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The effects of composting approaches on the emissions of anthropogenic volatile organic compounds: A comparison between vermicomposting and general aerobic composting

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ABSTRACT

Emission patterns of 13 VOCs were investigated in three types of vermicomposting systems (*Eisenia fetida*, *Metaphire posthuma*, and *Lampito mauritii*) in reference to a traditional aerobic composting system by feeding the systems with mixtures of three materials (coal ash (CA), municipal solid waste (MSW), and cow dung (CD)). On an average, the emission rates of aromatic VOCs (benzene, toluene, xylenes, and styrene) were two to three times higher than all other groups (aldehyde, ketones, esters, and alcohols) from all three types of feeding mixtures. However, the emission rates of aromatic VOCs were generally reduced over time in both aerobic composting and vermicomposting systems. Such reduction in the emission rates was most prominent from *Eisenia*-treated CD + MSW (1:1), *Lampito*-treated CD + CA (1:1), and *Metaphire*-treated CD. The results clearly indicated that the increase in humified organic C fractions (humic acid and fulvic acid) and the microbial biomass present during the biocomposting processes greatly reduced the emissions of VOCs. Hence, the study recommends that vermicomposting of coal ash and municipal solid waste in combination with cow dung in 1:1 ratio is an environmentally gainful proposition.

1. Introduction

The ever-increasing worldwide production of municipal solid wastes (MSW) due to rapid economic development poses serious environmental threats. According to a recent estimate, global generation of MSW increased by 37.3% between 2007 and 2011 (Dorado et al., 2013). Additionally, the uncontrolled combustion of coal for energy generation has produced huge amounts of coal ash (CA) and has contaminated land and water resources. For instance, annual CA production in India alone exceeded 180 million tons during 2009–10 (Bhattacharya et al., 2012). Thus, the major concern of national and local governments is to ensure effective and sustainable management of various types of solid wastes. The main aim of any waste treatment facility is to focus on volume reduction and stabilization of wastes through biological and chemical processes. With this in mind, vermicomposting and aerobic composting are two important bioprocessing technologies that can be used to stabilize different kinds of solid wastes. In addition to volume reduction, these techniques are also capable of converting wastes into valuable fertilizer materials. However, during the bioprocessing of solid wastes, large quantities of odorous volatile organic compounds (VOCs) are known to be emitted (Dorado et al., 2013).

VOCs emitted from natural sources have significantly contributed to the increased CO_2 concentration in the Earth's atmosphere (Bouvier-Brown et al., 2012). VOCs also transform nitrogen oxides into ozone in the presence of sunlight (Westburg and Rasmussen, 1972). Therefore, these compounds can create health hazards for different populations ranging from composting plant workers to consumers of vegetables produced with compost fertilizers. A good composting method not only ensures sufficient hygiene of the finished product but also promotes chemical decontamination.

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Additionally, technology should be employed to facilitate adequate maturity of composts; this refers to the extent of humification and stabilization of microbial activity (Deportes et al., 1995). The major indicators of humification are the humic acid and fulvic acid fractions of carbon and the microbial biomass.

Recently, a comprehensive inventory of odorous VOCs was presented to deal with the various source types of aerobic composts (Dorado et al., 2013). Shen et al. (2012) reported that VOC emissions were accelerated during mesophilic phase of composting with the circulation of air within the compost piles. In addition, many researchers also observed that the rate of VOC emission increased significantly during the initial stage of composting compared to the later stages (Turan et al., 2007; Kumar et al., 2011). All these studies indicated that the acceleration in microbial activities during composting is the major driving factor for VOC emission. However, comparable information is scarce with respect to vermicompost. Under these perspectives, the dynamics of humified organic carbon fractions (humic acid and fulvic acid carbon) and microbial biomass carbon during the composting periods can be good indicators to assess the fluctuations in VOC emissions. Considering the dearth of information on such relationships in vermicomposting, we attempted to evaluate the significance of this subject through correlation and regression approaches. Nonetheless, the nature and properties of composts and their maturity may vary greatly depending on the earthworm species employed in the vermireactors. This, in turn, may considerabtly influence the dynamics of gaseous emission due to vermicomposting. Because the emission of VOCs is complicated by the variability in their formation throughout the composting process, it is difficult to accurately estimate their emissions from different composting systems (Pagans et al., 2007). Among various instrumental techniques, TD-GC is a highly reliable tool for the quantitative analysis of a diverse range of VOCs (Ullah and Kim, 2014). For such application, the target analytes captured in a sorbent tube are analyzed by TD-GC setups that are interfaced with different types of detectors such as flame-ionized detectors (FIDs) and MS detectors (Kim and Kim, 2013).

