



Greenhouse gas emissions from home composting of organic household waste

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ABSTRACT

The emission of greenhouse gases (GHGs) is a potential environmental disadvantage of home composting. Because of a lack of reliable GHG emission data, a comprehensive experimental home composting system was set up. The system consisted of six composting units, and a static flux chamber method was used to measure and quantify the GHG emissions for one year composting of organic household waste (OHW). The average OHW input in the six composting units was 2.6–3.5 kg week⁻¹ and the temperature inside the composting units was in all cases only a few degrees (2–10 °C) higher than the ambient temperature. The emissions of methane (CH₄) and nitrous oxide (N₂O) were quantified as 0.4–4.2 kg CH₄ Mg⁻¹ input wet waste (ww) and 0.30–0.55 kg N₂O Mg⁻¹ ww, depending on the mixing frequency. This corresponds to emission factors (EFs) (including only CH₄ and N₂O emissions) of 100–239 kg CO₂-eq. Mg⁻¹ ww. Composting units exposed to weekly mixing had the highest EFs, whereas the units with no mixing during the entire year had the lowest emissions. In addition to the higher emission from the frequently mixed units, there was also an instant release of CH₄ during mixing which was estimated to 8–12% of the total CH₄ emissions. Experiments with higher loads of OHW (up to 20 kg every fortnight) entailed a higher emission and significantly increased overall EFs (in kg substance per Mg⁻¹ ww). However, the temperature development did not change significantly. The GHG emissions (in kg CO₂-eq. Mg⁻¹ ww) from home composting of OHW were found to be in the same order of magnitude as for centralised composting plants.

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1. Introduction

Home composting is an interesting alternative to centralised composting. Since the landfill directive came into force in 1999 (CEC, 1999), the organic fraction of waste going to landfills in the European Union has been diverted to other treatment facilities such as composting plants. This has generated a greater need for well-managed composting plants or the possibility of avoiding organic waste in municipal waste streams by composting at home. The actual amount of organic household waste (OHW) that is composted at home and thereby diverted away from landfills is poorly researched. However, it has been estimated that approximately 20% of OHW could be diverted to home composting in a study area of west London, UK (Smith and Jasim, 2009). This number, however, depends on the motivation of the people in the survey area compared with the motivation of people in the average home composting community.

Like centralised composting, home composting has some advantages such as the production of a nutrient-rich humus-like material for use on soil as a substitute for fertiliser and/or for peat in growth media. When composting organic waste in private gardens, less waste has to be directed to centralised composting (or other treatment facilities) thereby saving emissions related to collection and transportation. The use of electricity, diesel, lubricating oils, and motor oil during the operation of centralised composting plants is also avoided when organic waste is home composted (Andersen et al., in press). Home composting is a unique waste management option because the waste producer is also the processor and end-user of the product. This, however, results in a large variety of operation schemes, which means that there is no standardised procedure for home composting. This is one of the reasons for the lack of scientific knowledge in this field.

Like centralised composting, there are environmental impacts associated with home composting, in which the potential emission of greenhouse gases (GHGs) is one of the most important (Colón et al., 2010). The GHGs of interest are mainly methane (CH₄) and nitrous oxide (N₂O) because they have high global warming potentials (GWPs) and thereby contribute to climate change. The GWP of CH₄ and N₂O is 25 and 298 over a 100-year time frame, respectively (Solomon et al., 2007), indicating that they are 25 and 298 times more potent GHGs than (fossil) carbon dioxide (CO₂). The CO₂ emitted during composting originates from the degradation

Abbreviations: EF, emission factor; GHG, greenhouse gas; GWP, global warming potential; OHW, organic household waste.

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of plant material and is usually accounted as neutral with respect to global warming (i.e. the GWP is zero) (Christensen et al., 2009).

GHG emissions have previously been addressed in composting studies in bench scale (Beck-Friis et al., 2001), pilot scale (Beck-Friis et al., 2000), and full scale (Amlinger et al., 2008; Andersen et al., 2010) studies, with a variety of waste types such as garden and food waste. In addition, Boldrin et al. (2009) reported on a wide range of estimated and measured GHG emission data in a literature review covering open and closed technologies as well as home composting. Collectively, it was found that CH₄ is produced and emitted when composting organic waste even under well-aerated conditions. Nitrous oxide is also produced under all these different operation schemes. GHG emissions have previously been addressed in home composting but with very different approaches and conclusions. Some studies have found GHG emissions to be negligible because the measuring systems were set with too high detection limits. In home composting studies by Wheeler and Parfitt (2002), McKinley and Williams (2007), and Smith and Jasim (2009), CH₄ emissions were quantified with measuring equipment with detection limits of 0.1%, 0.1% and 1% (by volume). The detection limit has to be significantly lower (in the $\mu\text{L L}^{-1}$ level) to measure CH₄ emissions from home composting units. Other authors argue that home composting piles are rarely large enough to permit anaerobic conditions and, therefore, their studies neglect CH₄ emissions (USEPA, 1998; Smith et al., 2001). By contrast, Amlinger et al. (2008) reported in a comprehensive experimental setup (high-load home composting) that GHG emissions from home composting are at the same level as from centralised composting. Weidema et al. (2006) modelled (in a lifecycle-based cost-benefit assessment) that home composting is an intermediate between aerobic and anaerobic digestion. This resulted in home composting being the least preferable waste management option in respect to global warming, even worse than central composting and uncontrolled landfills. In a life cycle assessment by Lundie and Peters (2005) different food waste management options were assessed in relation to global warming contributions. The most favourable option was found to be home composting assuming aerobic conditions (no methane) while the least favourable option was home composting assuming anaerobic conditions. These studies show the need for reliable GHG emission factors (EFs) from home composting systems. In this context, EFs are expressed as the mass of the respective gas per mass of input OHW (in kg Mg^{-1} input wet waste (ww)). Emission factors can be used in green accounts and for environmental assessments, but it is important to gather quan-

