Biodegradation (2006) 17: 285–292
DOI 10.1007/s10532-005-7566-4

Efforts to explain and control the prolonged thermophilic period in two-phase olive oil mill sludge composting

Thrassyvoulos Manios[1,5,]*, Konstantinos Maniadakis[1], Maria Kalogeraki[2], Eirini Mari[1], Emmanouil Stratakis[1], Stelios Terzakis[1], Panagiotis Boytzakis[1], Yiannis Naziridis[3] & Leonidas Zampetakis[4]
[1]*School of Agricultural Technology, Technological Education Institute of Crete, 71004, Heraklion, Crete, Greece;* [2]*Department of Natural Resources, Technological Education Institute of Crete, 73200, Chania, Crete, Greece;* [3]*Department of Environmental Engineering, Technical University of Crete, 73100, Chania, Crete, Greece;* [4]*Department of Production Engineering & Management, Technical University of Crete, 73100, Chania, Crete, Greece;* [5]*Department of Technical Civil Engineering, Technological Education Institute of Crete, 71004, Heraklion, Crete, Greece (*author for correspondence: e-mail: tmanios@steg.teiher.gr)*

Accepted 19 May 2005

Key words: composting, crude oil, olive mill wastewater, olive oil mills, olive tree branches, olive tree leaves, sludge, woodchips

Abstract

The aim of this paper was to evaluate the use of different bulking agents in different ratios as a means to control, optimise and eventually reduce the duration of the thermophilic period in two-phase olive oil mill sludge (OOMS) composting. The bulking agents used were: (i) olive tree leaves (OTL), (ii) olive tree shredded branches (OTB) and (iii) woodchips (WDC). The selection of these materials was based on their abundance and availability on the island of Crete, the southernmost point of Greece. The ratios studied were: Pile 1, OOMS:OTL in 1:1 v/v; Pile 2, OOMS:WDC in 1:1.5 v/v; Pile 3, OOMS:OTL in 1:2 v/v; Pile 4, OOMS:OTL:OTB in 1:1:1 v/v; and Pile 5, OOMS:OTL:OTB in 1:1:2 v/v. The composting system used was that of windrows with the volume of each pile approximately 20–25 m^3. The experiments took place over two consecutive years. A composting turner was used and turnings were performed at one and two week intervals. In each pile a variety of physiochemical parameters were monitored. Temperature remained high in all five trials. Piles 1, 2, 3, 4 and 5 temperatures recorded values of above 50 °C for 106, 158, 160, 175 and 183 days, respectively. Volumes were reduced by approximately 67%, 62%, 63%, 80% and 84%, respectively. Temperature remained high, mainly due to the presence in large amounts of oily substances which during their complete oxidation release important amounts of energy and aid the cometabolism of more stable molecules such as lignin. This process is better described as the slow "burning" of a "fuel" mixture in an "engine" than composting. This approach is based on the extensive similarities of this process to that of crude oil sludge or similar waste composting.

Introduction

The olive tree is the main cultivation on the island of Crete, the southernmost point of Greece. Over 350,000 tonnes of olive oil, of 900 M€ gross value, are produced annually, accounting for over 80% of the total agricultural income of the island (Louloudis 1985). Currently there are over 650 olive oil mills (OM) operating on the island (Manios et al., 2004).

In the two-phase centrifugal olive oil mill (TPOM), the two separate wastes of the three-phase centrifugal olive oil mill (the most common type of mill in Crete), the olive press cake (OPC) and the olive mill wastewater (OMW) are homogenized, creating the two-phase olive oil mill sludge (OOMS). OOMS is the single waste of this type of mill and has an appearance and texture similar to dewatered sewage sludge, with approximate moisture content of 65%. The ratio of OOMS to oil for the TPOM is 0.38 while the ratio of OMW (not considering OPC amounts) to oil for the three-phase mill is 1.38, which supports the idea that TPOM are more environmentally friendly. At the moment the number of TPOM operating on the island is very small (approximately five). However, if a viable (technically and financially) solution were found for the handling of OOMS, it is estimated that this number would increase substantially. Altering a three-phase mill to a TPOM requires minimal technical changes.

