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Inside the small-scale composting of kitchen and garden wastes: Thermal performance and stratification effect in vertical compost bins

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A B S T R A C T

Decentralized composting has been proposed as a best available practice, with a highly positive impact on municipal solid wastes management plans. However, in cold climates, decentralized small-scale composting performance to reach thermophilic temperatures (required for the product sanitization) could be poor, due to a lack of critical mass to retain heat. In addition, in these systems the composting process is usually disturbed when new portions of fresh organic waste are combined with previous batches. This causes modifications in the well-known composting evolution pattern. The objective of this work was to improve the understanding of these technical aspects through a real-scale decentralized composting experience carried out under cold climate conditions, in order to assess sanitization performance and to study the effects of fresh feedstock additions in the process evolution.

Kitchen and garden organic wastes were composted in 500 L-static compost bins (without turning) for 244 days under cold climate conditions (Bariloche, NW Patagonia, Argentina), using pine wood shavings in a ratio of 1.5:1 v: v (waste: bulking agent). Temperature profile, stability indicators (microbial activity, carbon and nitrogen contents and ratio) and other variables (pH and electrical conductivity), were monitored throughout the experience.

Our results indicate that small-scale composting (average generation rate of 7 kg d^{-1}) is viable under cold weather conditions, since thermophilic sanitization temperatures (> 55 °C) were maintained for 3 consecutive days in most of the composting mass, according to available USEPA regulations commonly used as a reference for pathogens control in sewage sludge. On the other hand, stability indicators showed a differentiated organic matter degradation process along the compost bins height. Particularly, in the bottommost composting mix layer the process took a longer period to achieve compost stability than the upper layers, suggesting that differential organic matter transformation appears not to be necessarily associated to the order of the waste batches incorporation in a time line, as it could be expected. These findings suggest the need to discuss new ways of studying the composting process in small-scale compost bins as well as their commercial design.

1. Introduction

Decentralized or small-scale composting is an effective tool to treat the organic fraction of municipal solid wastes (MSW) and has been proposed as a best available practice with a highly positive impact on MSW management plans. This technology contributes to reducing waste transportation, treatment costs and landfilling volumes, as it was demonstrated in several life cycle assessments reported in literature (Chan et al., 2011; Colón et al., 2010; Lleó et al., 2013). Decentralized composting has been successfully implemented for kitchen and garden organic wastes treatment in institutions, neighborhoods and homes, at low costs

Abbreviations: EC, electrical conductivity; LSD, least significant difference; m.a.s.l., meters above the sea level; MSW, municipal solid wastes; NW, Northwest; OM, organic matter; PC, principal component; PCA, principal component analysis; PFRPs, process to further reduce pathogens; TKN, total Kjeldahl nitrogen; TOC, total organic carbon; USEPA, United States Environmental Protection Agency; WSC, water-soluble carbon.

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(Platt et al., 2014; Smith and Jasim, 2009). Thus, this system represents an attractive technology alternative for the municipal organic waste fraction treatment in various socio-economic and technological contexts (Kalamdhad and Kazmi, 2009a; Kalamdhad and Kazmi, 2009b). Furthermore, small-scale composting is also an innovative way to involve generators as a key factor in their own waste treatment, raising community environmental awareness (Adhikari et al., 2010; Faverial and Sierra, 2014).

Nevertheless, small-scale composting frequently presents a poor performance at reaching the thermophilic temperatures recommended by the United States Environmental Protection Agency (USEPA) standard for the product sanitization of sewage sludge, known as "Process to Further Reduce Pathogens" or "PFRPs" (Abdullah et al., 2013; Barrena et al., 2014; Benjawan et al., 2015; Sánchez et al., 2015; USEPA, 2003). This may generate mistrust in technicians, public officials and common users who wish to promote decentralized composting of organic wastes, particularly in adverse (cold) weather conditions.

Composting temperature, among other physical, chemical and operational aspects, has a fundamental role in "cleaning" composting materials, since high temperatures aids in destroying pathogenic microorganisms, minimizing the attraction of vectors and helping to eliminate unpleasant odours and weed seeds viability (Diaz et al., 2007; Onwosi et al., 2017; USEPA, 2003). In sewage sludge composting in closed containers (in-vessel composting), the PFRPs standard requires to maintain the temperature above 55 °C for three consecutive days throughout the composting matrix, for the material sanitization and a suitable process performance. Nevertheless, the temperature evolution has been extensively studied and employed for regulating the composting process of sewage sludge, but not for kitchen and garden wastes, and much less at small-scale composting.