titative data to improve the comparability, consistency, and accuracy of databases and models.

The main objectives of this paper were to establish a representative single-family home composting system and measure the GHG emissions to obtain reliable EFs from home composting of OHW. It was important that the experimental setup represented a common single-family home composting practice based on conditions in Denmark, which is in a temperate climate zone with average winter temperatures of 0.5 °C and average summer temperatures of 15 °C. All EFs given in this paper are representing the contributions from the actual degradation of OHW. All other contributions from for example making the composting unit, collection, transport and mechanical turning have not been included.

2. Materials and methods

2.1. Composting units

The six home composting units (Humus/Genplast, 8230 Åbyhøj, Denmark) used in the study are the most commonly used units in Denmark. They are cone-shaped, made of recycled PE and PP and weigh 22 kg. The total volume is 0.32 m³ and the dimensions are 95 cm in height and 48 cm and 105 cm in diameter (top and bottom, respectively). The composting units are equipped with a lid, a fine-meshed steel net at the bottom, which prevents mice and rats from entering, a hatch where the mature compost can be withdrawn, and a net to prevent flies from entering. The bottom has plenty of holes from where the surrounding air can enter the composting unit. A plastic rim, which acted as a base for the flux chamber (used to measure the emissions; see Section 2.5), was inserted below the lid of each unit. The plastic rim was inserted below the anti fly net so it functioned as the only outlet during the emission measurements. A schematic drawing of one of the composting units is shown in Fig. 1 (left) and a picture is shown in Fig. 1 (right). The only differences in the management of the six units were the type and amount of input waste and frequency of mixing. Mixing consisted of manually aerating the material using a mixing stick made of recycled PE and PP (delivered together with the composting unit). Units 1 and 2 represented eager management (mixing every week), which is not considered a likely management approach. Units 3 and 4 were considered the most likely setup for home composting (mixing every sixth week), whereas Units 5 and 6 represented the lazy home composters that spend little time on the process (no mixing). The management of the composting

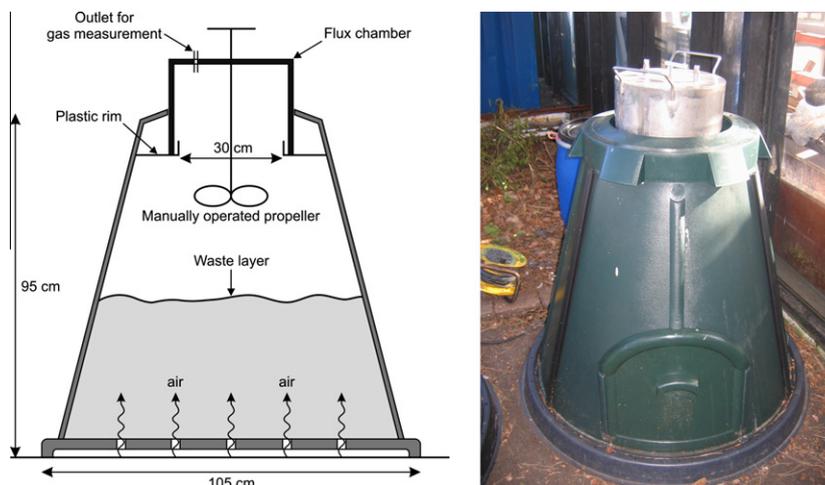


Fig. 1. Left: Schematic drawing of one of the composting units including the position of the flux chamber system during measurement campaigns. The possible flow of air through the bottom of the composting unit is shown with arrows on the drawing. Right: Picture of one of the composting units.

Table 1

Mixing frequency, amounts of input waste to the six composting units during the experiment and moisture content of the input waste. The numbers in brackets are for the high-load phase.

Unit number	Mixing frequency	Incoming ww ^a (kg)	Average addition of ww ^a per week (kg)	Moisture content of input ^b (%)
1	Every week	184	3.5	71.4
2	Every week	176	3.4	76.0
3	Every 6th week	146	2.8	73.0
4	Every 6th week	151 (130)	2.9 (8.9)	78.9
5	No	115 (20)	2.2 (1.4)	63.8
6	No	169	3.2	77.6

^a ww, wet waste.

