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Mass balances and life cycle inventory of home composting of organic waste

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ABSTRACT

A comprehensive experimental setup with six single-family home composting units was monitored during 1 year. The composting units were fed with 2.6–3.5 kg organic household waste (OHW) per unit per week. All relevant consumptions and emissions of environmental relevance were addressed and a full life-cycle inventory (LCI) was established for the six home composting units. No water, electricity or fuel was used during composting, so the major environmental burdens were gaseous emissions to air and emissions via leachate. The loss of carbon (C) during composting was 63–77% in the six composting units. The carbon dioxide (CO_2) and methane (CH_4) emissions made up 51–95% and 0.3–3.9% respectively of the lost C. The total loss of nitrogen (N) during composting was 51–68% and the nitrous oxide (N_2O) made up 2.8–6.3% of this loss. The NH_3 losses were very uncertain but small. The amount of leachate was 130 L Mg^{-1} wet waste (ww) and the composition was similar to other leachate compositions from home composting (and centralised composting) reported in literature. The loss of heavy metals via leachate was negligible and the loss of C and N via leachate was very low (0.3–0.6% of the total loss of C and 1.3–3.0% of the total emitted N). Also the compost composition was within the typical ranges reported previously for home composting. The level of heavy metals in the compost produced was below all threshold values and the compost was thus suitable for use in private gardens.

1. Introduction

Home composting (or backyard composting as it is sometimes called) is a waste management option for organic household waste (OHW) in a number of countries. Home composting is considered to be a horticultural recreational activity, but recently home composting has been considered as a potential major diversion route for OHW (Jasim and Smith, 2003) in order to comply with the European landfill directive (CEC, 1999). It is difficult to describe home composting as one single standard technology because the waste producer is also the processor and end-user of the compost (Jasim and Smith, 2003). The composting process is taking place in many different ways and with very different operational schemes, which is one of the reasons for the lack of scientific studies in this field. Home composting should not be seen as an alternative treatment option for all organic waste in a region, but instead as a supplementary solution. The potential of doing home composting is to provide a flexible, low-cost approach to waste management and facilitate sustainable recycling for individual home owners. However, it requires the active participation of a significant proportion of the home owners in a region to impact waste diversion rates. This could be obtained by promoting home composting on a municipal level.

The most obvious environmental advantage of doing home composting compared to centralised composting is the avoidance of collection and transportation of the organic waste. Another advantage that is relevant for both centralised and home composting is the production of compost, which could potentially be used in the garden as a soil improver and thereby substitute the use of less "green" soil improvers such as mineral fertilisers and peat in growth media. This could, however, also constitute a problem, if the produced compost is not of good quality (stable, mature and low heavy metal content). The main disadvantage of home composting is the emissions of greenhouse gases (GHGs) from the composting unit contributing to global warming. Another potential disadvantage of home composting is leachate production.

Some inventory data for home composting are found in the literature. Amlinger et al. (2008) focused on the GHG emissions from multi-family (high input) home composting. Colón et al. (2010) performed a full life-cycle inventory (LCI) of home composting, but in this case some of the inventory data were not included (leachate generation) or not well assessed (e.g. GHG emissions). In addition, the reported studies employed weekly additions of

Abbreviations: EF, emission factor; GHG, greenhouse gas; GWP, global warming potential; LCI, life-cycle inventory; MFA, mass flow analysis; OHW, organic household waste; SFA, substance flow analysis; ww, wet waste.

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waste that was significantly higher that what a typical single-family household would add to the home composting unit. Amlinger et al. (2008) added as much as 53 kg per week and Colón et al. (2010) as much as 18 kg per week, while it is estimated that for a Danish single-family household 1–4 kg of OHW could be composted per week (Petersen and Kielland, 2003). Thus, there has until now been a lack of full LCIs for single-family home composting.

LCIs cover all consumptions and emissions of environmental importance (ISO, 2006). In this inventory study, only the direct emissions from the composting process have been included. This means that processes such as the production of the composting units, tools that were used during the process and transport associated with this were not addressed. The provided LCI form the basis for doing environmental assessments of home composting. The data include GHG emissions factors (EFs) that for the first time have been extensively investigated and quantified from single-family home composting. The method and the underlying data for these GHG EFs are given in Andersen et al. (2010a), where the experimental setup (the same as for this paper) is described in detail and the temperature development is presented for the entire composting period of 1 year.

