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The effect of airflow rates and aeration mode on the respiration activity of four organic wastes: Implications on the composting process

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ABSTRACT

The aim of this study was to assess the effect of the airflow and of the aeration mode on the composting process of non-urban organic wastes that are found in large quantities worldwide, namely: (i) a fresh, non-digested, sewage sludge (FSS), (ii) an anaerobically digested sewage sludge (ADSS), (iii) cow manure (CM) and (iv) pig sludge (PS). This assessment was done using respirometric indices. Two aeration modes were tested, namely: (a) a constant air flowrate set at three different initial fixed airflow rates, and (b) an oxygen uptake rate (OUR)-controlled airflow rate. The four wastes displayed the same behaviour namely a limited biological activity at low aeration, while, beyond a threshold value, the increase of the airflow did not significantly increase the dynamic respiration indices ($DRI_{1\ max}$, $DRI_{24\ max}$ and AT_4). The threshold airflow rate varied among wastes and ranged from 42 NL air kg^{-1} DM h^{-1} for CM and from 67 to 77 NL air kg^{-1} DM h^{-1} for FSS, ADSS and PS. Comparing the two aeration modes tested (constant air flow, OUR controlled air flow), no statistically significant differences were calculated between the respiration activity indices obtained at those two aeration modes. The results can be considered representative for urban and non-urban organic wastes and establish a general procedure to measure the respiration activity without limitations by airflow. This will permit other researchers to provide consistent results during the measurement of the respiration activity. Results indicate that high airflows are not required to establish the maximum respiration activity. This can result in energy savings and the prevention of off-gas treatment problems due to the excessive aeration rate in full scale composting plants.

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1. Introduction

Current legislation on solid waste management has highlighted the importance of recycling and recovering organic solid wastes as a sustainable management practice to substitute traditional final disposal through incineration and landfilling. The alternatives are biological treatments, based on composting, anaerobic digestion or both combined treatments. In all cases, it is important to know the biological activity of the waste, because it will determine the type of operation, the energy requirements and recovery, and its exploitation costs (Barrena et al., 2011a).

Composting is a natural process where microorganisms decompose organic matter into their simple elements. Compost, the final product, is stable and sanitized. Several studies highlight the importance of establishing a reliable measure of the waste biological activity and its biodegradability (Lasaridi and Stentiford, 1998; Barrena et al., 2009; Pognani et al., 2011), because other chemically-based parameters such as TOC (total organic carbon), COD (chemical oxygen demand), total organic matter content (OM, expressed as volatile solids) and DOC (dissolved organic carbon) are not precise enough because not all organic matter is biodegradable in real operation times. In consequence, there would be an overestimation of its biodegradability using these parameters (Barrena et al., 2009). Actually, measures of biological activity are a way to have a realistic value on the overall efficiency of the biological treatment process either in composting or in anaerobic digestion processes (Ponsá et al., 2008). Having a reliable method to assess these indices is of crucial relevance in waste management, such as the proper determination of final compost quality and the environmental impact assessment of composting facilities (Colón et al., 2012; Scaglia and Adani, 2008). Although a consensus has not been reached yet and there are still various suggested methodologies in the scientific literature to assess biodegradability, all of them are based on biological activities.

Ponsá et al. (2008) found a good correlation between aerobic and anaerobic indices. Barrena et al. (2009) also found a significant

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correlation between cumulative oxygen consumption and ultimate biogas production. Both correlations were found using samples from mechanical-biological treatment (MBT) plants treating municipal solid wastes. This indicates that both indices can be used to express the degree of biological stability. Aerobic indices were recommended for its shorter time of assay. In general, aerobic respiration indices have been highlighted as the most suitable tool for biodegradability and stability assessment, to monitor the process and to implement new improvements (Ponsá et al., 2010a; Barrena et al., 2009). Dynamic Respiration Indices (DRI) are well established (Scaglia et al., 2011) and used in composting research because of their advantages over static respiration indices or BOD with solids samples, such as the presence of a continuous airflow during the measurement, that do not limit the oxygen transfer through the biomass layer (Adani et al., 2003, 2006).

Barrena et al. (2011b), studied the behaviour of respiration activity on different wastes, classified in four groups: municipal solid wastes, wastewater sludge, manure, bulking agents and other wastes. Authors observed that municipal solid wastes with higher percentage of organic matter showed higher respiration ctivity. This biological activity increased when studying the source-selected organic fraction of municipal solid wastes (OFMSW). With regard to wastewater sludge, the anaerobic digestion process decreases the respiration activity by 60–70% (Ponsá et al., 2008). Fresh wastewater sludge biodegradability can change depending on the treatment applied or its origin, but digested wastewater sludge is usually more homogeneous. Manure shows a moderate respiration activity, far from those obtained with OFMSW and non-digested wastewater sludge (Barrena et al., 2011b). Part of this activity can be lost during their storage, as a part of its treatment (Bonmatí and Flotats, 2003). In summary, organic wastes from different origins, organic matter content and history will present different level of respiration activity. This will directly affect the aeration requirements and the composting process overall performance.

