ASSESSING THE ENVIRONMENTAL IMPACTS OF HOME COMPOSTING

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SUMMARY: A methodology for quantitatively assessing the environmental impacts of home composting is demonstrated. The problem of measuring air flow rates through home compost bins was tackled by making comparisons with simultaneously run, forced-aeration sealed compost reactors at known air flow rates. Analysis of headspace gases for VOCs, CH_4, NH_3 and N_2O are reported with concentrations of NH_3 up to 15ppm and no CH_4 or N_2O above atmospheric concentrations under tested conditions despite headspace CO_2 concentrations as high as 15%. Headspace CO_2 concentration and compost temperature profiles are reported for a range of composting scenarios and the mass balance methodology is demonstrated. The benefits of home produced composts as soil improvers are measured in terms of water extractable nutrients and potentially toxic elements, with findings confirming previous work indicating they are safe and beneficial. The future direction of research and ongoing modelling work is discussed.

1. INTRODUCTION

Home comopsting is becoming an increasingly significant waste disposal route for biodegradable household waste in the UK with approximately 15% of households involved by 2004 (DEFRA 2005). Typical household diversion rates of between 100-400 kg/household/yr have been reported (Punshi 2000; Mansell and Grant 2001; Smith and Jasim 2001; Bexley Coucil, Cleanaway Ltd. et al. 2004), which equates to between 0.15-0.65 million tonnes of waste diverted per year in the UK. With 73% of authorities distributing bins in 2004 and rising public awareness from a multi-million pound recycling campaign launched by the Waste Resources Action Programme (WRAP), participation is likely to continue to grow. Diversion of biodegradable waste via home composting currently does not count towards Local Authority recycling targets, a situation which seems likely to change within the next few years (The Composting Association 2006).

As participation rates grow, so too does the need for a better understanding of the emissions from home composting and the composition and quality of the compost produced. Ideally, composting is the aerobic microbial degradation of organic substrates to produce carbon dioxide, water, heat and a final product that is stable and can be safely and beneficially applied to land (Haug 1993). Outputs from an individual process depend on the specific microbial activity taking place, which is linked to the type and quantity of feedstock, management regime,

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temperature fluctuations, oxygen availability and pH levels of the compost in ways not currently understood in detail (Beck-Friis, Smars et al. 2001). Depending on these parameters, composting can also lead to emissions of CH_4, N_2O, NH_3 and volatile organic compounds (VOCs) (Hellman, Zelles et al. 1997). Although the emissions per bin may be quite low, when considered collectively they may make a substantial contribution to total CO_2 emissions, and hence to global warming. A separate issue, which could potentially impact home composters, is the attraction of flies and rodents to compost bins. As well as a nuisance factor these could pose health and safety concerns.

Previous investigations have focused on monitoring home composting bins at selected households (Wheeler 2003; Smith, Jasim et al. 2004). This approach has contributed to our understanding of 'typical' home composting carried out by the public, but physico-chemical analysis tends to be infrequent and much of these data are reliant on the accuracy of the householder's records. An alternative approach adopted for this study was to simulate home composting under typical conditions, allowing more frequent monitoring and better control/certainty over key parameters.

In order to quantify gaseous emissions from a composting unit, the rate of gas exchange from the bin to the atmosphere is required. Gas exchange will occur through a combination of diffusion and bulk convective airflow driven by biologically generated heat in the compost. Based on the oxygen requirements of the process and the relative transport rates, the primary mode of exchange is likely to be by bulk convective movement (Haug 1980).

The purpose of this study was to:

- Identify and evalutate an appropriate methodology for monitoring home comoposting emissions to air;
- Investigate airflow through open-bottomed compost bins by comparison with forced aeration sealed reactors at known air flow rates;
- Monitor and evaluate key parameters, including temperature, moisture contents, and CO_2 concentrations in headspace gases;

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2. EXPERIMENTAL STUDY

2.1 Apparatus

Two types of composting unit were run: a forced aeration unit, which was sealed and had air pumped in at a known flow rate; and a natural aeration system using typical home compost bins (Blackwall 220 l). The forced aeration composting unit was composed of a 180 l plastic cylinder (0.53 m diameter, 0.81 m height) sealed at both ends. Air is pumped into the bin at the base and exits through the top. Inside the bin a perforated plate is set 5 cm above the base to support the compost while allowing free movement of air beneath it.

