Methane and carbon dioxide emission in a two-phase olive oil mill sludge windrow pile during composting

Thrasyvoulos Manios a,*, Konstantinos Maniadakis a, Panagiotis Boutzakis a, Yiannis Naziridis b, Katia Lasaridi c, George Markakis a, Edward I. Stentiford d

a School of Agricultural Technology, Technological Education Institute of Crete, Heraklion 71004, Crete, Greece
b Department of Environmental Engineering, Technical University of Crete, Chania 73100, Crete, Greece
c Department of Geography, Harokopio University of Athens, Kalithea 17671, Athens, Greece
d School of Civil Engineering, Leeds University, Leeds LS2 9JT, UK

Accepted 23 May 2006

Abstract

The aim of this work was to make some preliminary evaluations on CO₂ and CH₄ emissions during composting of two-phase olive oil mill sludge (OOMS). OOMS, olive tree leaves (OTL) and shredded olive tree branches (OTB) were used as feedstock for Pile I and Pile II with a 1:1:1 and 1:1:2 v/v ratio, respectively. Each pile was originally 1.2 m high, 2.0 m wide and approximately 15.0 m long. Four 500 ml volume glass funnels were inverted and introduced in each pile, two in the core (buried 50–60 cm from the surface) and two near the surface under a thin 10–15 cm layer of the mixture. Thin (0.5 cm diameter) plastic, 80 cm long tubes were connected to the funnels. A mobile gas analyser (GA2000) was used to measure the composition (by volume) of O₂, CO₂ and CH₄ on a daily basis. The funnels were removed prior to each turning and reinserted afterwards. From each pair of funnels (core and surface) of both piles, one was kept closed between samplings. Two way ANOVA was used to test differences between piles and among the tubes. Post hoc Tukey tests were also used to further investigate these differences. There was a significant difference (at \( p < 0.001 \)) in the two piles for all three gases. The average concentrations of O₂, CO₂ and CH₄ in Pile I, from all four funnels was 16.86%, 3.89% and 0.25%, respectively, where for Pile II the average values were 18.07%, 2.38% and 0.04%, respectively. The presence of OOMS in larger amounts in Pile I (resulting in more intense decomposing phenomena), and the larger particle size of OTB in Pile II (resulting in increasing porosity) are the probable causes of these significant differences. Samples from open funnels presented lower, but not significantly lower, O₂ composition (higher for CO₂ and CH₄) in comparison with closed funnels in both depths and both piles. Not significant were also the different mean gas compositions between core and surface funnels in the same pile.

© 2006 Published by Elsevier Ltd.

1. Introduction

Greenhouse gases and their global effect on the earth’s environment have altered the scientific community’s approach towards what is and is not environmentally friendly (Botkin and Keller, 1998; Pickering and Owen, 1997). As a result, composting must be re-evaluated regarding: (i) the amount of gases that are produced during both the thermophilic and maturation periods, (ii) gas composition during both periods, (iii) the effect physiochemical characteristics of the raw materials have on gas production and synthesis, and (iv) the effect that management practices such as turning and watering have on gas emission (Peigne and Girardin, 2004).

Hao et al. (2001) evaluated the effect on greenhouse gases (GHG) emissions of the composting method. Both CO₂ and CH₄ emission was higher in the windrow system than the passive aeration system. Beck-Friis et al. (2000) suggested that there is a considerable effect on the GHG emission from a windrow of both the handling of raw materials (size of piles) and of its composition. According
to their findings, the larger the pile the more CH4 is generated, regardless of the frequency of turnings. In smaller piles, aerobic and anaerobic conditions co-exist, resulting in lower concentration of CH4, a gas that is considered to have more impact as a greenhouse gas than CO2. The key role of the raw material in GHG emission was additionally supported by work of Peigne and Girardin (2004), who conclude that it affects the moisture content and porosity of the mixture. Larger porosity increases air entrapment that results in organic matter decomposition in a predominantly aerobic way, with smaller CH4 and CO2 emissions. There is additional work on the subject by a large number of researchers, mainly with different organic wastes, their GHG production and emission profiles (Sommer and Möller, 2000; Amon et al., 2001; Sommer et al., 2004).

