International Biodeterioration & Biodegradation 113 (2016) 357–366

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Co-composting of various organic substrates from municipal solid waste using an on-site prototype vermicomposting reactor

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ARTICLE INFO

Article history:
Received 2 February 2016
Received in revised form
9 May 2016
Accepted 9 May 2016
Available online 24 May 2016

Keywords:
Co-composting
Organic substrate
Vermicompost bin (VCB)
Vermicomposting reactor (VCR)
On-site prototype system

ABSTRACT

Vermicomposting is a biotechnological process that converts organic materials into compost through the combined activities of red worms and microorganisms. This research investigation involved two stages of experiments. The initial stage was the experiment of co-composting using vermicomposting pile and the second stage was to develop the novel prototype vermicomposting reactor to enhance the biodegradation activity of the co-composting. The utilization of the municipal solid waste through conversion via vermicomposting practice was performed with the on-site system operation, using the earthworm *Eudrilus eginiae*. Here, various co-substrates were investigated for the vermicomposting practice. They were dry cow dung (CD), kitchen waste(KW), sewage sludge(SS) and vegetable-market waste(VW), respectively. The seven different mixture ratios of MSW were investigated in this study; CD as single control (Tr1), CD:KW in 20:80 (Tr2), CD:SS in 20:80 (Tr3), CD:VW in 20:80 (Tr4), CD:KW:SS:VW in 25:25:25:25 (Tr5), CD:KW:VW in 20:40:40 (Tr6), and CD:KW:SS in 20:40:40 (Tr7). Chemical changes of these MSW at different mixture ratios during vermicomposting were analyzed. Compost derived from this process contained higher nutrients than general compost. The developed prototype vermicomposting reactor could produce the compost as required by the compost standard. This reactor can be applied to the co-composting process and practically generate value-added benefits to residential areas due to its high efficiency of vermiprocess.

1. Introduction

The rapidly growing population, urbanization and modern lifestyle are key factors for the massive increases of solid wastes in several developing countries (Rajpal et al., 2014; Suthar, 2009; Tchobanoglous and Kreith, 2002). Thailand, like in most developing countries in Southeast Asia, has witnessed an accumulating problem on solid waste management and disposal. The municipal solid waste (MSW) is defined by the Pollution Control Department (PCD) as any solid wastes generated from community activities, e.g., residential (household), commercial and business organizations, fresh market, institutional facilities, and construction and demolition waste, excluding hazardous and infectious wastes. It has been reported that Thailand generated approximately 26 million tons of wastes in 2014; of which only 18.4% could be reused or recycled. The waste composition in Thailand is of a large proportion of compostable organic materials (64%) followed by recyclable wastes (30%) such as plastic and paper (Sinlapasuwan, 2014). At present, MSW has been commonly disposed in open dumpsites without precautionary environmental and health measures.

Vermicomposting process is a low-cost biotechnology which enables the recycling of various organic wastes from different sources through the combined actions of earthworms and microorganisms (Fernandez-Gomez et al., 2011). The earthworms degrade and homogenize substances through the muscular actions of their foreguts, and adding mucus to the ingested substances; thereby increasing the surface areas for microbial action (Manuel et al., 2007; Rajpal et al., 2012). Moreover, they accelerate the mineralization rate and convert the manures into casts with higher nutritional values and degree of humification than traditional method of composting (Jeybal and Kuppuswamy, 2001). Earthworms can consume all kinds of organic matters typically that are placed in a compost pile; and they can convert the wastes typically

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http://dx.doi.org/10.1016/j.ibiod.2016.05.009
0964-8305/

equal to their own body's weight per day (El-Haddad et al., 2014; Misra et al., 2003). The castings are rich in nitrate, phosphorus, potassium, calcium and magnesium. The quality of vermicompost depends on environmental factors, such as type of organic residues, aeration, humidity, pH, temperature, and earthworm species. Therefore, it is necessary to evaluate specific characteristics, such as organic C, total N, P and K content, in order to know the dynamics of vermicomposting (Pramanik et al., 2007).

The main objectives of this research are to develop a novel prototype vermicomposting reactor for on-site co-composting of various organic wastes and also to investigate the characteristics of vermicompost products from different feed types of organic wastes (i.e. cow dung, kitchen waste, and vegetable-market waste). Hereupon, a novel vermicomposting reactor was designed and constructed as a prototype system made of steel structure for an on-site community application. The prototype system has received organic MSW from a community in Samkhok district, Pathum Thani province. This reactor could continuously fill the organic wastes up to 0.263 m^3 or approximately 260 L per tank. The reactor had two tanks in order to consistently switch its operation. The advantages of the developed prototype vermicomposting reactor (VCR) are that the VCR can be an on-site small-scale system to enhance the degradation rate of organic waste at the optimal operating environmental condition. Moreover, smaller space can be used for system installation instead of the required larger space by the traditional vermicomposting pile.

