} d.w.	1168
Mn	mg kg^{-1} d.w.	77
Cu	mg kg^{-1} d.w.	33.9
Zn	mg kg^{-1} d.w.	34.9
Pb	mg kg^{-1} d.w.	< 1
Cd, Co,Cr, Hg	mg kg^{-1} d.w.	< 1

d.w., dry weight

agronomical value of the final product, analyses on the nutrient and heavy metal content were performed (Table 6). The analyses revealed the presence of considerable amounts of mineral nutrients and stabilized organic matter and the absence of harmful levels of heavy metals. These characteristics together with the specific weight and maximum water capacity made the compost thus obtained a «safe and quality» amendant for agricultural purposes (Zucconi and De Bertoldi, 1986).

CONCLUSIONS. — The bioremediation with other agricultural residues can be a useful alternative to the combustion of olive mill pomace, produced during oil extraction by the low water consuming system. During composting of OMP with wheat straw, C/N, HI, DH and HR show an evolution of organic matter towards humification. The process does not permit a high lignin degradation due to chopped stones which have a very reduced surface for microbial attack. No phytotoxicity was recorded on the end product. It can be considered as a safe and quality amendant, with considerable amounts of mineral nutrients.

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venti per la migliore utilizzazione delle risorse nel settore della olivicoltura nelle regioni meridionali».

SUMMARY. — Olive mill pomace (OMP) produced by low water consuming mill technologies (LWCT) were composted with chopped wheat straw in a forced aerated static pile. During the process temperature, oxygen consumption, moisture content, pH, electrical conductivity, total organic carbon, total extractable carbon, humic and fulvic acids, nitrogen, C/N, phenols, lipids and lignin were determined. Urease and casein-hydrolysing protease activities were also assayed. The humification was assayed following the degree of humification, the humification rate and the humification index which respectively reached the values of 0.12, 89% and 15% during the maturation phase. The analyses of final product revealed the presence of considerable amounts of mineral nutrients and stabilized organic matter and absence of harmful levels of heavy metals. The phytotoxicity disappeared at the end of the thermophilic phase.

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