Bioresource Technology 118 (2012) 563–571

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Swine manure vermicomposting via housefly larvae (*Musca domestica*): The dynamics of biochemical and microbial features

ZhiJian Zhang [a,b,*], Hang Wang [a], Jun Zhu [c], Sundar Suneethi [b], JianGuo Zheng [d]

[a] *College of Natural Research and Environmental Sciences, Center of Water Ecosystem and Watershed Sustainability, ZheJiang University, YuHangTang Ave. 688, HangZhou, ZheJiang Province 310058, China*
[b] *Department of Earth and Environmental Engineering, Henry Krumb School of Mines, Columbia University, 500 West 120th Street, New York, NY 10027, USA*
[c] *Department of Bioproducts and Biosystems Engineering, University of Minnesota, 1390 Eckles Ave., St. Paul, MN 55108, USA*
[d] *GuoSheng Resource Insect & Bio-Technology Company, 518 ChengJiaYu Ave., XingAi Town, DeQiang County, ZheJiang Province 314502, China*

HIGHLIGHTS

- ▶ The greenhouse-assisted larvae vermireactor acted the key of manure reduction.
- ▶ The seven-day vermireactor resulted in a total mass reduction rate of 106 ± 17 kg/(m^3 d).
- ▶ Activities of microbes and extracellular enzymes were lower in vermicompost.
- ▶ The microbial diversity in vermicompost was lower than the raw fresh manure.
- ▶ Organic C may be a key indicator of the bio-processes of larvae vermireactor.

ARTICLE INFO

Article history:
Received 18 February 2012
Received in revised form 6 May 2012
Accepted 11 May 2012
Available online 18 May 2012

Keywords:
Animal manure
Waste reduction
Vermireactor
Extracellular enzymes
Microbial diversity

ABSTRACT

Improper handling of animal manure generated from concentrated swine operations greatly deteriorates water ecosystems. In this study, a full-scale vermireactor using housefly larvae (*Musca domestica*) was designed to investigate the effectiveness and efficiency of swine manure reduction, and to explore the associated biochemical–biological mechanisms. The one-week larvae vermireactor resulted in a total weight reduction rate of 106 ± 17 kg/(m^3 d) and moisture reduction of 80.2%. Microbial activities in manure decreased by 45% after vermicomposting, while the activities of cellulose, proteases, and phosphatases in the vermicompost were significantly 69 times, 48%, and 82% lower than those in raw manure, respectively. The vermicompost was exclusively dominated by *Entomoplasma somnilux*, *Proteobacterium*, and *Clostridiaceae bacterium* where the microbial diversity was decreased from 2.57 in raw manure to 1.77. Correlation coefficients statistic showed that organic C might be a key indicator of the biochemical features and microbial functions of the larvae vermireactor.

1. Introduction

Concentrated swine operations throughout the world currently produce a considerable amount of manure with abundant nutrient and organic matter (Zhu, 2000). Swine manure may be utilized as bio-fertilizer for providing essential nutrients for agricultural crops (Shafqat and Pierzynski, 2011). However, the continued land application for manure disposal may result in excessive nutrient loss from soil to water, causing water eutrophication and deteriorating ecosystem stability (Westerman and Bicudo, 2005; Zhang et al., 2004). Therefore, there is an acute need for the development of novel technologies for manure treatment that can reduce waste and be environmentally safe, among which vermicomposting by resource entomology may hold future promise.

Vermicomposting was originally defined as a bio-process that involves the oxidation and stabilization of organic wastes through the joint action of earthworms and microorganisms (Dominguez et al., 2004; Westerman and Bicudo, 2005; Yadav and Garg, 2011), and turns waste into a valuable soil amendment, termed vermicompost, together with value-added worm product. Due to its ability of improving biochemical features, reserving nutrients, eliminating pathogens, and reducing odor emission, this technique has been widely used to process a various types of wastes, including animal manure, food-processing waste, municipal sludge, and

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* Corresponding author at: College of Natural Research and Environmental Sciences, Center of Water Ecosystem and Watershed Sustainability, ZheJiang University, YuHangTang Ave. 688, HangZhou, ZheJiang Province 310058, China. Tel.: +86 571 8697 1854; fax: +86 571 8697 1719.
E-mail address: zhangzhijian@zju.edu.cn (Z. Zhang).

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http://dx.doi.org/10.1016/j.biortech.2012.05.048

even industrial waste (Bai et al., 2007; Diener et al., 2009; Elboushy, 1991; Marchaim et al., 2003; Yadav and Garg, 2011).

The biochemical and biological processes of vermicomposting are crucial mechanisms for waste reduction (Yadav and Garg, 2011). One role of worms in the decomposition of organic waste is the biodegradation of cellulosic and proteinaceous materials in organic waste due to the presence of various enzymes in the worm gut, such as proteases, lipases, amylases, cellulases, and chitinases (Kim et al., 2011), as well as the modification of the microorganism community in the intestinal tract (Aira et al., 2007; Gomez-Brandon et al., 2011; Jeon et al., 2011; Monroy et al., 2009). The process of vermicomposting also regulates the dynamic curves of the enzymatic activity of β-glucosidase, cellulases, proteases, and phosphatases in the waste/vermicompost (Aira and Dominguez, 2011; Aira et al., 2007), which directly determines the biodegradation of organic carbon (C), nitrogenous organic compounds, and phospholipids in waste. Moreover, detritivore earthworms also excrete large amounts of casts containing more soluble and available nutrients, such as nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca), compared to those present in raw manure (Bai et al., 2007; Knapp et al., 2009). These biochemical reactions, including worm casting and extracellular enzymatic activity, remarkably reduce the waste biomass by 20–75% and change the C–N–P element cycles in the vermicompost. Microbial activities, such as basal and substrate-induced respiration (Aira and Dominguez, 2011; Aira et al., 2007; Gomez-Brandon et al., 2011) as well as the microbial community (Jeon et al., 2011; Yasir et al., 2009; Zhao et al., 2010), have been studied to elucidate the microbial functioning mechanisms of earthworm vermireactors, which may control the pace of the vermicomposting process. However, the link between biochemical features and microbial functioning has not been sufficient to evaluate waste reduction from vericomposting.