One treatment-management method suggested was composting-production of organic soil improver. If OOMS is transformed into a good quality soil improver, the market value of the end product could cover the capital and operating costs of a commercial composting site. Composting of OOMS, however, has not been investigated thoroughly. Manios & Balis (1983) undertook a series of experiments with OPC (an important component of OOMS), which showed good compatibility with the method, accompanied by a longer than expected thermophilic phase. Garcia-Gomez et al. (2003) did some experimental trials with material similar to OOMS and recorded a prolonged thermophilic phase of 180 days with temperatures above 30 °C.

If this prolonged thermophilic period is inevitable, then the construction and running of any such treating site would be uneconomical. Windrows systems require a large surface area, which would have to be further extended if OOMS were the main raw material. The number of turnings required for stabilising the waste mixture would increase, adding to the overall operating cost. Taking into account the fact that OOMS is produced only during the four-month olive harvesting period, it is reasonable to doubt the viability of any such commercial exploitation.

The aim of this work was to use bulking agents easily found in large amounts in the island of Crete, such as olive tree leaves (OTL), olive tree branches (OTB) and woodchips (WDC), in such a manner as to control and optimise the thermophilic period of OOMS composting and eventually reduce its length. At the same time we would be able to determine the effect of these bulking agents on the quantity and quality of the produced compost, through a variety of physiochemical parameters. Such information is required in order to evaluate the viability of a commercial composting site treating OOMS.

Materials and methods

One of the largest TPOM in Crete, producing up to 1200 tonnes of olive oil, is found in the village of Panagia in the Municipality of Arkarlochori, in the centre of the Heraklion Prefecture. Sludge and OTL were taken from that plant. OTL are piled up in almost all Cretan olive oil mills and then used by local farmers as animal feed. OTB were collected from the TEI of Crete olive trees, after harvesting and pruning. The branches were shredded into approximately 2.0 cm diameter chips using a knife shredder. WDC with a varying diameter of 0.5–1.5 cm were acquired from a local wood factory.

Five different trials took place, using the windrow technique over a period of two years, in the pilot composting plant of TEI of Crete (Manios et al. 2003). The following ratios were used: Pile 1, OOMS:OTL in 1:1 v/v; Pile 2, OOMS:WDC in 1:1.5 v/v; Pile 3, OOMS:OTL in 1:2 v/v; Pile 4, OOMS:OTL:OTB in 1:1:1 v/v; and Pile 5, OOMS:OTL:OTB in 1:1:2 v/v. A composting turner was used and turnings were performed at one to two week intervals. Temperature was measured on a daily basis, and samples were collected from the core of the pile after each turning and analysed using the Standard Methods for the Analyses of Compost (FCQAO 1996) for:

- Moisture (in % of w/w bases)
- Electrical Conductivity (EC in mS cm^{-1}) and pH (watery extract by the 1:1.5 v/v method).
- Total C (as a % of dry weight)
- Organic content
- Total N (as a % of dry weight)
- C/N Rate
- NO_3-N and NH_4-N,
- Total coliforms
- In the final compost, particle size distribution was evaluated also.

Results and discussion

Table 1 presents physiochemical and biological characteristics of the raw materials used in the experiments. OOMS had a moisture content of around 65%, suggesting the need for a drier bulking agent. Electrical conductivity was 2.58 mS cm^{-1}, lower than that presented by Alburquerque et al. (2004) for OOMS in Spain, while the pH was similar. The values of all parameters are considered as normal and no real problems were expected for the composting process and the quality of the end product. The physiochemical and biological parameters of the three bulking agents are also within normal range (Alburquerque et al. 2004; Garcia-Gomez et al. 2003; Manios 2004). Tables 2–5 present the physical characteristics of the feedstock mixtures of the five experimental piles. The moisture levels in Piles 1 and 3 are higher than in the other three plies due to the use of leaves in larger amounts. Pile 2, as expected, presents the lowest moisture content due to the use of WDC.

