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Volatile fatty acid evolution in biomass mixture composts prepared in open and closed bioreactors

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ABSTRACT

In this study we observed the production of volatile fatty acids (VFAs) during the composting process of compost heaps in two different bioreactors (open and closed) at three different depths (0, 40 and 80 cm). The compost was prepared as a mixture of bio-waste, horse manure, grass and sawdust to ensure sufficient pH conditions in compost heaps. VFA contents in the composting materials were analysed weekly over 14–119 d. The degradation process was monitored, along with temperature, pH, total organic carbon, oxidizable carbon and mono- and oligosaccharides. VFA contents were evaluated with regard to the depth of the sample site in the compost heap and to conditions in the bioreactors. The maximum VFA occurrence was observed during the first 35 d; acetic and propionic acids in particular were determined to occur in each sample. Considerable variations in their formation and elimination were observed in the two bioreactors as well as at the various depths in the compost heaps. Significant correlations were found between individual VFAs, as well as between VFA concentrations and organic carbon contents.

1. Introduction

Compost production and its application to agriculture represent an attractive solution for the treatment of organic waste (Zmora-Nahum et al., 2007). The composting process is based on bio-oxidative reactions in an aerobic environment, leading to mineralisation and partial humification of organic matter, resulting in compost material with certain humic properties (Veeken et al., 2000; Young et al., 2005; Bernal et al., 2009). Bacteria, fungi and other microorganisms are the main agents in the process. In the early stage of organic matter degradation, low molecular weight molecules such as volatile fatty acids (VFAs), saccharides, amino compounds, CO_2, NH_3 and H_2O are formed, in addition to heat. The second stage of composting is the maturation and stabilisation phase, which results in stabilised organic matter (Bernal et al., 1997; Baffi et al., 2007; Bustamante et al., 2008; Som et al., 2009; Barneto et al., 2010; Raj and Antil, 2011). One of the main difficulties of composting is that the process is rarely controlled due to various reasons and the composts usually evolve as it is allowed to. However, the compost procedure should be performed under controlled conditions (e.g., pH, C/N, moisture, temperature, oxygen supply) to ensure optimal conditions over the entire process (Garcia et al., 1991; Bernal et al., 2009).

VFAs including acetic, propionic, butyric, isobutyric, valeric, isovaleric and hexanoic acid, are intermediates formed during microbial decomposition, particularly under anaerobic and semi-anaerobic conditions (Brinton and Tränkner, 1999; Adani et al., 2006; Brinton, 2006). Their formation is also related to the rotting of organic matter in the absence of aerobic microbial populations. They are known to cause phytotoxicity and inhibit microbial activities in biological processes if they occur in high concentrations. They are toxic to microorganisms in their undissociated forms, for instance at low pH (Beck-Friis et al., 2001, 2003; Bergersen et al., 2009; Cheung et al., 2010).

The composting process is not strictly aerobic. Semi-anaerobic fermentation can occur at any point in the process due to, e.g., oxygen stress. The microorganisms producing VFAs under semi-anaerobic conditions are facultative microorganisms. Hence, the process of composting is not necessarily disturbed by their presence, and VFAs produced serve as an energy source for consequent aerobic microbial activity, once favourable aerobic conditions return (Brinton, 2006).

The anaerobic conditions in the poorly aerated interiors of compost aggregates cannot be ignored and have to be taken into consideration (Beck-Friis et al., 2003; Sundberg and Jönsson, 2008). VFAs are also found in raw bio-waste material (Bergersen et al.,

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2009). Their concentrations usually increase during the composting process, especially in the initial phase, when they are formed due to the rapid microbial activity in degrading compost material but they also enter compost in the source material. They can be a key factor in influencing the pH of the composting material by decreasing the pH (<5) in the environment, particularly during the composting of acidic waste, such as organic household waste (Sundberg et al., 2004).

The lower pH allows acids to be present in undissociated forms, which can lead to inhibition of microbial activities. The consequences may include slow organic matter decomposition, stagnation and unpleasant odour. The resultant compost does not reach maturity or stabilisation, and it is phytotoxic if applied to soil. Such compost may contain ammonia and inorganic or organic compounds that may reduce seed germination or impair root development (Brinton and Tränkner, 1999; Adani et al., 2006; Bergersen et al., 2009). If the composting process is controlled such that it occurs under optimal conditions, including optimal pH, the acids are decomposed readily because they serve as easily degradable substrate in their dissociated form. In that case, no inhibition occurs.

The research of processes that proceed during composting process in various conditions is one of topics of our research team. This paper describes a part of our study that was aimed to observing behaviour of organic carbon in two biomass composting material performed under different conditions. We used two identical bioreactors containing identical mixture of raw materials for the composting processes and both of processes were performed under identical weather conditions. The only difference was that one of the bioreactors was uncovered and the second was covered with cloth. The purpose of this study was an observation if there are considerable differences during the composting processes in evolution of several parameters (temperature, pH, TOC, C_{ox}, saccharides and especially VFAs).