In the Mediterranean region, one of the most important agricultural–industrial wastes is that produced by olive oil mills. In the two-phase centrifugal olive oil mill (TPOM), 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 an approximate moisture content of 65%. The ratio of OOMS to olive fruits for the TPOM is 0.7:1, while the ratio for just OMW of the three-phase mill (the most common type of mill) is 1.5:1, which supports the idea that TPOM are more environmentally friendly. The standard practice with OMW is its transfer to a lagoon until the summer sun evaporates the water leaving a thin layer of sludge in the bottom. This practice has as a result the anaerobic decomposition of the organic fraction of OMW (BOD5 up to 100,000 mg/L) producing excessive amounts of CH4 (Lagoudianaki et al., 2003). On the other hand the lower volume of OOMS could be composted, meaning aerobically treated, and consequently release lower impact GHG gases (mainly CO2). Work by Manios et al. (in press) and García-Gómez et al. (2003) has indicated that a very serious problem with this material is the prolonged thermophilic phase, which is three times longer than for most other organic wastes. Such a prolonged thermophilic phase will require composting sites and commitment of equipment and personnel three times larger than an equal amount of sewage sludge, for example, increasing substantially the production cost. Additionally, during this period, up to 84% of the weight of the OOMS and bulking agent mixture is lost, decreasing the amount of commercially valuable end product (Manios et al., in press).

In order to establish the overall environmental impact of the composting processes, it is important to estimate both qualitatively and quantitatively the GHG emission. The work in this paper aims to:

(a) provide some preliminary data for methane and carbon dioxide production and composition in OOMS windrows;

(b) evaluate the effect of bulking ratio on methane and carbon dioxide gas concentrations;

(c) determine the most appropriate measuring–monitoring technique; and

(d) evaluate the effect of turning on methane and carbon dioxide gas concentrations.

2. Materials and methods

One of the largest TPOM in Crete, producing up to 600 tonnes of olive oil, is found in the village of Panagia in the Municipality of Arkarofhori, in the centre of the Heraklion Prefecture. Sludge and olive tree leaves (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. Olive tree branches (OTB) were collected from the Technological Education Institute of Crete’s (TEI of Crete) olive trees, after harvesting and pruning. The branches were shredded into approximately 2.0 cm long chips using a knife shredder.

Using the windrow technique in the pilot composting plant of TEI of Crete (Manios et al., 2003), two different trials took place. The following ratios were used: Pile I, OOMS:OTL:OTB in 1:1:1 v/v; Pile II, OOMS:OTL:OTB in 1:1:2 v/v. Each pile was 1.2 m high, 2.0 m wide and approximately 15.0 m long. A composting turner was used, and turning took place at 1–3 week intervals. Temperature was measured in the core of the piles on a daily basis using long digital thermometers, which were calibrated annually. Samples were collected, also from the core, after each turning and analysed using the Standard Methods for the Analyses of Compost (FCQAO, 1996) for a variety of physiochemical parameters such as moisture, electrical conductivity, and pH. Table 1 presents some important physiochemical characteristics for both piles. The duration of the process was determined by the temperature profile of the piles. The frequency of turnings was based on temperature fluctuation, turner availability and research team experience.

Four 500 ml volume glass funnels were inverted and introduced in each pile, two in the core (buried 50–60 cm from the surface) and two near the surface under a thin 10–15 cm layer (Fig. 1). Thin plastic tubes 80 cm long tubes were connected to the funnels. For each pair of funnels, one tube was kept closed during sampling events. For Pile I, the funnels were given the following code names: PISO surface funnel open, PISC surface funnel closed, PICO core funnel open, and PICC core funnel close. The respective code names for Pile II were: PISO, PISC, PIICO and PIICC. A mobile gas analyser (GA2000, Geotechniques Instruments) was used to measure the volume composition of O2, CO2 and CH4. The methane detection limit using this instrument was 0.1%. The analyser was operated for approximately 45 s before recording the presented values. This time was calculated as being appropriate for a gas mixture in the funnel to reach the analyser and to avoid
analysing the air in the tubes. Before starting another measurement, the analyser was operated in open air until values indicated that it had been flushed with clean air. The funnels were removed prior to each turning and reinserted afterwards. Measurements were taken on a daily basis. Mean values of the measurements conducted after the nine turnings, for all three gases, for all eight funnels and in both piles, were calculated. Data before the first turning are not included in the analysis. Two way ANOVA was used to test the significance of differences among these nine mean values, among the funnels in the two piles and among the funnels of each pile. Post hoc Tukey tests were used to further investigate these differences ($p < 0.001$).

### 3. Results and discussion

Figs. 2–5 show the fluctuation of all three gases in Pile I, and Figs. 6–9 show the results from Pile II. Table 2 presents the two way ANOVA and Post hoc Tukey test results for all eight funnels and for all three gases, together with the average of the nine recorded values after turnings. In each column for each gas, average values followed by different symbols are significantly different. According to the test results, there is significant difference between the two piles for all three gases, independent of the way it was monitored (open-closed funnels/core–surface location). Since all handling processes were the same for both piles, as well as the physiochemical characteristics of the raw materials, it is the rate (by volume) of the raw materials used to compose the two piles that is responsible for this significant difference.