Figure 1. Forced aeration sealed compost unit (left) and naturally aerated open bottomed compost unit (right)

2.1.1 Waste inputs

Fresh grass cuttings and shredded mixed garden waste from a centralised composting facility for the South Hampshire region were used as feed materials. The mixed garden waste was predominatly composed of woody, brown, high carbon content materials, which mature at a slower rate to green, high nitrogen content materials. Despite its variable age it is therefore a suitable source for these brown materials. The feed composition was based on advice from the Composting Association and Community Composting Network to add equal parts green material to brown material, with the centrally collected mixed garden waste treated as the brown material and grass as the green material. Each bin had an initial loading of 100L of mature compost, to represent old material present in home compost bins. Feed quantities were based on a literature review for data on typical home composting additions and home compostable waste. This data is summarised in Table 1.

Table 1. Home composting additions broken down by waste type and season. (Data from: Punshi 2000; Chartered Institute of Public Finance and Accountancy. Statistical Information Service. 2001; Mansell and Grant 2001; Smith and Jasim 2001; Hogg and Mansell 2002; Parfitt 2002; Wheeler 2003; Williams and Kelly 2003; Bexley Coucil, Cleanaway Ltd. et al. 2004; Coggins 2004; Smith, Jasim et al. 2004; Wheeler and Parfitt 2004; Rodger, Reeve et al. 2005)

	Timescale/ season	Average annual addition (kg/yr)	Average weekly addition (kg/week)	Weekly addition range (kg/week)	Standard deviation (kg/week)
Average total compost additions	Annual	296	5.7	2.6-7.9	1.8
	Winter	240	4.6	3.6-5.3	0.9
	Summer	357	6.9	5.1-8.3	1.6
	Unspecified	259	5.0	2.3-8.1	1.9
Kitchen waste	Annual	118	2.3	1.6-3.9	0.8
	Summer	73	1.4	0.9-2.2	0.7
	Winter	141	2.7	1.4-5	1.1
	Unspecified	96	1.8	-	-
Garden waste	Annual	224	4.3	0.5-5.6	1.9
	Summer	85	1.6	0.1-3.9	2.0
	Winter	86	1.6	0.4-2.6	1.0
	Unspecified	239	4.6	3.6-5.6	1.4
Paper	Annual	12	0.2	0.1-0.7	0.3
	Summer	26	0.5	-	-
	Winter	48	0.9	-	-
	Unspecified	12	0.2	-	-
Soil and other organic waste	Annual	25	0.5	0.2-0.8	0.4
	Summer	25	0.5	-	-
	Winter	27	0.5	-	-
	Unsupecfied	15	0.3	-	-

2.1.2 Monitoring methodology

An Infra-Red gas analyser (Geotechnical Instruments Model GA 94A) was used to monitor carbon dioxide, methane and oxygen, sampling from the bin headspace. Temperature was monitored using a datalogger and thermocouple wire for experiment 1 (Section 2.2.1) and DS1921 i-button dataloggers for experiment 2 (Section 2.2.2). Moisture content was measured by drying a composite sample at 105°C for 24 h (BSI - British Standards Institution 2000). Tenax passive diffusion tubes were used to monitor for N_2O, NH_3 and VOCs. Elemental compositions of the feed materials and composts were determined using a Leco CHNS-932 elemental analyzer, following the manufacturer's standard procedures. Reported gas composition, temperature and moisture content values are averages of the results from duplicate experiments.Elemental composition data are averages of triplicate analyses performed on duplicate experiments.

2.2 Protocols

2.2.1 Experiment 1: Airflow investigation

Two sealed composting reactors and two open bottomed compost bins were run in parallel with identical feed additions. The first feed addition was larger than normal at a total of 32kg while all following fortnightly additions were 16kg in total. This is equivalent to an 8kg weekly feed, which is in the upper range of average summer compost additions (Table 1).

