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Life cycle assessment of a food waste composting system: environmental impact hotspots

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A B S T R A C T

A life cycle assessment (LCA) approach was used to identify the processes and stages in organic waste composting that have the largest environmental impacts. The LCA included impacts associated with the collection of feedstock, production and distribution of compost, and its use as a replacement for peat for soil conditioning. The use phase of the compost product has not been included in previous LCA studies in the United States. Nine LCA impact categories were analyzed (global warming potential, ozone depletion, smog, acidification, eutrophication, carcinogens, non-carcinogens, respiratory effects, and ecotoxicity) using TRACI 2 methodology.

The functional unit was defined as the collection, processing, transportation, and application of one tonne of compost that meets USEPA composting standards. The compost was produced at the Organics Material Processing and Education Center (OMPEC) at The Pennsylvania State University. The data used in the assessment was collected from seven composting windrows over thirteen consecutive months (December 2010–January 2012). Given the wide range of decomposition emission factors reported in the literature for methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3), three emission scenarios were calculated: average, minimum, and maximum emission scenarios. Carbon dioxide (CO_2) emissions from the compost were considered biogenic and not included in the assessment.

For all scenarios, compost processing was the stage with the largest environmental impact, with decomposition emissions contributing the most to global warming potential, acidification and eutrophication impact categories under the average and maximum emissions scenarios. To account for the avoided environmental impacts of peat mining and transport, these values were subtracted from the composting life cycle. The avoided impacts from peat replacement were higher than the impacts from composting for all categories, illustrating that using compost instead of peat results in net environmental gains. This study highlights the importance of minimizing life cycle impacts associated with CH_4, N_2O and NH_3 emissions during the decomposition process and the need for more consensus in the literature on emission values from composting processing.

1. Introduction

Food waste is the second largest component of municipal solid waste (MSW) generated in the United States, second only to paper (USEPA, 2011a). In 2010, only 3 percent of the 31 million tonnes of food waste generated in the United States was recycled, resulting in food waste being the largest category of MSW reaching landfills and incinerators (USEPA, 2011a). In addition, studies have estimated that 35% of food purchased by consumers is not utilized, based on the difference between the calories brought into the home and calories consumed (ERS, 2007). In defining MSW, the US Environmental Protection Agency (USEPA) includes residential, commercial, institutional, and industrial wastes, but excludes municipal sludge, agricultural, mining, oil and gas, industrial nonhazardous (process waste), and construction/demolition debris (USEPA, 2011b).

Composting is considered a more sustainable alternative to landfilling and incineration for managing food waste, but only 0.85 million tonnes of 20.8 million tonnes of MSW recovered in the US for composting in 2009 was food waste, with the remaining 19.9 tonnes originating from yard trimmings (USEPA, 2010). During the composting process, organic materials are decomposed by microorganisms under low moisture, aerobic conditions, resulting in a nutrient

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rich product that can be used as a replacement for peat, fertilizers and manure in agricultural and horticultural activities, such as landscaping, home gardening, and erosion control (Levis et al., 2010; Okafor, 2011; USEPA, 2011a). Numerous studies have shown the horticultural benefits of using compost as a replacement for peat in the production of ornamental plants (Chen et al., 1988; Martínez-Blanco et al., 2011; Raviv et al., 2005; Rea et al., 2009; Russo et al., 2008, 2011). Additional research has highlighted the environmental benefits of compost use for improving soil quality, including: 1) incorporation of organic matter, nutrients and electrolytes into the soil, 2) reducing the need for fertilizer, pesticides and peat use, 3) improvements in soil structure, density and porosity, which increases water retention capacity and reduces erosion and nutrient leaching, and 4) enhanced carbon storage capacity in the soil, thus, reducing global warming (Favoino and Hogg, 2008; Martínez-Blanco et al., 2009; ROU, 2007). Conversely, composting production can have negative environmental impacts, such as CO_2 emissions from fossil fuel use in transportation and processing equipment, and methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) emissions from methanogenic and denitrification processes when anaerobic conditions are present during the composting process, resulting in odor and additional greenhouse gas emissions (Amlinger et al., 2008; Boldrin et al., 2009; Edwards and Williams, 2011).

Life cycle assessment (LCA) has been used to evaluate and compare the impacts of different waste disposal scenarios, including composting. By using a common metric, LCA methodology allows for the quantification and comparison of environmental impacts between stages of a product or service throughout its life cycle, including raw material acquisition, processing, distribution, use, and end of life. Researchers have utilized LCA to analyze MSW disposal scenarios (Clearly, 2009; Eriksson et al., 2005; Khoo, 2009; Zhao et al., 2009) and determine the environmental impacts of organic waste disposal (Andersen et al., 2011; Kim and Kim, 2010; Lundie and Peters, 2005; Martínez-Blanco et al., 2009; PE Americas, 2011).