Pile II contains larger amounts of shredded OTB, resulting in a lower density mixture than Pile I, which would allow: (a) better flow of air inside the windrow, and (b) increased air entrapment. This difference could explain the increased concentrations of O$_2$ and the far smaller CH$_4$ concentrations in Pile II, which were 18.07% and 0.04%, respectively, compared to those of Pile I, which were 16.86% and 0.25%, respectively. The larger presence of CH$_4$ in Pile I than in Pile II indicates that anaerobic conditions in that pile are more predominant resulting also in higher CO$_2$ concentrations of 3.89% compared to the 2.38% of Pile II. According to Tchobanoglous et al. (1993), during the methane fermentation phase in a landfill
the gas that is produced by the anaerobically decomposing organic fraction of MSW is a mixture of CH$_4$ and CO$_2$ in similar concentrations (around 50%).

According to Table 3, at installation the dry weights of Pile I and Pile II were 7150 kg and 7100 kg, respectively. Pile I weight was reduced by almost 80.0%, where Pile II weight was reduced by almost 80.0%, where Pile II

Fig. 3. Gas composition recorded for Pile I, Surface sampling and Closed Funnel (PISC). Methane concentration of 1.3% was recorded at 72 days and is not shown.

Fig. 4. Gas composition recorded for Pile I, Core sampling and Open Funnels (PICO). Methane concentration of 6.0% was recorded at 2 days and is not shown.

Fig. 5. Gas composition recorded for Pile I, Core sampling and Closed Funnel (PICC). Methane concentration of 4.0% and 2.4% was recorded at 2 and 52 days, respectively, and is not shown.

Fig. 6. Gas composition recorded for Pile II, Surface sampling and Open Funnels (PIISO). Methane concentration of 1.1% was recorded at 82 days and is not shown.

Fig. 7. Gas composition recorded for Pile II, Surface Sampling and Closed Funnel (PIISC).

Fig. 8. Gas composition recorded for Pile II, Core Sampling and Open Funnel (PIICO).
The prolonged thermophilic period of more than 160 days was the reason for these large mass losses in both piles (Fig. 10). For Pile I, the mean temperature during 161 days was 63.6 °C (with standard deviation of ±5.9 °C), where for Pile II the mean temperature was 58.8 °C (with standard deviation of ±6.6 °C) for the same period of time. Even though those differences were not significant, they indicate a more energy generating decomposition process in Pile I than in Pile II, which was the result of more active substrate (i.e., larger concentrations of OOMS).

The mean ratio of CO₂ to CH₄ composition in each pile and from all four funnels was 16.5:1 for Pile I and 55.2:1 for Pile II. Combining data presented in Table 1 with those of Table 3, the carbon weight initially in Pile I was approximately 3700 kg and in Pile II was 3670 kg. At the end of the trial the respective loses were 2960 kg and 3052 kg. Based on the ratios of CO₂ to CH₄ emissions from those two piles, it is suggested that the carbon lost as CO₂ in Pile I was equivalent to 2791 kg and for CH₄ was 169 kg. For Pile II those equivalent values were 2998 kg and 54 kg, respectively.

These are strong indications that the additional bulking agent results in far more aerobic conditions in Pile II than Pile I. Sommer and Moller (2000), when composting deep litter from pig production using various amounts of straw, recorded similar results. Where straw was used in larger amounts, the production of CO₂ and CH₄ was reduced while O₂ was high and near to atmospheric as is the case with Pile II. Also, as can be seen in Figs. 2–6, CH₄ appears far later in the process in Pile II than in Pile I (after day 71) and only when turnings are becoming less frequent, allowing the buildup of CO₂ and the consumption of O₂. These conclusions are also supported by work published by Beck-Friis et al. (2000).

Based on Figs. 2–5 and the ANOVA analysis presented in Table 2, there is no significant difference between the PISO and the PICO for O₂, CO₂ and CH₄, as well as between PIISO and PIICO (Figs. 6–9 and Table 2). Similarly, there is no significant difference between PISC and PICC for all three gases, as well as between PIISC and PIICC. These results indicate that the depth does not play an important role, at least in windrow piles of similar dimensions. The insignificance of sampling depth can be explained as a result of the vertical flow of gases through the pile from the core, due to the difference in temperature, filling the volume of the inverted surface funnels with similar gases as those produced in the core. Sommer and Moller (2000) and Hao et al. (2001) presented some variations between surface and deeper measuring points; however, Beck-Friis et al. (2000) suggested that in a small pile of