^b The moisture content was measured by sampling 1% of the input material to each of the composting units, followed by drying the samples at 70 °C for 72 h (or until stable weight).

units, the amounts of input waste for one year of composting and the moisture content of the input materials are presented in Table 1.

2.2. Experimental outline

The home composting experiments were divided into three phases. The initial phase consisted of a two-month start-up period (mid-March to mid-May 2008) in a single composting unit to test the analytical equipment and experimental setup in general (results from the start-up phase are not presented here). After the start-up phase, the waste in the composting unit was mixed, sampled, and distributed into six equivalent units for a base load of waste to be added for the main experiment. The main composting phase (second phase) in the six composting units was monitored for one year (May 2008 to May 2009). The third and last phase consisted of a maturation phase in which no more waste was added to the units, except for Units 4 and 5, in which additional experiments (high-load phase) were performed for three months (June 2009 to August 2009) to examine the effect of increased amounts of input waste. Up to 25 kg of OHW was added every fortnight to Unit 4 and large amounts of garden waste (around 3 kg every fortnight) was added to Unit 5 during the high-load phase. These additional experiments tested whether the temperature and gas emissions were affected by increased waste input. An increased waste load can simulate multi-family composting rather than single-family home composting. Including the start-up phase, the composting phase, the maturation phase, and the high-load phase, the system was monitored for nearly two years (March 2008 to January 2010).

2.3. Feedstock

The composting units were fed with OHW and low amounts of garden waste. In this context, OHW was primarily food waste but also consisted of small amounts of dead flowers, flower clippings, and soil from plants in the household. The units were fed approximately twice a week and the waste was weighed before adding. The OHW was supplied by volunteers from the Department of Environmental Engineering, Technical University of Denmark, and it was assumed that the feedstock for each of the composting units represented food waste from a Danish single-family household. Each of the composting units was fed with waste from two volunteers, which means that the input material was different in all composting units. A typical Danish household engaged in home composting on average process 45–55 kg OHW year⁻¹ (0.9–1.1 kg week⁻¹) according to Petersen and Kielland (2003). The amounts of food waste added to the composting units in this study were larger (2.6–3.5 kg week⁻¹ on average during the composting phase) than the average suggested by Petersen and Kielland (2003). This was considered to represent “good home composting practice”, meaning that it

represented households that composted more OHW than the average family. The waste suppliers were provided with the normal official guidelines for composting from the manufacturer of the composting units, but they had no additional information on what kinds of waste materials were suited to composting. The guidelines discouraged composting of paper, cardboard (difficult to degrade) and meat and dairy products (to avoid odours and attraction of vectors and vermin). The authors added the garden waste in regular small amounts (0.12–0.15 kg week⁻¹) to supply structural material to the compost material.

2.4. Temperature measurements

Temperature development was followed during composting in all six units as well as in the ambient air. Temperature was measured twice a week during the main experiment and less frequent in the maturation phase. The measurements were performed in the centre of the waste material with a thermometer attached to a rod (Ebro TFN520, Ingolstadt, Germany).

2.5. Measurements of gaseous emissions

To measure GHG emissions, a static flux chamber system was fixed to each of the composting units. The monitored gases were CO₂, CH₄, N₂O and carbon monoxide (CO). The static flux chamber method has been described by Livingston and Hutchinson (1995), Beck-Friis et al. (2000), and Scheutz et al. (2003) among others. It is based on diffusion as the dominant transport mechanism. The concentrations of gases inside the composting units were elevated because of the build-up under the lid. Before measuring the emission of gases, the air in the composting units was therefore, exchanged to start the measurement as close to ambient concentrations as possible. The flux chamber was placed on top of the composting unit (Fig. 1) and the emission of gases (E_{gas}) from the compost material resulted in a linear increase of the gas concentration over time (dC_{gas}/dt). When the total volume of air inside the unit (V_{total}) is known, E_{gas} can be calculated according to Eq. (1):

$$E_{\text{gas}} = \frac{dC_{\text{gas}}}{dt} \times (V_{\text{total}}) \quad (1)$$

V_{total} is in this case the volume of the flux chamber (0.015 m³) plus the volume of the head space in the composting unit, which decrease over time as the unit is filled with waste (initially 0.32 m³). It is assumed that the entire volume was totally mixed during emission measurements and this was ensured by mixing the air manually with a propeller. The head space volume was estimated for every emission measurement by measuring the height of the waste in the composting units. The flux chamber method was used approximately twice a week during the composting phase and less frequently in the maturation phase. The emission measurements were performed before each addition of waste. In this way, each emission measurement represented the emission of gases since the last addition of waste (normally 3–4 days before). All emission measurements were performed over approximately 6 min, which gave linear responses for all gases measured. In total, 98 emission measurements were performed per composting unit. To obtain emission estimates from the entire composting process, all the emission measurements were integrated over time (time between measurements) and summed over the entire year of composting. The emission estimates (in kg h⁻¹) were divided by the total input waste amount ($m_{\text{input waste}}$) to obtain EFs (in kg Mg⁻¹ ww) (EF_{gas}) as seen in Eq. (2)

$$EF_{\text{gas}} = \frac{\sum_{t_1}^{t_2} E_{\text{gas}} dt}{m_{\text{input waste}}} \quad (2)$$

Two sets of experiments were performed on the emission dynamics and effect of mixing the material in the composting units. The experiments were carried out in July 2008 and November 2008, and the objective was to follow the variations of emissions more intensively over a short period of composting. The experiments included around 15 emission measurements over approximately four days and included two additions of waste (including mixing of the material in Units 1 and 2).

