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ScienceDirect
Chemosphere 68 (2007) 1030–1040
CHEMOSPHERE
www.elsevier.com/locate/chemosphere

Oxidative biodegradation of dissolved organic matter during composting

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Received 17 October 2006; received in revised form 5 February 2007; accepted 5 February 2007
Available online 21 March 2007

Abstract

Dissolved organic matter (DOM) plays an important role in the microbial degradation of compost since it represents the most active organic fraction, both biologically and chemically. The detailed evaluation of the changes in the chemical and biochemical characteristics of DOM induced by oxidative biodegradation, presented in this work highlights the mechanisms involved in the degradation of soluble organic matter during composting. In fact, the results show that during the initial stages of composting, DOM is highly degradable under aerobic conditions, particularly due to the predominance of labile, hydrophilic compounds such as carbohydrates, amino acids and proteins. As such compounds are degraded more resistant aromatic moieties accumulate in solution resulting in a reduction in the degradability of DOM with composting time. This decrease in degradability was found to be highly correlated with microbial oxygen demand, and could have important implications in the evaluation of the composting process.

Keywords: Microbial respiration; Compost stability; Biodegradability; Oxygen demand; Specific oxygen uptake rate; Biochemical analysis

1. Introduction

Composting is used in waste management to convert organic waste into agriculturally useful products. The most important factors affecting the successful application of compost for agricultural purposes are its degree of stability and maturity. Application of unstable or immature compost may inhibit seed germination, reduce plant growth and damage crops by competing for oxygen or causing phytotoxicity to plants (Wu et al., 2000; Brewer and Sullivan, 2003; Cooperband et al., 2003). Since the biodegradation of organic matter (OM) is the principal process involved in the biostabilization of organic waste materials, compost stability is usually expressed as a function of the bioavailability of OM (Cooperband et al., 2003). It is generally defined in terms of the rate or degree of OM decomposition and is therefore strongly related to the rate of microbial activity in the composting mixture (Zmora-Nahum et al., 2005).

The aerobic biodegradation of OM during composting involves the consumption of oxygen and release of carbon dioxide by the microbial biomass (D'Imporzano and Adani, 2007). For this reason, respirometric analyses based on the determination of carbon dioxide production or, more recently, oxygen consumption, have been widely used as a direct measurement of compost stability (Iannotti et al., 1994; Lasardi and Stentiford, 1998; Adani et al., 2003; Brewer and Sullivan, 2003; D'Imporzano and Adani, 2007).

Moreover, various authors have reported a strong relationship between compost stability and dissolved organic carbon (DOC) concentration (Iannotti et al., 1994; Bernal et al., 1998; Chefetz et al., 1998; Adani et al., 2003; Chica et al., 2003; Zmora-Nahum et al., 2005; Said-Pullicino et al., 2007a). Furthermore, the soluble state is presumably a prerequisite for the diffusion of substrates through microbial cell membranes so that the degradation of solid phase OM or large molecules can only occur after dissolution

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0045-6535/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2007.02.012

or hydrolysis by exoenzymes (Marschner and Kalbitz, 2003). In fact, compost dissolved organic matter (DOM) is the organic fraction containing soluble breakdown products, bio-originating compounds and repolymerized macromolecules, that could be utilized by the microbial biomass as an energy source. It represents the most active fraction of compost, both biologically and chemically (Said-Pullicino et al., 2007a) and as such, plays an important role in the microbial degradation of compost OM. During composting, processes such as solubilization through the microbial degradation of the more labile compounds that form part of the bulk OM, biochemical synthesis of low-molecular weight compounds by the microbial biomass and degradation of soluble organic compounds are mainly responsible for the changes in the concentration and chemical composition of DOM (Said-Pullicino et al., 2007a,b). For this reason, a detailed evaluation of the changes in chemical and biochemical characteristics of DOM induced by oxidative biodegradation, could offer a deeper insight into the mechanisms involved in the biodegradation of soluble OM during composting and could help to identify fractions and chemical constituents implicated in DOM degradation. This approach is important to fully comprehend the contribution of DOM to oxygen uptake and further understand the role it plays in determining compost stability.