Figures 1–5 present the temperature profiles of all five piles. Arrows have been used to indicate when turnings took place. From these figures, it is easily noted that temperatures remained high in all five trials for a long period of time, longer than usually recorded with agricultural wastes (Manios 2004). In Pile 1 temperatures recorded values of over 50 °C for 106 days with a highest value of 64 °C, whereas Pile 3 recorded values

Table 1. Physicochemical characteristics of OOMS, OTL, OTB and WDC

	Moisture (%)	PH	E.C. (mS cm^{-1})	Total C (%)	Total N (%)	Rate C/N	Organic matter (%)	NO_3-N (mg l^{-1})	Total coliforms (cfu g^{-1})
OOMS	64.60	5.40	2.58	52.67	1.49	35.34	94.81	114.63	3.3×10^2
OTL	54.80	5.54	2.19	51.11	1.89	27.04	92.00	118.78	5.3×10^2
OTB	35.00	6.54	1.76	51.59	1.27	40.62	92.86	–	7.8×10^2
WDC	7.30	6.88	0.25	54.30	0.33	164.54	97.75	–	2.3×10^2

Table 2. Physical characteristics of Pile 1 (OOMS and OTL in 1:1 v/v)

Raw materials	Volume (m^3)	Net weight (kg)	Bulk density (kg l^{-1})	Moisture (%)	Dry weight (kg)
OOMS	15.6	15,600	1.001	64.60	5500
OTL	15.6	3000	0.193	54.80	1350
Mixture	21.0	18,600	0.885	63.01	6900

Table 3. Physical characteristics of Pile 2 (OOMS and WDC in 1:1.5 v/v)

Raw materials	Volume (m^3)	Net weight (kg)	Bulk density (kg l^{-1})	Moisture (%)	Dry weight (kg)
OOMS	10.8	10,800	1.001	64.60	3800
WDC	16.2	3450	0.211	7.30	3200
Mixture	23.7	14,250	0.600	50.85	7000

Table 4. Physical characteristics of Pile 3 (OOMS and OTL in 1:2 v/v)

Raw materials	Volume (m^3)	Net weight (kg)	Bulk density (kg l^{-1})	Moisture (%)	Dry weight (kg)
OOMS	11.9	11,900	1.001	64.60	4200
OTL	22.7	4400	0.193	54.80	2000
Mixture	23.9	16,300	0.681	61.95	6200

Table 5. Physical characteristics of Pile 4 (OOMS, OTL and OTB in 1:1:1 v/v)

Raw materials	Volume (m^3)	Net weight (kg)	Bulk density (kg l^{-1})	Moisture (%)	Dry weight (kg)
OOMS	10.8	10,800	1.001	64.60	3800
OTL	10.8	2100	0.193	54.80	950
OTB	10.8	3350	0.311	35.00	2180
Mixture	25.0	16,250	0.652	56.22	7150

Table 6. Physical characteristics of Pile 5 (OOMS, OTL and OTB in 1:1:2 v/v)

Raw materials	Volume (m^3)	Net weight (kg)	Bulk density (kg l^{-1})	Moisture (%)	Dry weight (kg)
OOMS	8.4	8400	1.01	64.60	3000
OTL	8.4	1600	0.94	54.80	730
OTB	16.8	5200	0.11	35.00	3400
Mixture	27.5	15,200	0.53	53.42	7100

over 50 °C for 158 days with a maximum of 65 °C. The other three, Piles 2, 4 and 5, retained a temperature over 50 °C for 160, 175 and 183 days, respectively, with a maximum of 68, 75 and 73 °C, respectively.

The prolonged thermophilic period recorded in Piles 1 and 3 during the first experimental year is obvious. This was a unique phenomenon, never before experienced in any of the wastes used in composting experiments in Crete (Manios 2004;

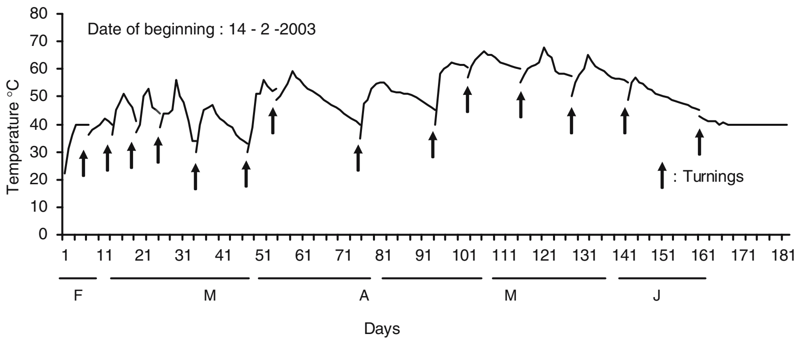

Figure 1. Temperature profile of Pile 1.