2.6. Analytical apparatus

The gas concentrations were analysed onsite for CO₂, CH₄, N₂O and CO using a photo acoustic gas monitor (INNOVA 1312, Lumasense Technologies A/S, 2750 Ballerup, Denmark). This instrument measures concentrations in real time, has high accuracy over a broad concentration range and only one calibration is necessary per year (calibration is done by the manufacturer). The inlet was equipped with a water filter (Genie membrane separator, A+ Corporation, Gonzales, LA, USA) to ensure that no moisture was transferred to the measuring chamber. Calibration was in the ranges 1.5–10,000 ppmv for CO₂, 0.4–20,000 ppmv for CH₄, 0.03–50 ppmv for N₂O, and 0.2–50 ppmv for CO.

3. Results

3.1. Temperature development during composting

Temperature development during home composting is presented in Fig. 2 with an example from Unit 1. All composting units showed the same temperature development as Unit 1. The temperature followed seasonal changes well. The ambient temperature was around 10–15 °C at the beginning of the process (in May 2008), increasing to 20 °C during summer and dropping to below 0 °C in winter. The temperature in the compost material was in all cases 1–10 °C higher than the ambient temperature but in most cases only 1–4 °C higher. The end of the composting phase (the last addition of waste to the unit) is shown with a dotted line in Fig. 2. It is clear that the same tendency continued throughout the maturation phase; however, the difference in temperature between the inside and ambience was slightly lower.

3.2. GHG emissions from home composting process

The linear relationship between the concentration increases over time using the static flux chamber method was in most cases good. An example of an emission measurement from Unit 1 is presented in Fig. 3 (measurement performed on 19th September

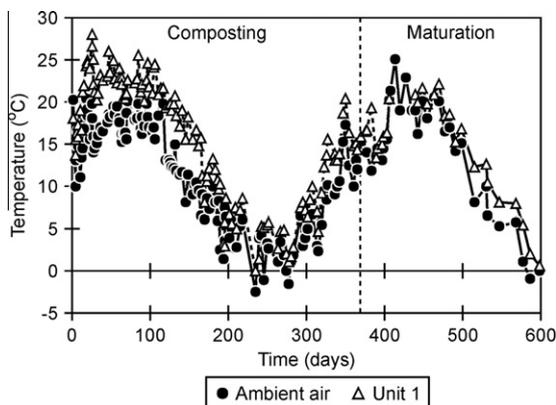


Fig. 2. Temperature development during home composting of OHW. The graph shows the development in Unit 1 during the composting and maturation phase. The two phases are distinguished from each other by a dotted line.

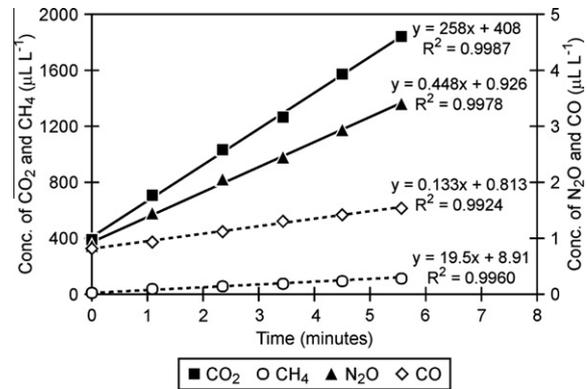


Fig. 3. Example of an emission measurement from Unit 1 on 19th September 2008 performed with a static flux chamber.

2008). The linear correlation is in this case very good (all $R^2 > 0.99$). The average R^2 values for all measurements (98 measurements per composting unit) were 0.95 for CO₂, 0.94 for N₂O, 0.89 for CH₄, and 0.76 for CO. The R^2 values generally increased with increasing emissions. The reason for the low R^2 values for CO might be explained by the relatively low emissions of CO.

The emission measurements (in g h⁻¹) plotted against composting time is presented in Fig. 4 for all composting units. The variations during the year and between the six composting units were significant. The general trend was a peak in the first spring/summer period (first 150 days) for all gases (especially Unit 1). The gas emissions then decreased during winter, which was after approximately 200–300 days of composting. In parts of this period, the ambient temperature was below 0 °C. In most cases, the gas emissions increased again towards the second spring/summer period (after 300 days of composting). Emissions of up to 12 g CO₂ h⁻¹, 0.25 g CH₄ h⁻¹, 0.027 g N₂O h⁻¹, and 0.016 g CO h⁻¹ were measured during the composting phase (all in Unit 1). The emissions from Units 1 and 2 were generally higher than those from the rest of the composting units. After the end of the main experiment (marked with dotted lines), the emissions decreased again; however, they did show an unexpected peak around 450 days. Fig. 4 shows that the GHG emissions did not stop when no further waste was added. This is referred to as the tail-emissions where the organic material is slowly degrading during maturation. The tail-emissions have been included in the total EFs.