Experimentally this could be best achieved by using the respirometric method reported by Lasardi and Stentiford (1998) which involves the measurement of oxygen uptake in an aqueous compost suspension under conditions ensuring optimum microbial activity and maximum reaction rates, and simultaneously monitor the changes in the chemical composition of soluble OM with time.

2. Materials and methods

2.1. The composting process and sample collection

The urban waste compost studied was produced mechanically on an industrial scale at the Gesenu SpA composting facility in Pietramelina (Perugia, Italy). The initial material was composed of source-separated municipal solid waste (55% w/w), yard trimmings from pruning activities (30%) and foliage residues from the tobacco agro-industry (15%). Composting was carried out under aerobic conditions and involved an active or thermophilic phase of approximately 28 d (with temperatures >55 °C for 20 d reaching a maximum of ~65 °C) during which the material was subject to daily turnings, followed by a curing phase in piles for approximately three additional months. The material was sampled at 13, 28, 70 and 250 d of composting to represent samples from the middle of the active phase (AM), end of the active phase (AE), curing phase (CM) and end of the process (CE) respectively. Collected samples were freeze-dried, crushed to pass through a 0.5 mm sieve and thoroughly mixed. Details of the composting process and sampling methods used have been reported elsewhere (Said-Pullicino et al., 2007a).

2.2. Oxidative biodegradation experiments

Compost samples obtained at different composting times were subject to oxidative biodegradation experiments. These involved the measurement of microbial respiration based on oxygen consumption using a procedure originally described by Lasardi and Stentiford (1998) and modified by Adani et al. (2003). All analyses were carried out in triplicate.

Briefly, the rate of oxygen uptake was determined by measuring the changes in the concentration of dissolved oxygen in an aqueous compost suspension under conditions ensuring optimum microbial activity (35 °C and pH 7.2) and maximum reaction rates over an incubation period of 24 h. A compost aliquot of 2.5 g dry weight was suspended in 500 ml of deionised water containing 5 ml of nutritive solution ($CaCl_2$ 0.25 M, $FeCl_3$ 0.93 mM and $MgSO_4$ 0.09 M) and 15 ml of phosphate buffer solution (NaH_2PO_4 28 mM, Na_2HPO_4 72 mM). The suspension inside a glass incubation bottle was continuously stirred by means of a magnetic stirrer and periodically purged with air through a glass frit to replenish the dissolved oxygen consumed by the microbial biomass. A control system was set to provide a repetitive sequence of 15 min purge time followed by 15 min continuous acquisition of dissolved oxygen concentrations by means of a Clark-type polarographic probe inserted into the suspension. The specific oxygen uptake rate (SOUR) was calculated by means of a linear regression analysis of dissolved oxygen against time over the repeated acquisition intervals and expressed as mg O_2 g^{-1} VS h^{-1} on the basis of the volatile solids (VS) content determined as the loss in weight after ignition at 550 °C. $SOUR_{max}$ represents the maximum rate of oxygen consumption while cumulative oxygen demand was calculated as the integral of the oxygen uptake over incubation time.

At 0, 4, 8, 12 and 24 h from the beginning of the biodegradation experiments, small aliquots of liquid phase were sampled from the suspension and filtered consecutively through a glass microfibre filter and a 0.45 μm membrane filter. The resulting solution was subject to the determination of DOC concentration, total phenolic compounds, total reducing sugars, hexose and pentose sugar content, protein and amino acid content, as well as the specific UV absorption at 254 nm to evaluate its aromatic content. Moreover, water extracts at the beginning and end of the incubation period were also subject to DOC fractionation and Fourier-transform infrared (FTIR) spectroscopic analysis to be able to characterize the major chemical changes that DOM undergoes during biodegradation. The contribution of chemical oxidative degradation of DOC during the degradation experiments was evaluated by means of a sterilized control. This involved carrying out the same experiments on autoclaved compost samples. In order to