The main objective of this study was to provide a comprehensive LCI of single-family (low input) home composting of organic household waste (OHW), based on comprehensive field studies, material flow analysis (MFA) and substance flow analysis (SFA). A secondary objective was to present the composition and assess the quality of the final compost product from home composting of OHW. The experimental setup was prepared with the intention of representing the most likely management of single-family home composting in Denmark.

2. Methodology

2.1. Composting units

The composting units (Humus/Genplast, 8230 Åbyhøj, Denmark) in this study are the most commonly used units for single-family home composting in Denmark, and they are offered to home-owners free of charge in some municipalities in order to promote home composting. The composting units are made of recycled polyethylene (PE) and polypropylene (PP) and weigh 22 kg. They are cone-shaped with dimensions of 95 cm in height and 48 and 105 cm in diameter (top and bottom, respectively) giving a total volume of 0.32 m^3. The composting units are equipped with a lid, an anti-fly net in the top to prevent flies from entering, a fine-masked steel net in the bottom to prevent rats and mice from entering and a hatch from where the mature compost can be collected. A picture and a schematic drawing of the composting units are presented in Andersen et al. (2010a).

A total of six composting units were used in the experimental setup and the difference in operation of the units was the difference in input waste and the frequency of mixing (see Table 1). The mixing consisted of manual agitation of the waste in the composting units with a mixing stick made of recycled PE and PP (delivered together with the composting unit). Units 1 and 2 were mixed every week and thus represented eager management, which is not considered to be a likely management approach. Units 3 and 4 were considered the most likely setup as they were mixed every sixth week, whereas Units 5 and 6 were not mixed at all, representing the "lazy" home composters.

2.2. Experimental outline and feedstock

The experiments were designed to represent a steady-state situation in a home composting scenario. However, the experimental time frame of the study and the need of sampling of the matured compost demanded some compromising. The home composting units were initiated by a start-up period of 3 months in order to get a base-load of OHW in the composting units. The main experiments were performed during the composting period from May 2008 to May 2009. During the start-up period and the composting period, the composting units received waste every week. After the composting period, the units did not receive any waste for a period of 3 months in order to ensure maturation of the compost prior to sampling and characterisation. The experimental period of Units 4 and 5 was extended for 3 months due to additional experiments with increased amounts of incoming waste. This is the reason for the elevated amounts of waste added in Units 4 and 5 (the extra amount is shown in brackets in Table 1). The effect of increased input has been described and discussed in Andersen et al. (2010a) and is not further addressed in this paper.

The input material consisted of OHW (food waste and small amounts of flowers and soil from the household) and low amounts of garden waste in order to provide structure. The OHW was delivered by families (volunteers from the Department of Environmental Engineering, Technical University of Denmark) approximately twice a week for 1 year. The total input per week per composting unit was 2.6–3.5 kg OHW and 0.12–0.15 kg garden waste on average during the composting period (see Table 1).

2.3. Collection of data

The LCI data were gathered from comprehensive field work campaigns. The emissions were primarily in gaseous form and via leachate. No water, electricity, fuels or other materials were used during composting. The output material was sampled and characterised in order to evaluate the quality of the product.

2.3.1. Sampling of solids

Sampling of the input waste was performed before every addition of waste (approximately twice a week). Two samples (duplicates), each of 1% (mass) of the input, were taken from each

Table 1
Mixing frequency, amounts and moisture contents of input and output from the six composting units during the experiment. Parts of the table are taken from Andersen et al. (2010a). Amounts lost include gaseous emissions and leachate.

Composting unit No.	Mixing frequency	Amount of input ww[a] (kg)	Moisture content of input (% ww)	Amount of output ww[a] (kg)	Moisture content of output (% ww)	Amount lost (% ww)
1	Every week	184	71.4	84	75.1	55
2	Every week	176	76.0	61	73.1	65
3	Every 6th week	146	73.0	52	69.4	64
4[b]	Every 6th week	151 (+130)	78.9	76	70.9	73
5[b]	No	115 (+20)	63.8	59	67.1	56
6	No	169	77.6	58	71.3	65

[a] ww, wet waste.
[b] Additional organic household waste was composted in Unit 4 and 5 during the high load phase (numbers in brackets show the input for the high load phase).