2. Material and methods

This research investigation was divided into two stages. The first part was to study the vermicompost cultivation as composting pile in a bin or vermicompost bin (VCB) for co-composting of various feed types of organic wastes as shown in Fig. 1(a). For the second part, the experiment was done with the developed prototype vermicomposting reactor (VCR) for co-composting of various feed substrates as illustrated in Fig. 1(b). The vermicompost products are obtained through the co-composting process by the cultivation of selected earthworms.

2.1. An on-site cultivated vermicomposting pile with different feed of organic wastes

The organic wastes were mixed in different proportions in order to produce different vermibeds (Table 1). The treatment 1 (Tr 1) consisted of only pure cow dung as an experimental control. Other treatments (Tr 2-Tr 5) were the studies on co-composting of cow dung with kitchen waste and vegetable market waste at different mixing ratios. All vermibeds were kept as typical piles in plastic bins (48 cm diameter and 18 cm in depth), which could contain 2.172×10^{-2} m^3-volume of mixing bedding and substrates, with a pierced lid for aeration for further vermicomposting experiments. All treatments were replicated three times (n = 3).

2.2. Development of a prototype vermicomposting reactor for organic waste management

The prototype vermicomposting reactor (VCR) was developed for organic waste management in the community. This reactor was designed to receive organic wastes up to 0.263 m^3 or approximately 260 L per tank. The reactor has two tanks in order to consistently switch its operation. The VCR environmental conditions and factors were controlled to be as same as vermibins. The system was filled with waste once a day. The performance of the prototype vermicomposting reactor was evaluated for its ability of vermicompost production and its user-friendliness. The comparison between a prototype vermicomposting reactor (VCR) and vermicomposting bin (VCB) was also done to investigate the feasibility of waste degradation enhancement using the VCR system.

2.2.1. Earthworm

Both juvenile and adult earthworms' specie *Eudrilus eugeniae* were cultured in two experiments in order to find that whether they were developing clitellum. The volumes of the sampling earthworms were approximately 5 kg-m^{-3} per a container or a reactor. They obtained vermicompost while survival rate, weight, length and cocoon production were monitored for 60 days to achieve high population of the earthworm (Jeybal and Kuppuswamy, 2001; Sen and Chandra, 2007; Shahmansouri et al., 2005; Singh and Suthar, 2012). The changes in individual biomass of earthworms were measured every 10 days in each experimental runs (after 10, 20, 30, 40, 50, and 60 days). Earthworms produced during experiment were separated from the substrate materials by hand sorting. The sampling earthworms were randomly checked for counting the numbers of earthworms by using the 5.12×10^{-4} m^3 box as a container. The following observation was recorded as total weight (TWE) for the earthworm with red or brown color and length of longer than 2 cm. The environment conditions exerted statistically significant ($p < 0.05$) effects on the earthworms.

2.2.2. Biodegradable waste collection

Dry cow dung (CD) was collected from livestock farm located in Pathum Thani, Thailand. The kitchen waste (KW) was collected from residential household and local restaurants. Vegetable-market waste (VW), consisting of fruits and vegetables, was collected from a waste disposal yard of the local markets in Pathum Thani province. The organic wastes were chopped and sieved (1 cm^{-3}).

2.2.3. Chemical analyses

The chemical characteristics of all treatments are shown in Table 2. The moisture level of all substrates in vermibeds was maintained at around 70–80% throughout the study period by periodic sprinkling of decent quality of filtered water. The on-site experimental systems were kept in a humid (55–90% RH) and indoor place, providing good ventilation at a room temperature between 27 and 33 °C. Data collection of the homogenized samples of substrate materials were conducted at day 0, 10, 20, 30, 40, 50 and 60 from each experimental container. The characteristics of pH, temperature and moisture content were measured daily. The chemical characteristics were analyzed from three replicates in each treatment (n = 3).

Thus, the chemical analysis of all treatments was done using standard protocols. The moisture content and temperature were measured by the moisture digital meter in percentage and the digital temperature in Celsius. The pH of vermicompost was determined using pH meter. Electrical conductivity (Ec) measurement was also done in according to the test method of TMECC 04.11-A (Richards, 1954). Organic matter content was determined according to TMECC 05.07-A (Reeuwijk, 2002). Total nitrogen (TN) was measured using the test method of TMECC 04.02-D (Reeuwijk, 2002). Total phosphorus used the ascorbic acid reductant method, while total potassium used a flame photometer spectrophotometer method for determination of the effluent and a saturated solution extract of substrate (Reeuwijk, 2002; Singh et al., 2013; Suthar, 2009). Each treatment was analyzed three times for replication.

2.2.4. Statistical analysis

The results were reported as the mean of three replicates. One-way analysis of variation (ANOVA) was applied to examine the