2.2.2 Experiment 2: Emissions investigation

5 pairs of open bottomed compost bins kept in the same physical location were monitored and fed at the same times. The base feed for the composters was 5kg of fresh grass cuttings and 7kg of mixed garden waste. The conditions in each pair of bins were altered according to the following parameters:

- Standard: No variation from the base conditions
- Lower C:N ratio: A greater mass of grass cuttings was added - 8.5kg instead of 5kg
- High load: A greater mass of both materials was added: 8.5kg of fresh grass cuttings and 10.5kg mixed garden waste
- Food waste: An additional 1kg/week of fruit and vegetable waste was added
- Insulated: The pair of bins were put under shade and insulated in order to remove the variable direct heating effects of the sun and be subject only to longer term ambient temperature changes.

3. RESULTS AND DISCUSSION

3.1 Experiment 1: Airflow investigation

The times at which the bins were fed are readily apparent from the sharp rise in temperature and carbon dioxide concentration visible in Figure 2. It is apparent that for the quantity of feed used the initial, most active stages of composting occur in the first two weeks following feeding and activity falls rapidly in this period. Temperatures during this period went from highs of around 70°C down to near ambient temperatures after two weeks. The temperature profiles of all four bins match very closely indicating similar levels of biological activity throughout the experiment despite the different systems. Greater differences are observed in the carbon dioxide concentrations where the maximum values reached in the sealed bins were 17.8% during the first larger feed and 14.3% otherwise while in the open bins they were 9.1% and 7.8%. the From the headspace carbon dioxide concentration profile over the two week period it is possible to calculate the total mass of carbon dioxide emitted in the sealed bins. This was performed by multiplying the headspace concentration by the flow rate and numerically integrating over the two week period. If it is assumed that the overall rate of emission of carbon dioxide is approximately equivalent in the open compost bins to that in the sealed bins it is possible to estimate the equivalent rate of air exchange. The results of these calculations are summarised in Table 2.

Table 2. Mass of carbon dioxide emitted for each feed and the associated rate of air exchange required in open bins

	Feed addition (kg)	Emitted CO_2 (kg)	Estimated rate of air exchange in open bins (litres per minute)
Feed 1	38	2.1	2.20
Feed 2	19	0.8	1.05
Feed 3	19	0.7	0.95
Feed 4	19	0.7	1.00