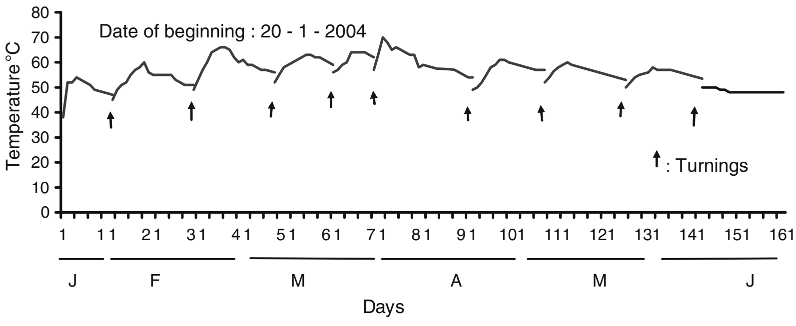

Figure 2. Temperature profile of Pile 2.

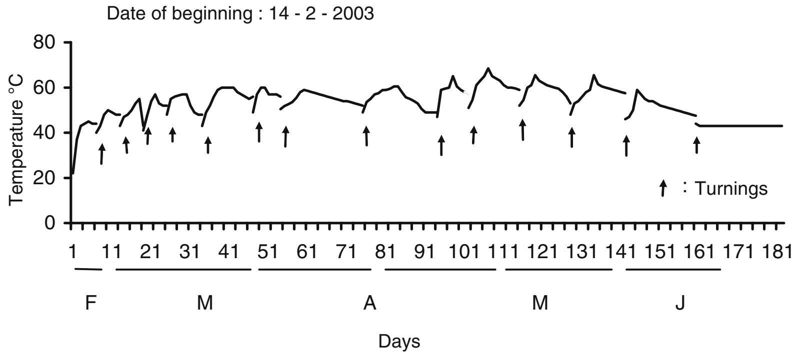

Figure 3. Temperature profile of Pile 3.

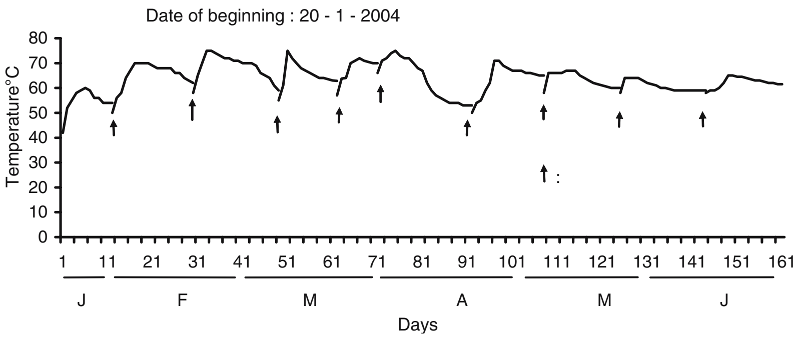

Figure 4. Temperature profile of Pile 4.

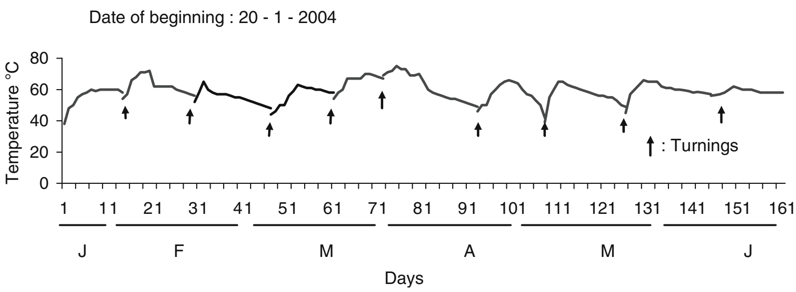

Figure 5. Temperature profile of Pile 5.