Since commercial compost bins volume usually range from 40 to 500 L, in these systems the thermal inertia is usually lower because the composting mass could not be enough to retain the metabolic heat generated during the composting active phase. Therefore, small-scale composting systems could have a poor performance in achieving USEPA PFRPs or other temperature sanitization standards or recommendations (Abdullah et al., 2013; Arrigoni et al., 2015; Benjawan et al., 2015; Iyengar and Bhave, 2006; Sánchez et al., 2015). In tropical and favourable climatic conditions or in controlled laboratory settings, small-scale composting has shown good temperature evolution performances (Barrena et al., 2014; Faverial and Sierra, 2014; Lleó et al., 2013; Varma and Kalamdhad, 2014). However, in cold climates, such as the Andean Patagonia region in Argentina, typical low ambient temperatures could maximize heat loss and restrict microbial activity, negatively affecting compost stabilization and sanitization, and also increasing the time required for the process to be completed (Arrigoni et al., 2015; Laos et al., 2002).

On the other hand, in a large-scale or centralized composting processes, the temperature profile as well as the evolution pattern of stability and maturity variables and indicators, are well-known. However, these parameters behaviour could be quite different in small-scale composting, and it has not been fully understood yet. Compost bins without a homogenization mechanism are the simplest, common and more promoted small-scale composting devices (Smith and Jasim, 2009; Storino et al., 2016a, 2016b). In these composters, the process usually starts when the first of various batches of organic waste is incorporated through an opening at top of the device, and it would end when the final product can be collected from a door usually placed in the bottom part of the composter. This implies that the organic matter transformation would occur according to the order of the waste portions incorporations. Thus, the first batch of waste that was incorporated would have a higher stability degree than the subsequent ones.

In this way, in small-scale systems the composting process is altered when another portion of fresh waste is combined with the material that is already being transformed. This probably causes modifications in the typical evolution of the process, further studied in centralized composting systems, generating a differentiated process evolution or a "stratification" in the organic matter transformation in a vertical direction. These modifications would be mainly related to the increase of easily degradable carbon with each fresh feedstock incorporation, and with changes in the moisture and oxygenation conditions of the composting mixture throughout the device (Iyengar and Bhave, 2006; Karnchanawong and Suriyanon, 2011; Smith and Jasim, 2009).

With the aim to contribute to small-scale composting understanding, for the technology optimization and development (particularly in cold climates), the objective of this work was two-fold: (i) to assess the temperature evolution and product sanitization performance in a decentralized composting experience carried out in NW Patagonia in Argentina; (ii) to study the "stratification effect" or differentiated evolution of the composting process at the different heights (or layers) of low complexity vertical and static (without homogenization mechanism or turning) compost bins, according to standard compost stabilization indicators.

2. Material and methods

2.1. Composters prototypes and experimental design

A small-scale composting experiment was carried out outdoors in San Carlos de Bariloche (41°07′S; 71°19′O), a city located in NW Patagonia (Argentina), about 890 m.a.s.l. This city is characterized by a cold-temperate climate with a dry season (summer). The average annual temperature is 8.4 °C and the annual rainfall average is close to 1000 mm, normally concentrated in autumn and winter seasons.

The composter prototype designed for this experience was constructed with recycled plastic tables that were assembled in a cylindrical shape, with a plastic support base. A circular lid was added to prevent access of rainwater or snow, animals and vectors (Fig. 1a). Also, two "perimeter doors" were placed at the bottom part of the device for compost extraction. The overall dimensions of the composter were: (i) total height: 120 cm (effective operational height: 100 cm), (ii) inner diameter: 80 cm; (iii) effective volume for waste treatment: 500 L. To allow leachates separation, a plastic plate was perforated with 20 holes of 2 cm diameter each and placed 20 cm up from the cylinder bottom. Between the perforated plate and the cylinder base, it was placed a tap for leachates collection. In this study, three of these composter prototypes were used (Fig. 1c).

The experience replicated the real operating conditions for a pilot case of composting in an institutional catering service. Feedstock used in the composting experiment were source separated kitchen organic wastes (pre and post-consumer), corresponding to a daily service of approximately 500 meals, and grass clippings from the garden of the same company (Fig. 1b). Animal products, such as meat, dairy and fats, were also included. Pine wood shavings (1 to 5 cm diameter) were used as bulking agent. In each composter (3 replicates), the organic waste to the bulking agent ratio was 1.5:1 in a volume basis, or 3:1 in a wet weight basis. Composters were fed for 52 days (three waste batches a week), until each composter was complete. In order to assure a comparable feedstock, kitchen waste batches were fractionated in qualitative similar portions of 10 L before being incorporated into each composter (Table 1).

The total amount of waste to be treated by each composter was 338 kg (± 2.4) (wet weight basis), with an average incorporation