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The importance of aeration mode and flowrate in the determination of the biological activity and stability of organic wastes by respiration indices

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HIGHLIGHTS

- The importance of aeration on compost activity and stability was assessed.
- Airflow rates were studied using constant and adjustable modes.
- The 'controlled respiration' mode resulted in the highest respiration activity.
- Respiration activity was limited at constant flows below 20 L kg^{-1} DM h^{-1}.
- Above an aeration volume of 3000 L kg^{-1} DM, respiration activity was constant.

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ABSTRACT

The aim of this study was to assess the effect of different air flowrates and different aeration modes on the respiration activity of three organic substrates of different stability degree: (i) a constant flowrate and (ii) a continuously adjusted air flowrate that optimized the oxygen uptake rate (OUR). Above 20 L air kg^{-1} DM h^{-1}, at the constant flow regime, the resulting dynamic respiration index at 24 h (DRI_{24}) and the cumulative respiration at four days (AT_4) were statistically similar. At the OUR based aeration regime, the DRI_{24} and AT_4 were statistically similar at all initial flowrates tested. Above a minimum threshold, cumulative air flow of around 3000 L air kg^{-1} DM during a 5 day period, the respiration activity was similar, particularly for the two less active substrates. This study highlights the importance of selecting the aeration to obtain reliable measures of biological activity and stability in organic wastes.

1. Introduction

Several studies have highlighted the importance of knowing reliable measures of the biological activity of an organic waste and the final stability of an end product. For instance, respiration indices can provide a realistic picture about the overall efficiency of a complete waste treatment plant based on biological processes, such as anaerobic digestion or composting (Ponsá et al., 2008; Pognani et al., 2011). In these cases, respiration indices permit the accurate determination of the performance of the plant and to propose actions to improve it (Ponsá et al., 2010a). In other advanced studies, respiration indices have been also used to compare different approaches to organic waste management, such as industrial and home composting. These indices have been demonstrated to be the most suitable parameters to have a fair balance of the pros and cons of both these technologies (Martínez-Blanco et al., 2010).

In some recent advanced works, respiration indices are being proposed in order to determine the full treatment efficiency of an organic waste in all the operation stages of the treatment process and to use this efficiency to assess the environmental impact related to the extent of the organic matter degradation (Colón et al., 2012).

Moreover, respiration indices have been shown to correlate well with anaerobic digestion tests, such as biochemical methane potential (BMP), which are time consuming. In consequence, respiration indices can provide a relatively rapid measurement of the biogas potential of a sample in any stage of the biodegradation process (Cossu and Raga, 2008; Barrena et al., 2009).

For all the above reasons, it is of major importance to have a reliable measure of the biological activity of an organic waste in all its stages of biodegradation (including, but not limited to, final product) and respiration indices are probably the most powerful tools that are available for researchers (Barrena et al., 2006).

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Despite the common use of dynamic respiration tests to evaluate the stability of composts and the biological activity of organic wastes, variable and diverse techniques do exist. Some of the main differences have to do with the adopted sample size (Komilis and Kletsas, 2012) as well as the aeration mode and flowrates used in the experiments. For example, the tests suggested by Scaglia et al. (2000) employ a pilot scale reactor that can accept up to 15 kg of sample size and in which air flow is continuously adjusted so that the oxygen content at the outlet stream is maintained always at 14% v/v. Most tests require a constant air flow throughout the experiment (Barrena et al., 2014), whilst a recent aeration mode designed by Puyuelo et al. (2010) continuously adjusted air flowrate to keep the oxygen uptake rate (OUR) optimized to achieve always the maximum respiration activity, which can result in a more realistic assessment of the respiration activity. Aeration rate is expected to influence the resulting microbial respiration activity indices and, in consequence, both the biological activity and the stability of organic wastes. In Komilis and Kanellos (2012), in which a constant flow regime had been used, a linear increase of the dynamic respiration index (DRI) as the unit air flowrate (UAF) increased was observed.

In this work, 500 mL custom made respirometers were used to measure respiration activity (RA). Two aeration regimes were used and compared, namely: (a) a constant aeration rate throughout the experiment so that to achieve a constant unit air flowrate (UAF), and (b) a continuously adjusted air flowrate that maximizes the OUR based on a novel control algorithm that has been described in detail in Puyuelo et al. (2010).

Therefore, goal of the study was to assess the effect of different air flowrates and different aeration regimes on the microbial respiration activity as this was assessed via several dynamic respiration indices. This information will aid in selecting or modifying existing stability limits and to have a reliable picture of the biological activity of any organic waste sample.