Manios et al. 2003, 2004). Manios & Balis (1983) studied OPC, which presented a rather long thermophilic period, but still considerably shorter than those presented in Figures 1 and 3. Neither the high organic matter content nor the frequent turnings could explain this. It was obvious that the oily substances present in the OOMS were the key elements responsible for this behaviour.

It was then suggested that if the concentration of bulking agent was increased, especially with some woodier material which does not decompose easily (i.e. does not contribute substantially to the energy released during composting), this would result in better control of the process and in a shorter thermophilic period. This is in fact an effort to "dilute" the thermogenic oily substances with far less active materials such as lignin, lignocellulose and cellulose. This approach was based on local experience with various materials (Manios 2004; Manios et al. 2003, 2004), as well as data resulting from similar research (Paredes et al. 2002; Sanchez-Monedero et al. 2001). Whenever a woodier bulking agent is used, the thermophilic period presents a modest profile, mainly characterised by lower temperatures.

However, as can be seen in Figures 2, 3 and 5, this was not achieved. The piles have been numbered and sorted based on the increasing rate of bulking agent, allowing the easier presentation of a very interesting situation. According to all five figures, the higher the presence of bulking agent the longer the thermophilic phase. Pile 1, with a bulking ratio of 1:1 with OOMS, records fewer-days of temperatures above 50 °C than Pile 2 (ratio 1:1.5), which in turn records almost the same number of days as Pile 3 (1:2), which records fewer days than Pile 4 (1:2) and far fewer than Pile 5 (1:3). Additionally, the woodier the bulking agent, which should provide the process with a lower rate of self-decomposition, the higher the temperatures. Piles 2, 4 and 5 for example recorded 68, 75 and 73 °C, even though their bulking agent was far woodier than Pile 3, in which only OTL were used.

Figure 6 presents the moisture content progress in Piles 1 and 3. When moisture dropped below 55%, the temperature recorded its highest values in both piles. Additionally, Piles 2, 4 and 5 had moisture content of around 55%, when established (Tables 2, 4 and 5), whereas Piles 1 and 3 had a higher original water content, i.e. above 62% (Tables 1 and 3). This suggests that a lower moisture content indicates better aerobic conditions in combination with the frequent turnings, resulted in the far better decomposition of the OOMS and bulking agent mixtures. If the explanation were this simple, then we should have come across similar phenomena when using high rates or drier bulking agents, with similar materials such as sewage sludge or manure. This however is not the case. Huang et al. (2001) showed that replacing sawdust with leaves resulted in a better decomposition of manure, even though the moisture content was increased. Similar results are presented in work contacted by Manios et al. (2003) and Manios (2004).

Also, if better aerobic conditions are the only reason, then how can the massive loss of volume be explained, especially in Piles 4 and 5? Volumes were reduced approximately by 67%, 62%, 63%, 80% and 84% in Piles 1, 2, 3, 4 and 5, respectively (Table 7). Such massive vaporisation of materials together with a prolonged thermophilic period has not been recorded in any other agricultural waste. Saletes et al. (2004) recorded a volume loss of 85% with oil palm empty fruit branches, accompanied by a 10-week thermophilic period (considerably shorter than that of OOMS) and a weight loss of just 50%, whereas OOMS weight loss reached 83.5%. The question

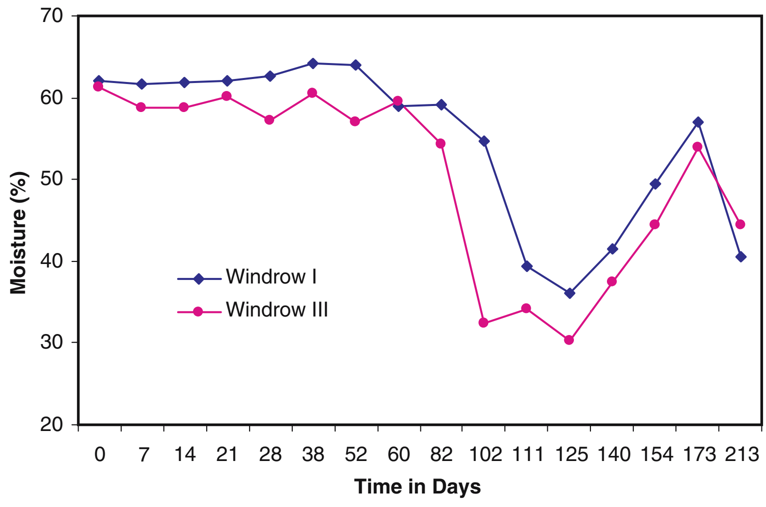

Figure 6. Evolution of moisture content in Piles 1 and 3 during composting.