The emission measurements were used to estimate the total emissions of CO₂, CH₄, N₂O and CO during the entire monitoring period by integrating the emission curves in Fig. 4 (according to Eq. (2)) and thereby calculating the total mass loss of each gas. The total accumulated emission of each gas from Unit 1 is shown graphically in Fig. 5. The emissions of GHGs were close to linear for CO₂, N₂O and CO during the whole composting period. Methane emissions, however, were high at the beginning and decreased during winter. In the maturation phase, emissions decreased and the slopes of the curves approached zero. The total emitted mass of each gas during composting (46 kg CO₂, 0.76 kg CH₄, 0.084 kg N₂O and 0.018 kg CO for Unit 1) were divided by the total mass of the input material (184 kg input waste in Unit 1) to obtain the EFs (in kg substance Mg⁻¹ ww). The moisture contents of the input material are given in Table 1. The EFs were measured as 177–252 kg CO₂ Mg⁻¹ ww, 0.4–4.2 kg CH₄ Mg⁻¹ ww, 0.30–0.55 kg N₂O Mg⁻¹ ww and 0.07–0.13 kg CO Mg⁻¹ ww in the six composting units. These EFs together with the total global warming EFs (including only CH₄ and N₂O; in CO₂-eq. Mg⁻¹ ww) are presented in Table 2 (GWPs of 25 and 298 for CH₄ and N₂O have been used, respectively). The EFs varied considerably between the six composting units. There was a factor of 2.4 between the lowest and the highest EF: 239 kg CO₂-eq. Mg⁻¹ ww for Unit 1 and 100 kg CO₂-eq. Mg⁻¹ ww for Unit 5. The highest EFs