We prepared the composting mixture of defined composition from different raw materials and composting process was performed in two ways: one of the compost processes was conducted in an open bioreactor; the second was performed in a container covered with waterproof breathable canvas cloth to protect it from rain. The composting mixture was composed of grass (60%), horse manure (20%), potato paste (10%), vegetable (5%) and sawdust (5%), the biomass composition is expressed as percentage by weight. The raw materials were chosen with respect to get the sufficient proportion of carbon and nitrogen in the composting mixture and also to prevent formation of undesirable conditions of composting (pH decreasing). It is well known that composting of waste organic materials such as potato paste, vegetable and grass is often accompanied with low pH values that can negatively influence the whole process. Thus, the addition of horse manure and sawdust to this mixture could prevent pH decreasing.

The VFAs are formed in raw organic waste materials and also during the compost processes. The pH values of 7.89 in our study were in optimal range in both bioreactors at the beginning of the processes in comparison with optimum pH values between 5.50 and 8.00 (Bernal et al., 2009). There were several questions: Are VFAs formed in both reactors identically during the whole process? What kinds of VFAs are formed? Do VFAs affect the conditions in both bioreactors?

2. Materials and methods

2.1. Experimental setup of the composting process

Tests of the composting process were performed under two different conditions: (1 in an open bioreactor of volume 15 m^3 (height 1.5 m, width 2.3 m and length 4.5 m) as described in Raclavská et al. (2011); and 2) in a bioreactor of identical dimensions covered with waterproof breathable cloth. The composts were labelled K1 (open bioreactor) and K2 (covered bioreactor). The composts were made from biomass (sawdust 5%, grass 60%, horse manure 20%, potato paste 10%, vegetable 5%, the biomass composition is expressed as percentage by weight); the composition of the initial raw materials was described in Raclavská et al. (2011). The moisture contents were maintained at a constant value of approximately 60% by watering with rainwater that was retained in extra barrels. The covered compost was periodically uncovered and watered by rainwater to reach demanded moisture in heap. The watering was performed according to detected moisture values approximately every 2 wk.

Mechanical turning of composting materials in the both bioreactors were done in wk 7 in the both bioreactors.

2.2. Sampling

The composting processes were performed over the course of 119 d. Sampling was conducted weekly from ten sampling points at three depths of 0, 40 and 80 cm, in both K1 and K2. The sampling holes were made by drilling into the top of each heap with a ground auger. The quantity of sample mass collected for chemical analysis was about 5 kg from each layer (0.5 kg from each sampling point). The samples were handled and prepared according to CEN/TR 15310-2:2006 (Raclavská et al., 2011). Quartation of total samples was done by using Gilson Sample Splitter P501. Sub-samples of raw materials (approximately 700 g) without any preliminary treatment were used for VFA analysis. They were stored at 4 °C and processed within 1–5 d of reception. The remaining samples were dried in 35 °C and grounded and sieved to the fraction below 2.0 mm and consequently used for analyses C_{ox}, TOC, monosaccharides and oligosaccharides and pH.

The samples were collected from layers 0, 40 and 80 cm deep for the first 10 wk; after that, only the surface layer (0 cm) was sampled. The reason was that chemical analysis of samples collected in wk 8–10 showed that values of monitored parameters did not change considerably in comparison with previous analysis sets, for example in case of TOC or VFA parameters. The both composting processes were finished according to the analysis of some parameters (pH, temperature, C/N ratio) after wk 16 when the parameters values were approximately stable. The final composts were dark brown in colour without unpleasant odours.

2.3. Chemical analysis

During the composting processes, the following parameters were monitored: concentrations of acetic, propionic, butyric, isobutyric, valeric, isovaleric and hexanoic acids (VFAs), organic oxidizable carbon (C_{ox}) and total organic carbon (TOC) contents, monosaccharides and oligosaccharides, pH and temperature. The temperature inside the heaps in three sites (in depths of 0, 40 and 80 cm) was measured constantly in situ with a TESTO thermometer with probe. The pH values were determined according to the standard method ISO 10390:2005 Soil quality – determination of pH. TOC was measured according to CEN/TS 15407:2006 and EN 13370:2003.

C_{ox} (expressed as percentage) was determined for each sample by the modified Walkley–Black dichromate method (De Vos et al., 2007). The principle of this method is that oxidizable matter in the sample is oxidised by $Cr_2O_7^{2-}$, and the reaction is facilitated by the heat generated; concentrated H_2SO_4 is then mixed with $K_2Cr_2O_7$ solution. The excess of $Cr_2O_7^{2-}$ is determined by titration with standard $FeSO_4$ solution, and the quantity of substances oxidised is calculated from the amount of $Cr_2O_7^{2-}$ reduced.