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Greenhouse gas emissions from green waste composting windrow

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ABSTRACT

The process of composting is a source of greenhouse gases (GHG) that contribute to climate change. We monitored three field-scale green waste compost windrows over a one-year period to measure the seasonal variance of the GHG fluxes. The compost pile that experienced the wettest and coolest weather had the highest average CH_4 emission of 254 ± 76 g C day^{-1} dry weight (DW) Mg^{-1} and lowest average N_2O emission of 152 ± 21 mg N day^{-1} DW Mg^{-1}compared to the other seasonal piles. The highest N_2O emissions (342 ± 41 mg N day^{-1} DW Mg^{-1}) came from the pile that underwent the driest and hottest weather. The compost windrow oxygen (O_2) concentration and moisture content were the most consistent factors predicting N_2O and CH_4 emissions from all seasonal compost piles. Compared to N_2O, CH_4 was a higher contributor to the overall global warming potential (GWP) expressed as CO_2 equivalents (CO_2 eq.). Therefore, CH_4 mitigation practices, such as increasing O_2 concentration in the compost windrows through moisture control, feedstock changes to increase porosity, and windrow turning, may reduce the overall GWP of composting. Based on the results of the present study, statewide total GHG emissions of green waste composting were estimated at 789,000 Mg of CO_2 eq., representing 2.1% of total annual GHG emissions of the California agricultural sector and 0.18% of the total state emissions.

1. Introduction

Composting of green waste materials to avoid disposal in landfills has several benefits, including the use of the mature compost as a natural fertilizer or as an amendment to improve soil structure (CalRecycle, 2010). The main disadvantage of composting is the production and emission of greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O), which contribute to global warming. Another GHG carbon dioxide (CO_2) emitted from composting originates from degradation of plant material and is considered neutral with respect to global warming (Christensen et al., 2009). Limited studies have quantified GHG released in the composting process (Andersen et al., 2010; Hellebrand, 1998). For these reasons, the benefits and disadvantages of composting need better quantification to address sources of GHGs.

Green waste, such as residential yard trimmings, accounts for 13.5% of the estimated annual 254 million Mg of solid waste in the United States (U.S.EPA, 2013). Considering the large quantities of green waste generated annually and the concerns over GHG emissions from landfill this material, better understanding of CH_4 and N_2O production during composting is required. Microorganisms under anaerobic conditions generate CH_4 (Beck-Friis et al., 2000; Hellebrand, 1998; Jäckel et al., 2005). Nitrous oxide is known to form during the process of incomplete ammonia oxidation (nitrification) and incomplete denitrification (Firestone and Davidson, 1989; Zhu et al., 2013). Previous studies on composting show CH_4 and N_2O emissions are associated with these microbial processes and are strongly affected by oxygen (O_2) status, moisture, pH, temperature, and organic carbon (C) and nitrogen (N) form and availability (Beck-Friis et al., 2000, 2003; Hellebrand, 1998; Jäckel et al., 2005; Zhu et al., 2013). Higher levels of aeration can decrease CH_4 emissions (VanderGheynst et al., 1998). The specific pathways contributing to the majority of N_2O emissions from composting process remain largely uncharacterized.

Windrow composting is one of the main methods to conduct large-scale composting. It is popular because of its simplicity and relatively low expense. In this system, compostable material, such as municipal green waste, is laid out in long windrows in lengths anywhere from 15 m to greater than 115 m. Windrows range between two meters in height and five meters in width (Andersen et al., 2010; Beck-Friis et al., 2000). Windrow turners are used to mix piles for even composting of materials. It is thought that turning these piles leads to a lower GHG emissions by introducing oxygen (Beck-Friis et al., 2000; Rynk, 1992). However, the frequency of turning and overall management of windrows varies from facility to facility, although in California, U.S., windrow facilities perform five turns within a 15-day period to maintain

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windrow temperatures of approximately 55 °C to reduce pathogens according to the state regulation (Title 14, California Code of Regulations, Division 7, Article 7, Section 17868.3). The need to characterize and understand GHG emissions in the windrow system has become important to evaluate the sustainability of compost operations and to address California's climate change law.