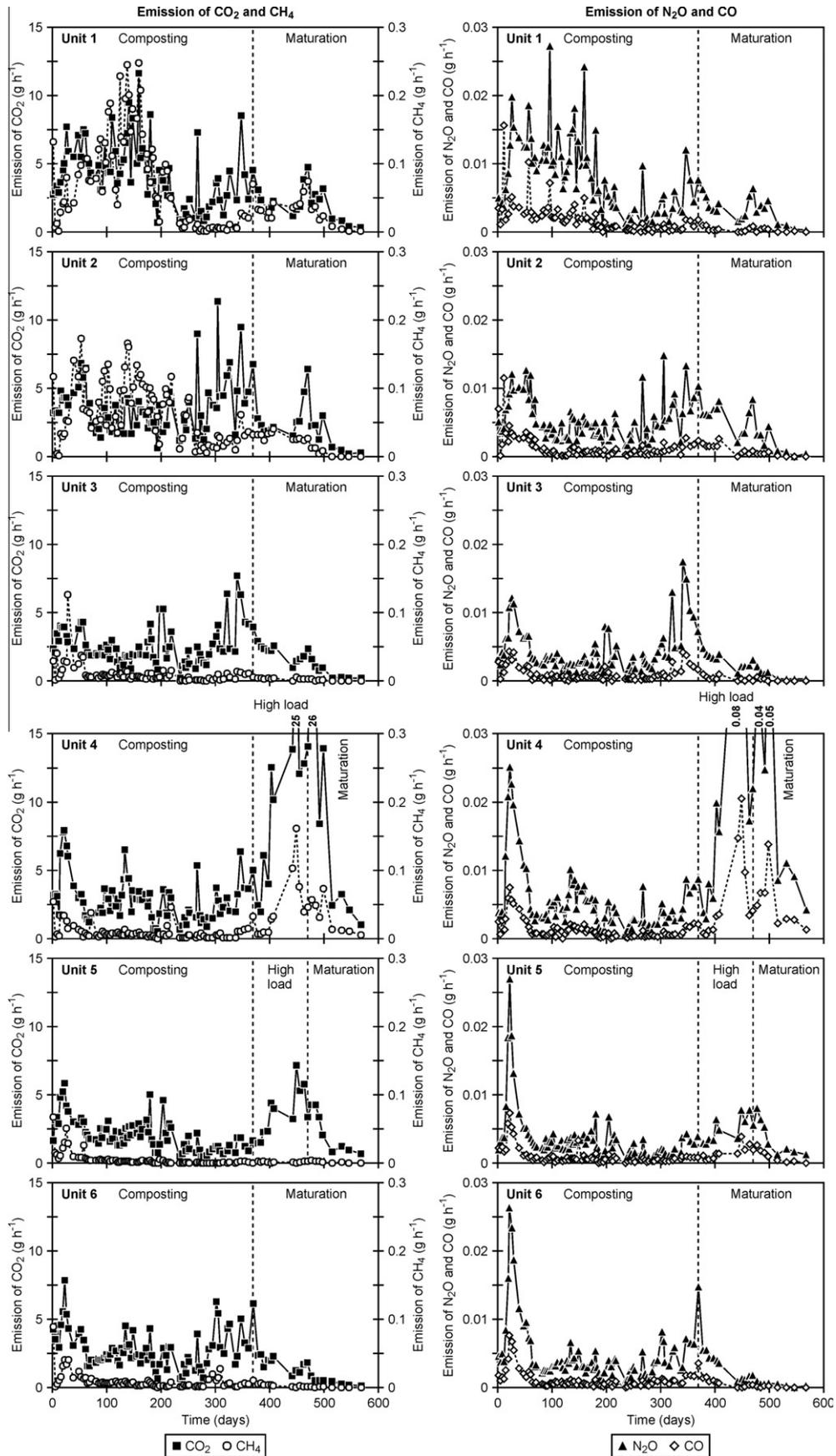


Fig. 4. Emissions of CO₂ and CH₄ (left column), and N₂O and CO (right column) in Units 1–6 during composting and maturation. The different phases are distinguished from each other by dotted lines.

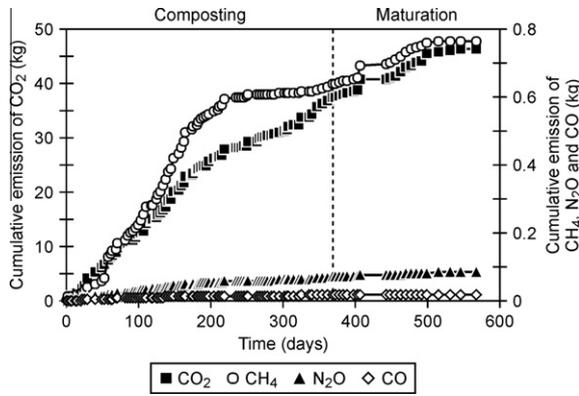


Fig. 5. Cumulative emissions of CO₂ (primary y-axis), CH₄, N₂O, and CO (secondary y-axis) in Unit 1 during composting and maturation.

were found in Units 1 and 2 where the addition of waste and mixing frequency was highest and the lowest EFs were found in Units 5 and 6 where no mixing took place. In general, the CO₂, N₂O and CO emissions were comparable between the composting units, whereas the CH₄ emissions were highly affected by how the units were operated. A higher mixing frequency of the material seemed to entail a higher emission of CH₄.

3.3. GHG emission dynamics and effect of mixing

As presented in Fig. 4, the variations in gas emissions were significant even within short periods of time. The dynamics experiment showed gas emission measurements over three days as presented in Fig. 6 for Unit 1 (July 2008). Fig. 6 shows that the CH₄ emission is mostly affected by mixing the material (time of mixing is shown with arrows in Fig. 6). The emission of CH₄ increased significantly after mixing the material but decreased drastically to the original level within the first hour. The additional emission of CH₄ caused by the mixing was estimated (by integrating the area under the graphs in Fig. 6) to be 8–12% of the total emission of CH₄ for each period in the dynamics experiments. This extra emission of CH₄ is excluded from the EFs shown in Table 2. The development of CO₂, N₂O and CO showed the same tendency but to a lesser extent. The emissions of CO₂, N₂O and CO were more stable over the four-day period with a small peak after adding and mixing the waste and slightly decreasing emissions between waste additions. The same trend was observed for Unit 2 during the dynamics experiment, whereas the development differed in Units 3–6 where no mixing took place.

Table 2

Emission factors (in kg Mg⁻¹ ww) from home composting of organic household waste in Units 1–6. The total global warming emission factors are calculated in the last column (in kg CO₂-equivalents Mg⁻¹ ww). Global warming potentials of 25 and 298 for CH₄ and N₂O have been used, respectively (Solomon et al., 2007).

Unit number	Emission factors (kg Mg ⁻¹ ww ^a)				
	CO ₂	CH ₄	N ₂ O	CO	Total EF (CO ₂ -eq.)
1	252	4.2	0.45	0.10	239
2	240	3.7	0.39	0.09	210
3	209	0.8	0.36	0.08	127
4	236	1.0	0.55	0.13	187
5	177	0.4	0.30	0.08	100
6	189	0.6	0.32	0.07	111
4 (only composting) ^b	175	0.7	0.34	0.08	117
4 (high load + tail-emission) ^b	306	1.3	0.78	0.19	265
5 (only composting) ^b	156	0.4	0.29	0.08	95
5 (high load + tail-emission) ^b	295	0.1	0.41	0.11	125

^a ww, wet waste.

^b The lower part of the table shows the emission factors for each phase (composting and high-load phase including tail-emissions) in Units 4 and 5.