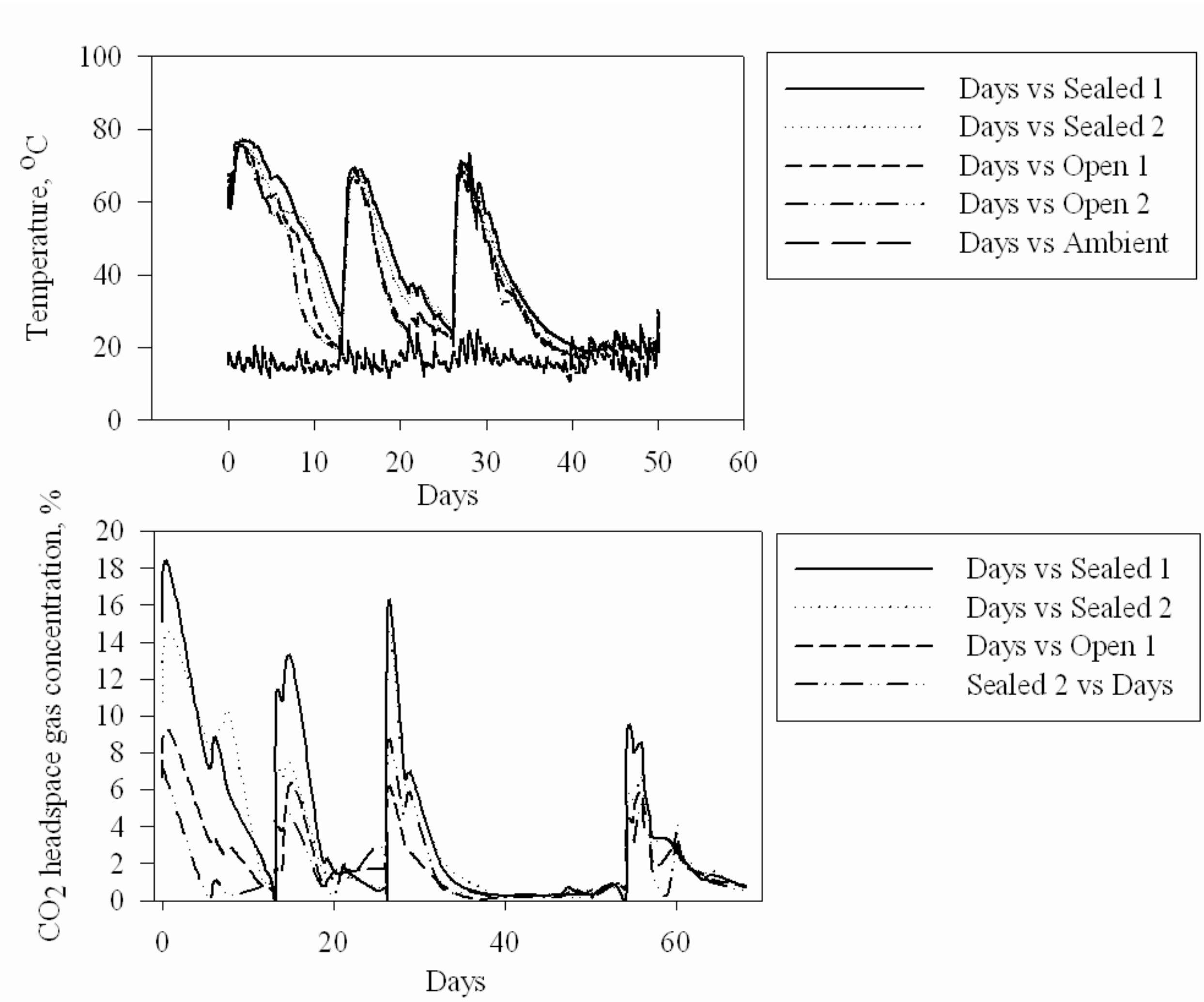

Figure 2. Temperature (Upper) and Headspace carbon dioxide concentration (Lower) profiles of the sealed and open bins

3.2 Experiment 2: Emissions investigation

3.2.1 CO_2 and temperature profiles

The headspace CO_2 concentration and temperature profiles averaged across each pair of bins are shown in Figure 3. It can be seen that at the feed rates used a high level of biological activity was achieved in all cases with temperatures reaching between 40-60°C and concentrations of CO_2 at least above 5% and as high as 10-15% in bins with higher material loading. Even in the same pairs of bins, however, there was significant variation between the maximum CO_2 concentrations reached after feeding. Specifically at 28 and 52 days highs of 14-15% were reached in some cases while at the intervening 42 days highs were only 6-7%.