Use of the housefly (*Musca domestica*) in the bioconversion of animal manure can be traced back to the 1970s (Elboushy, 1991). Rearing larvae provide a prolific source of proteins that have been used in chick and fish feed (Moon et al., 2001; Yadav and Garg, 2011). The use of larvae for medicinal purposes has also been found to have beneficial effects on wounds, such as for debridement or elimination of necrotic tissues (Marchaim et al., 2003). Compared to earthworms (30–90 days) (Aira and Dominguez, 2011; Tamis et al., 2011; Zhao et al., 2010) and black soldier fly larvae (two weeks) (Diener et al., 2009; Kim et al., 2011), the shorter gestation period of housefly larvae (5–7 days) (Elboushy, 1991; Moon et al., 2001; Su et al., 2010) theoretically provides a larger advantage as a vermireactor for highly efficient manure bioconversion. Although housefly larvae vermicomposting was developed over twenty years ago, the ability of this approach for waste reduction in manure treatment and the corresponding biochemical and biological mechanisms have not been reported. The lack of these data places a serious restriction on optimally designing a larvae vermireactor and improving the bioconversion efficiency for swine manure treatment.

Using this technological innovation, a farm-scale operation of swine manure bioconversion with housefly larvae (*Musca domestica*) vermicomposting was established in 2008 in DeQing County, ZheJiang Province, China. In this study, the effectiveness and efficiency of housefly larvae vermicomposting in swine manure reduction were investigated, and the corresponding biochemical and biological mechanisms were also discussed. We hypothesized that housefly larvae vermicomposting alter the biochemical and microbial features of swine manure and thus cause waste reduction.

2. Methods

2.1. Full-scale vermicomposting and operational processes

A full-scale swine manure vermicomposting operation using housefly larvae (*Musca domestica*) was installed at the GuoSheng Biotech firm (30°34′35.68″N, 120°13′26.30″E) in September 2008. The operation is located in DeQing County, ZheJiang Province, which is in the Southeast costal region of China. The GuoSheng farm currently possesses 3800 m^2 of greenhouse-assisted larvae bioreactors with a maximum daily treatment capacity of 35 tons per day of fresh raw manure. The raw swine manure (Table 1) was collected from a neighboring finishing swine farm without solid–liquid separation within a few hours of being stored. The full-scale swine manure vermicomposting operation using housefly larvae was comprised of four main processing units in series: (1) seed-fly breeding and fly oviposition, (2) larvae vermicomposting, (3) larvae-vermicompost separation, and (4) seed stocking and eclosion (Fig. 1). Among the processes, technical design on greenhouse-assisted larvae vermireactor is the most important section for swine manure bioconversion.

2.2. The experimental design of swine manure vermicomposting

The greenhouse-assisted larvae vermireactor consisted of three main components: a greenhouse, a larvae vermireactor, and a manure feeding technique (Fig. 1). The size of the greenhouse for supporting larvae growth was 28 m (length) × 5.5 m (width) with a dome roof that arched 3.5 m above the surface of the ground. The greenhouses were covered with 0.5 mm thick plastic sheets and equipped with rolling shades on both sides for maintaining the air temperature at 18–35 °C. The larvae vermireactors consisted of a series of ten cement blocks that created sharp square pools with dimensions of 2 m (width) × 5 m (length) × 20 cm (height).

Table 1
Comparison of the physico-chemical parameters in swine manure prior to and after the housefly larvae (*Musca domestica*) vermicomposting.

		Before vermicomposting		After vermicomposting		t-Test *p*-value[b]
		Average	*n*[a]	Average	*n*	
Moisture	%	78.3 ± 5.4	8	47.6 ± 1.6	8	<0.001
Organic C	%	32.5 ± 12.4	8	53.3 ± 4.7	8	<0.001
Crude fiber	%	17.2 ± 2.8	4	20.5 ± 2.7	4	0.008
Crude fat	%	4.61 ± 0.54	4	1.35 ± 0.43	4	0.002
TKN	% (N)	2.99 ± 0.65	8	2.20 ± 0.31	8	0.346
AN	% (N)	0.575 ± 0.079	8	0.441 ± 0.125	8	0.021
TP	% (P)	1.82 ± 0.54	8	2.86 ± 0.36	8	0.054
AP	% (P)	0.827 ± 0.43	8	1.15 ± 0.07	8	0.017
Odor (3-MI)	mg/kg	40.4 ± 7.5	2	2.24 ± 1.41	3	<0.001
Fecal coliforms	Log/g	33.7 ± 16.9	2	3.01 ± 0.78	2	<0.001

[a] *n* Refers to the number of samplings.

[b] *p* Values smaller than 0.05, 0.01 indicates significant difference, and strongly significant difference, respectively.