Table 2
Mean gas concentrations measured and results of two way ANOVA and Post hoc Tukey analyses on gas concentrations

<table>
<thead>
<tr>
<th>Location of sample</th>
<th>Surface</th>
<th>Surface</th>
<th>Core</th>
<th>Core</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funnel condition</td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
<td>Closed</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pile I</td>
<td>16.42*</td>
<td>16.91*</td>
<td>16.88*</td>
<td>16.97*</td>
<td>16.79</td>
</tr>
<tr>
<td>Pile II</td>
<td>17.74*</td>
<td>18.17*</td>
<td>17.64*</td>
<td>18.09*</td>
<td>17.91</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pile I</td>
<td>4.38*</td>
<td>3.68*</td>
<td>3.91*</td>
<td>3.80*</td>
<td>3.94</td>
</tr>
<tr>
<td>Pile II</td>
<td>2.75*</td>
<td>2.36*</td>
<td>2.81*</td>
<td>2.33*</td>
<td>2.56</td>
</tr>
<tr>
<td>CH₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pile I</td>
<td>0.330</td>
<td>0.132</td>
<td>0.261</td>
<td>0.389</td>
<td>0.278</td>
</tr>
<tr>
<td>Pile II</td>
<td>0.072*</td>
<td>0.032*</td>
<td>0.047*</td>
<td>0.033*</td>
<td>0.184</td>
</tr>
</tbody>
</table>

The detection limit for all gases was 0.01%. *: In each column for each gas, mean values followed by a different symbol are significantly different (p < 0.001).

Table 3
Physical characteristics of Pile I (1:1:1 v/v) and Pile II (1:1:2 v/v) at installation

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Volume (m³)</th>
<th>Wet weight (kg)</th>
<th>Bulk density (kg/l)</th>
<th>Moisture (%)</th>
<th>Dry weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOMS</td>
<td>10.8</td>
<td>10,800</td>
<td>1.001</td>
<td>64.60</td>
<td>3800</td>
</tr>
<tr>
<td>OTL</td>
<td>10.8</td>
<td>2100</td>
<td>0.193</td>
<td>54.80</td>
<td>950</td>
</tr>
<tr>
<td>OTB</td>
<td>10.8</td>
<td>3350</td>
<td>0.311</td>
<td>35.00</td>
<td>2180</td>
</tr>
<tr>
<td>Pile I</td>
<td>25.0</td>
<td>16,250</td>
<td>0.652</td>
<td>56.22</td>
<td>7150</td>
</tr>
<tr>
<td>OOMS</td>
<td>8.4</td>
<td>8400</td>
<td>1.001</td>
<td>64.60</td>
<td>3000</td>
</tr>
<tr>
<td>OTL</td>
<td>8.4</td>
<td>1600</td>
<td>0.194</td>
<td>54.80</td>
<td>730</td>
</tr>
<tr>
<td>OTB</td>
<td>16.8</td>
<td>5200</td>
<td>0.311</td>
<td>35.00</td>
<td>3400</td>
</tr>
<tr>
<td>Pile II</td>
<td>27.5</td>
<td>15,200</td>
<td>0.553</td>
<td>53.42</td>
<td>7100</td>
</tr>
</tbody>
</table>
In one case, turning did appear to have an effect on gas composition. After turning at day 71, CH$_4$ presents large peaks between days 74 and 85. This is independent of the composition of the two piles, and the placement and status of funnels (open or closed). Peaks can be found in other time periods also, but never as common as in this period.

Fig. 10 presents the temperature variations in both piles. The arrows indicate where turning took place.
sting even a fraction of the OOMS currently produced (or which could be produced) in Crete, would require large quantities of OTB, resulting in increased composting costs. It is estimated that collection and shredding of the necessary OTB will be equal to 25% of the annual operating costs in a commercial composting site of OOMS in the centre of the main olive oil producing areas of Crete. The possible use of woodchips instead of OTB has been evaluated, showing similar costs since large amounts of woodchips would have to be transported from the urban areas of the island.

The turning of the piles every 2 weeks in this study appeared to be adequate to avoid major anaerobic episodes. This is probably because the porosity of the material was good for both mixtures. Additionally the results suggest that the placement of the monitoring system near the core of the winrow or near the surface has no significant effect on the accuracy of the recording, and neither does the choice of use of open or closed funnels. Further investigation on the use of such funnels must be conducted with a variety of other compost materials.

Acknowledgements

The Cooperative Olive Oil Mill of Panagia, in the Municipality of Arkarlochori, funded this research. We thank the President of the Cooperative, Mr. K. Dermitzakis, for his efforts and interest in the completion of the work.

References