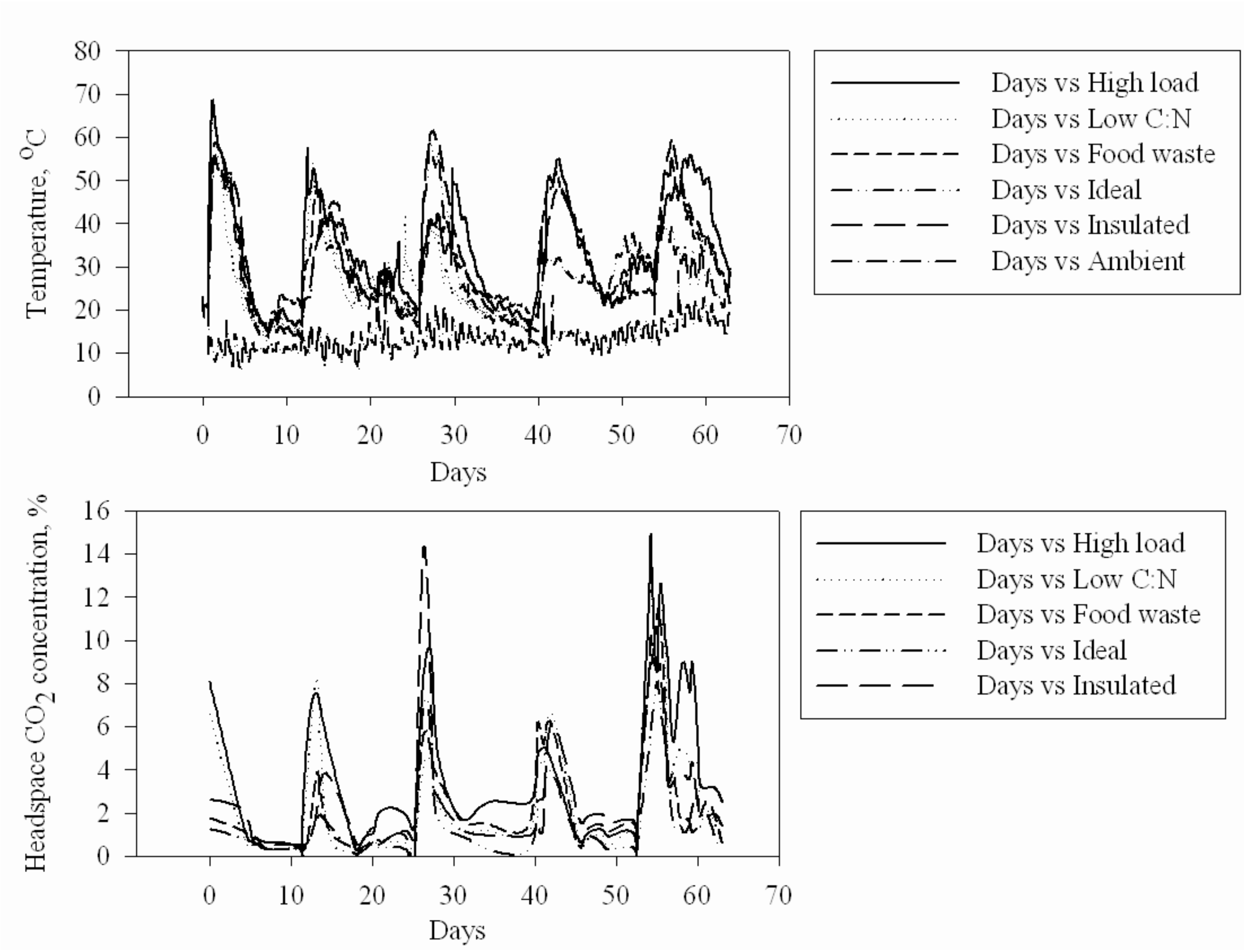

Figure 3. Temperature (Upper) and Headspace carbon dioxide concentration (Lower) profiles averaged for all pairs of bins

Table 3. Composition of intial matierals and final High load compost

	Moisture content (% Fresh material)	Total carbon (% Dry solids)	Total Nitrogen (% Dry solids)
Grass cuttings	82	57.8	3.4
Mixed garden waste	30	44	0.7
Final compost	60	22.5	0.15

Table 4. Composition of initial materials and average of final high load composts

	Feed addition (kg)	Final mass (kg)	Carbon lost (kg)	Nitrogen lost (kg)	Moisture lost (kg)
Feed 1	37.3	22.4	5.8	0.07	7.2
Feed 2	17.7	10.6	2.9	0.04	3.1
Feed 3	17.6	10.6	3.0	0.03	2.8
Feed 4	22.1	13.3	3.7	0.04	3.6
Feed 5	19.1	11.5	3.2	0.03	3.1

3.2.2 Mass balance

Mass balances have been performed for each feed addition on the input materials and final compost masses from measurements of the total C, total N, moisture contents and mass loss. An example is illustrated in Tables 3 and 4 using the high load pair of bins. From the total carbon lost according to the mass balance the associated average volumetric rate of emission of carbon dioxide can be calculated over the course of the experiment. This can be converted into the rate of air exchange from the average concentration of carbon dioxide in the headspace gases (Figure 3). As well as accounting for the effects of air temperature and humidity ongoing modelling work is aimed at adjusting for the variable flow rates that will occur during composting and quantifying the effects of diffusion which may become signficiant particularly at lower temperatures.

3.2.3 Environmentally significant gaseous emissions

Concentrations of NH_3, VOCs and N_2O were monitored for using passive diffusion tubes over 14 days during the fourth feed from day 42. Over the 14 day period ammonia concentrations of 15ppm were detected while nitrous oxide was not detected above atmospheric concentrations. The results of the VOC analysis, shown in Table 5, indicate raised concentrations of some VOCs but still at very low concentrations and none of signficiant environmental or health concern with normal exposure times. The GA-94A gas analyser used to detect CH_4 had a limited accuracy of ±0.5% down to 0.1% by volume. This gave very occasional readings of methane at above 0.1% but these results must be considered inconclusive at such low concentrations. Ongoing experiments with more sensitive methane analysis accurate to a few ppm have yet to find any methane emissions. With such high concentrations of carbon dioxide being found at times in the headspaces of some compost bins, it could be expected that methane emitting anaerobic regions would be present in the composts. It may be the case, however, that the small scale of home composting allows sufficient transport of air through the compost to prevent this from occuring. Further monitoring for ammonia and nitrous oxide is also ongoing. When complete these data will be combined with associated rates of air exchange calculated from the methods discussed in sections 3.2 and 3.2.2 in order to quantify the gaseous emissions and the environemental impacts for a range of scenarios.