Table 7. Volume and dry weight changes in Piles 1–5 at the end of the thermophilic period

	Pile 1		Pile 2		Pile 3		Pile 4		Pile 5	
	Volume (m^3)	Dry weight (kg)	Volume (m^3)	Dry weight (kg)	Volume (m^3)	Dry weight (kg)	Volume (m^3)	Dry weight (kg)	Volume (m^3)	Dry weight (kg)
Establishment	21.0	6900	23.7	7000	23.9	6200	25.0	7150	27.5	7100
Final compost	7.0	2500	8.7	1590	9.2	3400	5.0	1400	4.2	1200
Losses (%)	66.8	63.8	63.3	77.2	61.7	45.0	80.0	79.7	85.0	83.5

remains: why does OOMS presence in a pile result in such strange behaviour, contrary to all other agricultural – organic wastes.

The answer was found in composting experiments with crude oil, crude oil sludge or crude oil contaminated soils. The data presented in the relevant papers are very similar and do explain the behaviour of OOMS. According to Vasudevan & Rajaram (2001), when wheat bran was used as a bulking agent in co-composting of crude oil contaminated soil, then the percentage of degradation reached a highest value of 72% and the total number of microorganisms the highest number of 6×10^{13}. The authors explained that this phenomenon was due to the priming effect of the woody bulking agent on the development of the microbiological population. The strong bulking agent provides a surface for the bacteria to develop and these decompose the oil. The authors claim that the general good aeration effect should not be considered the main explanation for these results. This is additionally supported by Hupe et al. (1998), who suggest that any aeration above 1% vol O_2 has no effect on the crude oil decomposing process.

The above approach is supported by Beaudin et al. (1999), who presented data where an increase in the ratio of the bulking agent, consisting of alfalfa leaves (1 cm diameter), from 0% to 63% resulted in a linear increase of the decomposition rate from 0% to 43%, respectively. The same authors indicate that the higher the presence of such bulking agents, the longer the thermophilic phase and the greater the decomposition of the oil. Again, the reason is the development of an adequate surface for the microorganisms to develop and decompose the oil. According to experiments conducted by Kirchmann & Ewnetu (1998), the biodegradation of crude oil in composting soil ranged from 80% to 93%. The highest percentage was recorded when horse manure was continuously added.

What happens with crude oil sludge and soil contaminated with crude oil during composting is that all energy-providing substances are exposed to aerobic microorganisms, which burn the oil like "small engines", releasing energy. The woodier bulking agent originally helps in the development of this population (Vasudevan & Rajaram 2001). As decomposition proceeds, the lignin, cellulose and hemicellulose (in total over 80% of OOMS dry weight and 90% of most mixtures used in these experiments) are cometabolised by microorganisms that develop, which are in turn supported by the retained high temperatures (Tuomela et al. 2000). As result, what is left behind is a form of ash of far smaller volume than the original raw material, exactly as if it had been burned as a fuel.

According to Demirbas & Ilten (2004), the heating value in olive oil production residues is approximately 22 Mj kg^{-1}, while for olive oil it is 37 Mj kg^{-1} and crude oil 45 Mj kg^{-1}. The energy present in 1 kg of crude oil should be considered approximately equal to the energy found in 2–3 kg of OOMS. This explains the massive release of energy for such a long period of time during the composting of both materials. In this case aerobic decomposition (composting) should be considered more like fuel burning in the physical sense of the term rather than as a biological process.

Conclusions

OOMS is a unique material. It should not be considered similar to any other organic waste, especially as far as composting is concerned. It contains large amounts of energy, which are slowly released during aerobic degradation. The use of large amounts of drier bulking agents does not result in the control of this process; instead it enhances it, due to the greater exposure to air. Cometabolism, supported by the prolonged thermophilic phase, also plays an important role resulting in complete decomposition of all organic molecules, including the more stable lignin and cellulose.