In this study, we first quantified and characterized the emissions of GHG from outdoor full-scale green waste compost windrows over a year period to assess the effects of seasonality on composting of green wastes. Second, a mass-based GHG emission factor was derived from these results and the relationships among GHG emissions, compost parameters and seasons were determined. Third, the GHG emission rate data were used to inform statewide GHG emissions from green waste composting.

2. Materials and methods

2.1. Experimental site, windrow description, and sampling schedule

Greenhouse gas emissions and compost chemistry were monitored at a northern California compost facility (latitude 38.77564°N, longitude 121.88007°W). The green waste material, comprised of yard trimmings collected from surrounding cities north of San Francisco Bay, was mixed with woodchips or chopped branches (woodchips to yard trimming ratio 1:9) to increase porosity and aeration as a standard practice. Three windrow piles were monitored during three different seasons. The first pile (Pile I) represented a summer windrow (57 days); the second pile (Pile II) represented a winter windrow (43 days); the third pile (Pile III) represented a spring windrow (54 days) (Table 1). The green waste was laid out in a windrow and turned using a windrow turner with a rotary drum and flails, shown in Fig. 1 (Rynk, 1992). The sizes of the piles in this study were approximately 18 m × 3.5 m × 1.3 m (Length × Width × Height). The compost moisture in the pile was maintained at approximately 50% gravimetric moisture content according to the specifications determined by facility management (Fig. 1). Water applications when necessary mostly occurred before turning. Each pile was turned five times within the first 15 days of initial construction, and thereafter, the pile was turned weekly. On a few occasions the piles were not turned according to schedule because of weather conditions or equipment malfunction.

During the first 15 days of the turning period, gas samples were collected before (on the day of turning) and after (<1 h) the pile turning at each turning event. During the weekly turning period, gas samples were collected once between the two contiguous turning days, as well as before and after turning at each turning event. Compost samples were collected within one hour of pile turning at each turning event. Temperature and oxygen samples were collected at each gas sampling event. As discussed in the introduction, oxygen concentrations and temperature have been considered important variables that affect GHG emissions, and turning would significantly change these variables.

2.2. Compost sampling and analyses

Compost material in the piles were sampled to quantify the moisture content, ammonium (NH_4^+), nitrate (NO_3^-), dissolved organic carbon (DOC), total C, and total N on a mass-specific basis. Immediately following each turning event grab samples were taken from three different sections of the pile (Sections 1–3) (Fig. 2). In each of these sections, five different locations (approximately 15 cm below the surface of the pile) from the cross sections

Table 1
Characteristics of the input and output material for each pile in Windrow system.

	Pile I		Pile II		Pile III	
	5/22/2012 Input	7/19/2012 Output	11/5/2012 Input	12/18/2012 Output	2/21/2013 Input	4/16/2013 Output
Material, Mg (DW[a])	13.2	9.5	11.6	10.6	10.5	13.2
Pile Dimension (L × W × H, m)	18.3 × 3.3 × 1.7	13.7 × 3.7 × 1.7	17.7 × 3.8 × 1.5	18.0 × 3.7 × 1.2	20.8 × 3.6 × 1.4	15.4 × 3.4 × 0.96
C:N ratio	32	22	30	20	28	22
Total C, kg (DW)	4400	2500	3600	2500	3200	3100
Total N, kg (DW)	140	115	120	130	120	140
NH_4^+-N, kg (DW)	2100	1700	12,000	470	20	200
NO_3^--N, kg (DW)	430	5.1	100	ND[b]	ND	ND
DOC, Mg (DW)	160	33	340	28	69	19

[a] DW indicates dry weight.
[b] ND indicates no data has been detected.

Fig. 1. Photograph of scarab turning the experimental windrow pile (left) and the water truck spraying the experimental windrow pile (right).

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