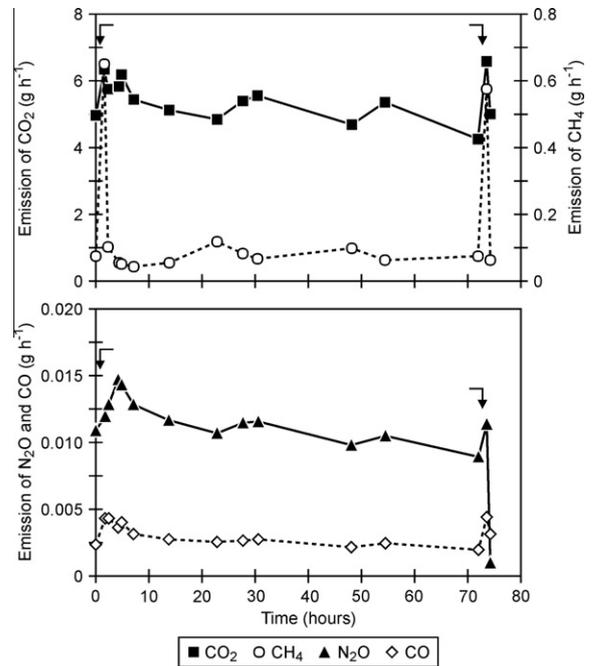


Fig. 6. Emissions of CO₂ and CH₄ (top) and N₂O and CO (bottom) in Unit 1 during the dynamics experiment in July 2008. The first emission measurement (at time 0 h) is performed before adding waste and mixing, whereas the second emission measurement (at time 1 h) is performed right after. The arrows show the time of mixing.

3.4. Effects of the high-load phase

After the composting phase, Units 4 and 5 were used for additional experiments with a higher addition of waste (high-load phase). Around 15–25 kg of OHW was added every fortnight to Unit 4 and approximately 3 kg of garden waste was added every fortnight to Unit 5 during the three-month experiment. The emission development in Units 4 and 5 with increased amounts of OHW is presented in Fig. 4. Unit 4 receiving OHW was mostly affected by the high load of waste, whereas the emissions from Unit 5 receiving garden waste were only slightly increased. The gas emissions from the composting phase are presented in the same graph (first 365 days; separated by a dotted line) and there is a drastic change in the magnitude of all gases in Unit 4 in the high-load phase. The maximum emission during the high-load phase was 26 g CO₂ h⁻¹, 0.16 g CH₄ h⁻¹, 0.08 g N₂O h⁻¹ and 0.02 g CO h⁻¹. During the maturation phase, the emissions decreased to a low steady level. The release of gases (in kg) in the composting and high-load phase in Unit 4 was comparable. However, when adding the tail-emissions to the high-load phase, the EFs (in kg Mg⁻¹ ww) for the high-load phase were significantly higher than the composting phase. The EFs for Unit 4 were 1.3 kg CH₄ Mg⁻¹ ww and 0.78 kg N₂O Mg⁻¹ ww during the high-load phase (three months + tail-emissions) compared with 0.7 kg CH₄ Mg⁻¹ ww and 0.34 kg N₂O Mg⁻¹ ww during the main composting phase (one year). The tail-emissions from the high-load phase were very high (41–50% on top of the emissions during the high-load phase), resulting in relatively high EFs during this phase. All EFs for Units 4 and 5 for both phases are presented in Table 2.

4. Discussion

The emissions of CH₄ and N₂O were quantified to 0.4–4.2 kg CH₄ Mg⁻¹ ww and 0.30–0.55 kg N₂O Mg⁻¹ ww which is equivalent to 100–239 kg CO₂-eq. Mg⁻¹ ww. The variation in EFs is due to differences in waste input and mixing frequency between the six composting units. However, this variation represents the

variation in operation modes that would actually be seen by different home composters. One interesting finding was that the release of CH₄ was highest for the composting units that were mixed most frequently (Units 1 and 2). The CH₄ emission was up to 11 times higher for the weekly mixed units compared with the units that were not mixed at all. This was surprising because it would be expected that with less access to atmospheric oxygen due to less mixing, the risk of methanogenic conditions would be larger. [Jasim and Smith \(2003\)](#), for example, found the CH₄ concentrations measured in the compost material to be lowest in mixed composting units compared with non-mixed, but did not report on the emissions. The difference in CH₄ emissions between mixed and non-mixed units could be explained by the different levels of compaction of the material, air intrusion into the composting units, and CH₄ oxidation. From an environmental point of view, these results indicate that it might be beneficial to avoid too much mechanical aeration in the composting units. On the other hand, less aeration could lead to slower degradation and maturation of the organic material and possibly result in a different composition of the final product. The quality and maturity of the compost is the focus of a follow-up paper which is in preparation. Preliminary results indicate that the material is being composted since the C/N ratio decreased from 22 to 24 in the input material to 15–17 in the finished compost.

The most comprehensive previous study on GHGs from home composting was by [Amlinger et al. \(2008\)](#). In their study, the EFs of 76 and 187 kg CO₂-eq. Mg⁻¹ ww were measured for home composting of 2931 kg and 1775 kg biowaste (mix of OHW and garden waste), respectively. The study by [Amlinger et al. \(2008\)](#) is however, more likely representing composting in multi-family households because of the higher volume and waste loads. The composting units were 0.8 m³ in volume and the addition of waste was up to 53 kg week⁻¹ (compared to 0.32 m³ in volume and addition of 2.6–3.5 kg waste week⁻¹ in this study). This results in a high activity in the compost material and a lower heat loss and as a consequence much higher temperatures (up to 70 °C like in centralised composting plants). The temperatures are thus very much related to the mass, volume and specific surface area of waste ([Alexander, 2007](#)). Even though the home composting setup was different in this study, the EFs were comparable to the results by [Amlinger et al. \(2008\)](#).