The aim of this study was to provide a basic understanding about odorous VOC emissions from different vermicomposting systems that were mediated with the aid of different earthworm species (*Eisenia fetida*, *Lampito mauritii*, and *Metaphire posthuma*). These species were selected based on their commercial as well as scientific recognitions. *Eisenia fetida* is widely used for commercially viable vermicompost production (Singh and Suthar, 2012); *Lampito mauritii* has been recognized for its metal detoxification potential (Maity et al., 2009); and waste degradation capability of *Metaphire posthuma* has recently been recognized (Sahariah et al., 2015). The performance of vermicomposting systems was evaluated further in reference to aerobic composting. The VOCs emitted from all of these composting systems were measured by a thermal desorption (TD) - gas chromatography (GC) setup with a mass spectrometry (MS) detector. Using this study, we intend to elucidate the dynamics of VOC emissions from various feed mixtures of MSW, tea factory coal ash (CA), and cow dung (CD).

2. Materials and methods

2.1. Collection of municipal solid waste (MSW), tea factory coal ash (CA), cow dung, and earthworm species

MSW and CA were procured from Tezpur and Goalpara in Assam, India, respectively. Cow dung (CD) samples(with two to three days of aging)were collected from a nearby village area. The basic characteristics of these three components are presented in Table 1S in Supplementary Information. For this study, three earthworm species (*Eisenia fetida*, *Lampito mauritii* and, *Metaphire posthuma*) were selected. About two months old earthworms weighing between 350 and 400 mg were uniformly collected from the stock population of the vermiculture unit of the Department of Environmental Science, Tezpur University.

2.2. Vermicomposting and aerobic composting systems and the experimental setup

Aerobic composting was conducted by following a standardized methodology suitable for the local conditions (Goswami et al., 2013). Vermicomposting and composting was done in perforated, earthen vessels with dimensions of 0.45 m (width) × 0.45 m (length) × 0.30 m (height). Three types of feed mixtures [CA + CD (1:1), MSW + CD (1:1), and only CD] were used for the comparative experiment based on our previous experiences (Goswami et al., 2013; Sahariah et al., 2015). For this experiment, we used 3 kg of each feed mixture and incubated independently with the three earthworm species at 10 worm kg^{-1} of mass. The moisture content was maintained between 50 and 60% of the mass during the incubation period (60 days), and aeration was ensured by mixing the feed mixtures two times per day for 15 min. These operations ensured the maintenance of a mesophilic temperature range (26 °C to 31 °C) during the study period. The treatment combinations used for this experiment are presented in Fig. 1.

All the experimental feed mixtures were replicated three times, and samples of each category were drawn and analyzed to assess the variability in the VOC emissions and C fractions. Temporal dynamics in the content of microbial biomass C (MBC), humic acid C (HAC), and fulvic acid C (FAC) were analyzed by following the standard methods for each respective target (Tabatabai and Bremner, 1969; Page et al., 1982). Primary grade chemicals (with more than 90% purity) were used, and all analysis was executed in accordance with the general quality control guideline (USEPA, 2000).

2.3. Sorbent tube collection of VOC samples using an impinge-based chamber system

In this study, a total of 13 VOCs were selected as target compounds: butyraldehyde (BA), isovaleraldehyde (IA), valeraldehyde (VA), benzene (B), toluene (T), meta-xylene (m-X), para-xylene (p-X), ortho-xylene (o-X), styrene (S), methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), butyl acetate (BuAc), and isobutyl alcohol (i-BuAl). The basic properties of these target compounds are summarized in Table 1.

The procedures leading to the quantification of VOCs generated from the biocomposted samples using an impinger system as a small flux chamber have been described in detail in our previous studies (Iqbal and Kim, 2014). Air-dried biocomposted samples were first placed in a medium-sized impinger (175 mL). These impingers are designed in such a way that a controlled microenvironment can be created to intrude and excite the volatiles of solid samples with a constant supply of gas. In this experiment, N_2 was used as the sweeping gas, and 10 L of volatiles were collected at a flow rate of 100 mL min^{-1} for 100 min (i.e., 1.67 h) at 25 °C. The multi-bed sorbent tubes (ST) were prepared by packing three types of Carbopack sorbents (C,B, and X). The STs were conditioned for 7 h at 320 °C by passing 99.999% N_2 with a tube conditioner (ATC-1200, ACEN Co. Ltd., Korea). The preparation of STs and gas collection was done by following the procedure standardized in our previous studies (Kim and Kim, 2013).

2.4. Liquid standards, calibration, and analysis of VOCs

The analysis of the target VOCs collected in STs was carried out