Table 5. Concentration of top 5 VOCs in compost headspace gases

Top 5 VOC compounds	Concentration in headspace gas (ppb)	Concentration detected in air (ppb)
D-Limonene	95	Not detected
beta.-Phellandrene	76	Not detected
1S-alpha-Pinene	35	Not detected
Dimethyl disulfide	30	Not detected
3-Carene	21	0.41

3.2.4 Compost quality

Final composts from the high load, low C:N ratio and kitchen waste bins were analysed for water extractable nutrients and potentially toxic elements as an indicator of the quality of home produced composts. Analysis was carried out by an external laboratory approved by the Composting Association for conducting PAS 100 analysis. Table 6 shows the results of the water extractable nutrients analysis and Table 7 the potentially toxic elements compared to the PAS 100 limits. All the tested composts have lower concentrations of potentially toxic elements than required by the PAS 100 standards. This analysis and the concentrations of water extractable nutrients confirm previous work that show home produced composts are safe and beneficial as soil improvers (Wheeler 2003; Smith, Jasim et al. 2004). Plant growth tests performed by Smith and Jasim (2004) found several home composts performed better than tested commercial products.

Table 6. Water extractable nutrients in three tested composts

	Mass of extractable nutrient in Dry Matter (mg/kg)		
Parameter	High load	Low C:N ratio	With kitchen waste
Phosphorus as P	248	325	448
Potassium as K	4513	6712	7600
Calcium as Ca	355	398	347
Magnesium as Mg	53	57	55
Sulphur as S	319	568	508
Boron as B	4.0	4.6	5.0
Copper as Cu	0.4	0.5	0.5
Iron as Fe	23	26	26
Manganese as Mn	8.4	6.2	5.5
Molybdenum as Mo	0.2	0.4	0.5
Zinc as Zn	9.3	10.3	10.6
Sodium as Na	559	687	755

Table 7. Potentially toxic elements in three tested composts

	Element mass in dry matter (mg/kg)			
Parameter	High load	Low C:N ratio	With kitchen waste	PAS 100 upper limit
Cadmium as Cd	0.7	0.6	0.6	1.5
Chromium as Cr	12	8.8	11	100
Copper as Cu	47	36	37	200
Lead as Pb	93	69	82	200
Mercury as Hg **- less than**	0.5	0.5	0.5	1
Molybdenum as Mo	2.5	2.1	3.3	N/A
Nickel as Ni	8.4	5.8	7.8	50
Zinc as Zn	164	170	152	400

4. CONCLUSIONS

A methodology for assessing the environmental impacts of home composting has been sucessfully demonstrated. Through the use of sealed forced aeration reactors the first steps in quantifying gaseous emissions from open bottomed compost bins have been performed. Equivalent air exchange rates of between 1-2 Lpm in open bins were identified depending on the feed quantities and composition. Concentrations of NH_3 over the active composting period were found to be up to 15ppm. Concentrations of VOCs, nitrous oxide or methane have not reached detectable concentrations under the tested experiment conditions. Analysis of the quality of the produced composts confirms previous work finding it can be used as a safe and beneficial soil improver. The period of highest composting activity in terms of temperature and carbon dioxide emission has been found to occur in the first 2-3 days with conditions returning to near ambient after 14 days.

Ongoing modelling work using mass balances demonstrated in Section 3.2.2 will enable the reporting of total condensate and leachate production, and overall carbon and nitrogen losses. In conjunction with the data collected on air compositions and rates of air exchange this will enable a greater understanding of the air flow mechanisms through compost bins and the relative contributions of bulk convective movement and passive diffusion. Ultimately this will lead to the accurate assessment of emissions from home composting activities for a range of possible scenarios.

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