Commercial composting using mainly such material must be considered uneconomical, since it would result in extensive thermophilic periods (increasing construction and operation costs) and the production of very small amounts of compost (reducing possible income). It might be useful to investigate the use of OOMS at very small rates (under 1:5 v/v) in order to establish a clearer picture of this material and its behaviour. Again, however, the cost of gathering the required bulking agent substantially reduces the viability of such practice. New and more aggressive methods for treating OOMS should be considered: for example, using it as fuel or incorporating the composting process in greenhouse heating systems (through water heating).

Acknowledgements

This research was funded by the Cooperative Olive Oil Mill of Panagia, in the Municipality of Arkarlochori. We would like to thank the President of the Cooperative, Mr K. Dermitzakis, for his efforts and interest in the completion of the work.

References

Alburquerque JA, Gonzalvez J, Garcia D & Cegarra J (2004) Agrochemical characterisation of "alperujo", a solid by-product of the two-phase centrifugation method for olive oil extraction. Bioresour. Technol. 91: 195–200

Beaudin N, Caron RF, Legros R, Ramsay J & Ramsay B (1999) Identification of the key factors affecting composting of a weathered hydrocarbon-contaminated soil. Biodegradation 10(2), 127–133

Demirbas A & Ilten N (2004) Fuel analyses and thermochemical processing of olive residues. Energ. Sources 26: 731–738

FCQAO (1996) Methods Book for the Analysis of Compost. Federal Compost Quality Assurance Organization – Bundesgutegemeinschoft Kompost e.v, Abfall Now e.v. Publishing House, Stuttgart, Germany

Garcia-Gomez A, Roig A & Bernal MP (2003) Composting of the solid fraction of olive mill wastewater with olive leaves: organic matter degradation and biological activity. Bioresour. Technol. 86: 59–64

Huang GF, Fang M, Wu QT, Zhou LX, Liao XD & Wong JWC (2001) Co-composting of pig manure with leaves. Environ. Technol. 22: 1203–1212

Hupe K, Heerenklage J, Woyczechowski H, Bollow S & Stegmann (1998) Influence of oxygen on the degradation of diesel fuel in soil bioreactors. Acta Biotechnol. 18: 109–122

Kirchmann H & Ewnetu W (1998) Biodegradation of petroleum-based oil wastes through composting. Biodegradation 9: 151–156

Louloudis LP (1985) Socio-economic and environmental side effects of technological change: the case of olive oil mills in rural Greece., In: Hall DO, Myers N and Margaris N.S. (Eds) Economics of Ecosystems Management, Junk Publication, Dordrecht, Netherlands

Manios V & Balis C (1983) Respirometry to determine optimum conditions for the biodegradation of extracted olive press-cake. Soil Biol. Biochem. 15: 75–83

Manios T (2004) Evaluating the composting potential of different organic solid wastes from the island of Crete and the quality of the end product. Environ. Int. 29: 1079–1089

Manios T, Maniadakis K, Kalogeraki M, Mari E, Terzakis S, Magiatis P, Mikros E, Skaltsounis LA & Manios V (2004) Co-composting of olive residuals and green waste on Crete. Biocycle 45: 67–70

Manios T, Maniadakis K, Frantzeskaki N, Stentiford EI, Manios V, Kritsotakis I & Dialynas G (2003) Pilot scale sewage sludge composting in the Island of Crete, Greece. Biocycle 44: 53–55

Paredes C, Bernal MP, Cegarra J & Roig A (2002) Biodegradation of olive oil mill wastewater sludge by its co-composting with agricultural wastes. Bioresour. Technol. 85: 1–8

Saletes S, Siregar FA, Caliman JP & Liwang T (2004) Lignocellulose composting: case study on monitoring oil palm residuals. Compost Sci. Util. 12: 372–382

Sanchez-Monedero MA, Roig A, Paredes C & Bernal MP (2001) Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresour. Technol. 78: 301–308

Tuomela M, Vikman M, Hatakka A & Itavaara M (2000) Biodegradation of lignin in a compost environment: a review. Bioresour. Technol. 72: 169–183

Vasudevan N & Rajaram P (2001) Bioremediation of oil sludge-contaminated soil. Environ. Int. 26: 409–411