The measured EFs for single-family home composting were within the same range as for centralised composting (open technologies) (still only considering the actual process emissions from the degradation of OHW). [Hellebrand \(1998\)](#) reported 143 kg CO₂-eq. Mg⁻¹ ww from pilot-scale composting of garden waste, whereas [Andersen et al., 2010](#) reported an EF of 111 ± 30 kg CO₂-eq. Mg⁻¹ ww from full-scale windrow composting of garden waste. [Amlinger et al. \(2008\)](#) measured the EFs of 14–41 kg CO₂-eq. Mg⁻¹ ww for windrow composting of biowaste and 9–68 kg CO₂-eq. Mg⁻¹ ww for windrow composting of garden waste. In addition, the Intergovernmental panel on climate change (IPCC) has given default EFs for CH₄ and N₂O for the biological treatment of waste (composting and anaerobic treatment) of 4 (with a range of 0.03–8) kg CH₄ Mg⁻¹ ww and 0.3 (with a range of 0.06–0.6) kg N₂O Mg⁻¹ ww, respectively ([Eggleston et al., 2006](#)). These numbers give a total EF of 80 (with a range of 19–379) kg CO₂ Mg⁻¹ ww. Thus, in respect to global warming contributions, home composting does not seem that different to centralised composting. In centralised composting, additional GHG emissions from collection, transportation and mechanical turning have to be included when doing a full GHG account. This was however outside the scope of this paper. The most likely operation of home composting units was represented by Units 3 and 6 because of their low mixing frequencies and low amounts of waste input. When this is taken into account, the emissions would most likely be in the lower range of the interval given for home composting (100–239 kg CO₂-eq. Mg⁻¹ ww).

The quantification of GHG emissions in this study is robust because of the large amount of measured data. However, there are some uncertainties that need to be discussed. The mixing of the material facilitated an instant release of gases (especially CH₄) into the atmosphere (which was estimated to be an extra emission of CH₄ from Units 1 and 2 of 8–12%). This release of CH₄ was probably because of the purging of CH₄ stored in the compost material. This factor indicates that the real emissions could be slightly higher than the reported EFs (especially for Units 1 and 2 and to a lesser degree for Units 3 and 4).

One of the largest differences between home composting and larger scale composting is the lower temperature ([Illmer and Schinner, 1997](#)) and continuous addition of fresh material in home composting ([Preston et al., 1998](#)). In other related studies, home composting systems have been based on large additions of waste with a low frequency. As mentioned, the addition of waste was up to 53 kg per week in a study by [Amlinger et al. \(2008\)](#) and [McKinley and Williams \(2007\)](#) reported an addition of 16 kg every fortnight. In both cases the setup is more likely to represent multi-family home composting than single-family home composting, in which lower amounts of waste would be added more frequently (less than 4 kg week⁻¹). Large additions of waste entail a high degradation rate and an equivalent high temperature in the units. In both of the mentioned cases, the temperatures reached around 50–70 °C, which is much higher than we found and what is expected for normal home composting (a continuous addition of waste). This means that degradation and factors such as the gaseous emissions could be different in these different schemes. The high-load phase in Unit 4 showed that even with a single addition of up to 25 kg, the temperature did not exceed 30 °C, and it was never more than 10 °C higher than the ambient temperature. The GHG EFs from the high-load phase (three months + tail-emissions) were significantly higher than those from the composting phase (12 months), indicating that the emissions (in kg substance Mg⁻¹ ww) increased with increased waste input.

Some factors were not taken into account in the experimental setup such as the design and position of the composting units and the possibility of adding meat waste, and these factors might be of interest for the quantification of GHG emissions. Mixing frequency, however, was the most interesting parameter because it was assumed to affect the degradation process the most and thereby the degree of the resulting GHG emissions. In many residential houses in Denmark, the composting unit would be placed on soil to allow worms to enter. The presence of worms could potentially speed up the degradation process and facilitate compost aeration. The effect of worms on GHG emissions was, however, considered minor and was not assessed in this study.

5. Conclusion

An experimental setup was initiated to quantify GHG emissions from home composting of OHW. Carbon dioxide, CH₄, N₂O and CO were quantified using a static flux chamber method over one year of composting plus maturation. The emissions of these gases were measured and significant variations were both observed over time and between different composting units. The EFs were calculated in six differently managed composting units as 0.4–4.2 kg CH₄ Mg⁻¹ ww and 0.30–0.55 kg N₂O Mg⁻¹ ww which corresponds to 100–239 kg CO₂-eq. Mg⁻¹ ww. Weekly mixed composting units had higher EFs than non-mixed because of the higher CH₄ emissions (up to 11 times higher). In addition, an additional CH₄ emission of 8–12% was estimated from the instant release during the actual material mixing. A higher load of OHW increased the emission of gases and consequently significantly increased the total EFs. The EFs from composting of OHW are within the same order of magnitude as seen from large centralised composting plants.

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