Aeration rate is expected to have an important effect on the microbial respiration, thus in biological activity and stability of the material. In Komilis and Kanellos (2012), a positive correlation between the dynamic respiration index DRI_{24} and unit airflow rates (range 2.5–13 L air kg^{-1} DM h^{-1}) was observed, as well as a negative correlation between CO_2 index and unit airflow rate.

Almeira et al. (2015), studied the effect of different airflow rates (range 6–100 L air kg^{-1} DM h^{-1}) and different aeration modes on the microbial respiration activity. Three different organic wastes derived from the OFMSW were studied, using constant airflow and an OUR (oxygen uptake rate) controlled airflow, which is continuously adjusted to keep the oxygen uptake rate optimized (Puyuelo et al., 2010). Results showed that a constant airflow below 20 L kg^{-1} DM h^{-1} limited respiration activity, while airflows above that value resulted in statistically similar respiration activities.

Aeration conditions also influence the composting process performance in terms of biodegradation rate, process time and GHG emissions from the composting process. Insufficient aeration can lead to oxygen limitations that lead to poor biodegradation rates. Excess of aeration can eventually cause major water losses and hamper moisture control (Ruggieri et al., 2008). It is considered as one of the most important factors, as insufficient aeration can lead to anaerobic condition, resulting in an increase of CH_4 emissions (Jiang et al., 2011). Jiang et al. (2015) observed that higher aeration rates increased NH_3 and N_2O losses, but showed a higher mitigation on CH_4 emissions, when composting pig feces.

The aim of this study is to evaluate the effect of different airflow rates and different aeration modes on the microbial respiration using different organic wastes via several DRI. Four parameters were analysed: DRI_1 (1-h Dynamic Respirometric Index average), DRI_{24} (24-h Dynamic Respirometric Index average), AT_4 (cumulative oxygen consumed in four days) and lag phase. Four non-urban type organic wastes were tested and their performance was compared to the organic fraction of municipal solid waste tested by Almeira et al. (2015) that had used exactly the same setup as here. The four wastes used in this study were selected because of their relatively high production volume worldwide. For instance, the Catalonia region in Spain, with 7 million inhabitants, produces annually 2 million and 20 million tonnes of wastewater sludge and manure, respectively, with cow and pig manure being the main components. In consequence, these materials have been selected as representative wastes to illustrate the different typology of non-urban and livestock organic wastes (Campos et al., 2004; Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, 2012a,b). Two aeration regimes were used: (i) a constant unit airflow rate and (ii) a continuous and variable airflow rate as adjusted by the OUR controller. Results obtained will help to determine the necessary amount of air to accurately measure microbial respiration in the laboratory. In addition, results will aid to calculate the minimum aeration rates required and the minimum total air necessary in full scale composting facilities to provide an effective stabilization of different types of agricultural and industrial organic wastes

2. Materials and methods

2.1. Organic wastes

Four different non-urban organic wastes were used in this work:

(i) a fresh, non-digested, sewage sludge (FSS) from the wastewater treatment plant in Olot (Girona, Spain),
(ii) an anaerobic digested sewage sludge (ADSS) from the wastewater treatment plant in Sabadell (Barcelona),
(iii) cow manure (CM) obtained from a local farm in Catalunya, and
(iv) pig slurry (PS) from a farm in Vic (Catalunya).

FSS and ADSS were both sampled from a wastewater treatment plant, while cow manure and pig slurry were sampled from a storage pile and a storage pond, respectively, of a manure storage facility. The cow manure was already mixed with straw that had been used as a bedding material. As Table 1 shows the characterization of those substrates.

2.2. Respiration tests

Ninety (90) g of sample from each of the aforementioned substrates were used in each individual respiration run (i.e. per replicate). To ensure a good porosity of the material, 9 g of inert bulking agent were added and manually mixed with FSS, ADSS and PS. The bulking agent consisted of small pieces (1 × 2 cm) of dishclothes (Spontex) (Puyuelo et al., 2011). No bulking agent was added to

Table 1
Characteristics of the four substrates tested (mean ± stdev).

Substrate	Moisture (% wb)	Organic matter (% db)	pH
FSS	85.0 ± 1	85.0 ± 1	7.51
ADSS	85.3 ± 0.03	78.4 ± 0.1	8.21
CM	76.2 ± 0.1	91.9 ± 0.2	7.98
PS	86.7 ± 0.2	83.0 ± 7	8.14

Means ± stdev; FSS: fresh sewage sludge; ADSS: anaerobically digested sewage sludge; CM: cow manure; PS: pig sludge.

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