LCA studies have found composting to be more advantageous, i.e. less environmental impacts, than other organic waste disposal scenarios, such as landfill and incineration. Andersen et al. (2012) determined that home composting of organic food waste performed better than landfilling and incineration when comparing acidification, nutrient enrichment and photochemical ozone formation impact categories, and Lundie and Peters (2005) determined that home and centralized composting generated less greenhouse gases and consumed less water than landfilling. PE Americas (2011) conducted a LCA with 12 different disposal scenarios: composting, incineration, two landfills, and a food waste grinder in combination with eight wastewater treatment processes, and found that composting had least amount of smog potential, the second lowest primary energy demand and acidification potential, and the third lowest global warming potential of the compared scenarios.

Most previous LCAs have analyzed only the production of compost. Only a few LCA studies have analyzed the composting process from compost creation to “end of life,” i.e. the use of the compost. ROU (2007) conducted a LCA of a windrow composting system in Australia that included compost use and post application impacts. Similarly, Luske (2010) evaluated GHG emissions of the entire life cycle of compost in Egypt. In the US, the California Environmental Protection Agency (Edwards and Williams, 2011) developed a methodology to quantify greenhouse gas emissions and capture during compost management and use but no other impact categories were assessed. To date, no studies have analyzed the entire life cycle of composting in the US, including life cycle impact categories such as eutrophication, acidification, and smog.

The purpose of this study is to evaluate the environmental impacts of the food waste composting life cycle using a LCA approach to evaluate all the stages of the food waste composting process, including waste transport, compost production, and its use as a soil conditioner. The LCA used the food waste composting process at the Pennsylvania State University as a case study, and focused on greenhouse gases emissions, but also evaluated eight other impact categories: ozone depletion, smog, acidification, eutrophication, carcinogens, non-carcinogens, respiratory effects, and ecotoxicity. The research was based on a commercial composting process due to the higher volumes of food waste processed and the more consistent database of information available at a larger scale facility compared to individual households. The main goal of the research is to identify the composting stages and processes that have a higher contribution to environmental impacts in order to develop strategies that target the main impact drivers in the composting process.

2. Materials and methods

This study follows the ISO 14040 and 14044 standards (ISO 14040:2006a; ISO 14044:2006b), which define the LCA phases as: goal and scope definition, inventory analysis, impact assessment, and interpretation. Simapro 7 software developed by Pré Consultants was used to model and evaluate the different impact categories under TRACI 2 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) methodology, which was developed by the USEPA based on models, assumptions, and methodologies that represents potential effects in the United States (Bare, 2002).

2.1. System description

Data from the Organics Material Processing and Education Center (OMPEC) at the Pennsylvania State University (PSU) were used to build the life cycle inventory. OMPEC has a windrow composting system, a process in which a mixture of organic materials is placed in long and narrow piles and turned on a regular basis. The compost facility consists of: (1) open pre-processing area where feedstock is received, weighed and stored, with two concrete floor slabs next to pushwalls to load the stored feedstock, (2) an open processing area with a paved composting pad where windrows are formed, and (3) a post-processing area with a fabric high tunnel where the final compost is stored (Fig. 1).

Pre and post-consumer food waste generated in PSU’s dining facilities was the largest fraction of the composting mixture (Table 1). There were no specific measurements on the food waste generated, but it is likely similar to the average food waste composition quantified by MassDEP (2002) as 50% fruit and vegetable matter, 40–45% a combination meat (including poultry and fish) and bakery products, and 5–10% sugars, starches, and oil-based products. Additional inputs to the compost mixture included manure from the campus farm, cage waste from the small animal lab facility, leaves, gardening residues, grass clippings, and wood chips. The waste is separated at the source and placed in trash cans, which are collected by trucks and transported to the composting facility, weighed and stored.

The food waste has an elevated moisture content (74%) and a low C:N ratio (16.5), according to an internal Agricultural Analytical Services Laboratory report, and therefore, is combined with other stated materials to balance the C:N ratio and moisture content of the final mixture, as shown in Table 1 (Zhang and Matsuto, 2010; Kumar et al., 2010). After the compost is mixed, near optimal moisture content (60%) and carbon to nitrogen ratio (27:1) are obtained. Within the created windrows, microorganisms decompose the organic matter in the presence of oxygen, while emitting CO_2, water vapor and heat. The piles are turned to increase porosity, facilitate oxygen transfer, encourage continuous microbial activity, and control temperature. The optimal composting temperature range is 60–65 °C. Below this optimal range, microbial activity slows down, and