2. Methods

2.1. Organic material and sampling

Three representative organic substrates in terms of stability were used in this work: (i) a fresh (raw) source-separated organic fraction of municipal solid wastes (OFMSW), (ii) a semi-stabilized organic material (SSOM) derived from the aerobic stabilization of mechanically selected organic fraction of the residual (rest) fraction of MSW (after a composting period of 3–4 weeks at a local plant of Barcelona), and (iii) a well-stabilized compost (COMPOST) derived from the composting of OFMSW after a prolonged aeration period of 7–8 weeks and one month of curing. All materials were obtained from the same plant. In each case, samples were obtained from large piles of material. 3–4 kg of material were taken from at least six points of this pile to get a final sample of approximately 25 kg. This sample was manually mixed and stored by freezing at −18 °C in aliquots of 1 kg. It has been demonstrated that this procedure does not alter the respiration activity of the samples (Pognani et al., 2012). From those 1 kg aliquots, a random selection was done, and then an additional quartering process was performed on each 1 kg aliquot in order to obtain the 100 g needed for each replicate run.

2.2. Respirometry operation and aeration modes

The dynamic respirometers consist of 15 reactors as described elsewhere (Ponsá et al., 2010b). Briefly, 100 g waste sample was placed in each 500 mL reactor. Each reactor consisted of an Erlenmeyer flask, containing a plastic net to support the organic waste and to provide an air distribution chamber, placed in a water bath at 37 °C. Airflow in the reactors was adjusted by means of an air flow controller (Bronkhorst Hitec, The Netherlands). Air was passed through a humidifier at the same temperature of the reactor to avoid water losses and moisture changes. Exhaust air from the reactors was sent to an oxygen sensor prior dehumidification in a water trap. Both air flow meters and oxygen sensors were connected to a data acquisition system to continuously record these values for OUR on-line calculation.

The calculations to convert O_2 contents and air flowrates to O_2 consumption are based on the ideal gas law (Ponsá et al., 2010b) according to the following equation:

$$\mathrm{OUR} = F \cdot (0.209 - y_{O_2}) \cdot \frac{P \cdot 32 \cdot 60}{R \cdot T} \quad (1)$$

where: OUR is the oxygen uptake rate (g O_2 h^{-1}); F, airflow into the reactor (L min^{-1}); y_{O2}, is the oxygen molar fraction in the exhaust gases (mol O_2 mol^{-1}); P, pressure of the system assumed constant at 101,325 Pa; 32, oxygen molecular weight (g O_2 mol O_2^{-1}); *60*, conversion factor from minute to hour; R, ideal gas constant (8310 Pa L K^{-1} mol^{-1}); T, temperature at which F is measured (K). Regarding y_{O2}, the flow dynamics of the reactors was analyzed in previous works (Puyuelo et al., 2010) by the residence time distribution technique resulting in a completely mixed operation. In consequence, a homogenous oxygen distribution can be considered in the entire volume of the reactor.

In the constant air flow regime, air flow was simply adjusted to a constant initial value so that the UAF was maintained constant throughout the experiment. In the OUR based air flow regime, the air flow was adjusted every 60 min so that to optimize the OUR according to an optimization algorithm mentioned in Puyuelo et al. (2010). It is clarified here that in the OUR based regime, the flow presented in tables and figures refers to the initial air flowrate that, obviously, can continuously change during the process according to the programming algorithm and the biological activity of the material. The principal respiration indices calculated in this work were three, namely: (a) a 24 h based dynamic respiration index (DRI_{24}), which is the average of the instantaneous oxygen uptake rates during a 24 h period of maximum respiration activity, (b) the AT_4, which is the total oxygen consumed over a 4 day period beyond the initial lag time, (c) the total cumulative flow of air (F_{acum}) introduced into the reactors during a 5 day period. These indices (DRI_{24} and AT_4) are well established and used in the composting research (Adani et al., 2006). It is noted that the experimental period ranged from 5 to 7 days. Some runs were terminated earlier than others since the critical respiration indices (DRI_{24}, AT_4) could be anyway calculated.

Other calculated parameters relevant in respiration activity were: (d) the maximum value of the average of instantaneous OUR measurements in one hour (DRI_1) (Barrena et al., 2009), (e) the lag time (hours), finishes when the observed respiration activity is, at least, the 25% of the respiration activity observed during the largest increase in the oxygen consumption within the first 4 days (Federal Government of Germany, 2001) and (f) the times needed to reach the *first* and *second* (if existed) instantaneous peak in the OUR profile (Berthe et al., 2007).

The initial moisture content in all substrates was 54.3% ± 7.2% while the final moisture contents of all substrates ranged from 20.8% (in only one replicate run) to 68.0% with an average value at 51.1% wb (±9.7%), indicating that the average moisture content change (decrease) during the experiments was 6.0%.

2.3. Experimental design and statistical analysis

Four to five UAFs were used for each substrate and for each aeration mode. These UAFs ranged from 7.1 to 103 L kg^{-1} DM h^{-1} for