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Biotransformation of Biodegradable Solid Wastes into Organic Fertilizers using Composting or/and Vermicomposting

Ta Yeong Wu*[a], Su Lin Lim[a], Pei Nie Lim[a], Katrina Pui Yee Shak[a]

[a]Chemical Engineering Discipline, School of Engineering, Monash University, Jalan Lagoon Selatan, Bandar Sunway, 46150, Selangor Darul Ehsan, Malaysia
wu.ta.yeong@monash.edu

This review discusses the differences between composting and vermicomposting of biodegradable solid waste. Solid waste management is a major challenge worldwide due to the rise in population and industrialization, leading to larger amount of solid wastes being generated. Biological process has been widely recognized in converting solid organic materials into environmental friendly and value added products. Both composting and vermicomposting are regarded as a suitable way to manage organic waste because it not only helps solve the problem of waste disposal but also produces useful bio-amendment agent (organic fertilizer). In general, vermicomposting is a more superior process as compared to composting. This is because vermicomposting has higher organic matter decomposition rate and nutrients contents of final product. Besides, vermicompost produced higher concentration of hormones and enzymes that could stimulate plant growth and discourage plant pathogens. However, recent studies indicated that a successful combination between composting and vermicomposting has been considered as a possible way to obtain a better quality organic fertilizer. The suggestion to combine both systems is based on the premise that composting enables sanitization and elimination of toxic compounds from the solid wastes, while the subsequent or preceded vermicomposting rapidly reduces particle size and increases nutrient availability to the plants.

1. Introduction

During the past decade, the amount of solid waste has been escalating year by year due to the rapid urbanization and increasing population growth. A substantial amount of money was spent on managing the ever growing amount of solid waste. In the early 1990s, Asian countries disbursed around US$25 billion on solid waste management on an annual basis and an estimated amount of US$50 billion may be accrued by 2025 (Hoornweg and Thomas, 1999). In addition, it can be observed that waste generation rates of developing Asian countries will increase as income status shifts from low to high as seen in Table 1. Therefore, solid waste management is slowly emerging as a growing concern worldwide due to its costliness and potential of contribution to environmental pollution from landfills, waste collecting, transport and processing (Ng et al., 2013). According to Daskalopoulos et al. (1997), solid waste management can be classified as a field related to control of generation, storage, collection, transfer, processing and disposal of municipal solid waste (MSW), where public health, economics, engineering and environmental concerns are considered. In general, organic waste produced from agricultural production and processing industries are categorized as solid waste due to its potential as environmental hazards.
Waste management systems are influenced by socio-economic, political and environmental factors such as population growth, consumption pattern and technological development of waste systems (Zaman, 2013b). Of late, the importance of sustainability in waste management is being emphasized globally so that the needs of the present generation can be met without compromising the ability of future generations to meet their own needs (Wu et al., 2013). Due to the abundance of solid wastes for disposal, a sustainable and ecological approach on reusing the wastes should be proposed and implemented for pollution abatement by considering economical, health and environmental factors. Sustainable waste

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management practices are essential to preserve the surrounding environment, thus it is desirable to reutilize the waste products in other industry to create a desired product. However, the standards of waste management in most parts of the world are still poor. Poor handling of solid waste management could be due to several factors which include unsystematic and outdated documentation of waste statistics and characteristics, inadequate storage and collection systems, uncontrolled disposal of toxic and hazardous waste, uncontrolled disposal or dumping of wastes and inefficient utilization of disposal site space.

Waste management is a complex process because it involves different principles and processes (Nouri et al., 2012). Inadequate waste management contributes to climate change issues due to methane production and uncontrolled greenhouse gas emissions. Therefore, there is a need to amend or improve the current treatment systems applied in solid waste management by introducing and implementing sustainable treatment systems. In recent years, a method known as vermicomposting has been receiving growing interest. Vermicomposting can be regarded as a green biotechnology using earthworms to process biodegradable solid wastes. This paper is an attempt to discuss about the recent development in biodegradable solid waste management; with emphasis on the comparison between composting (conventional method) and vermicomposting (newer technology) of organic solid wastes.

Table 1: Solid waste generation rates (kg capita^{-1} day^{-1}) of selected Asian countries.

Countries	Income Status	Waste generation rates (kg capita^{-1} day^{-1})	Reference
China	Low	0.80	Hoornweg and Thomas (1999)
India	Low	0.79	Hoornweg and Thomas (1999); Khajuria et al. (2010)
Indonesia	Middle	0.80 - 1.00	Mukawi (2001)
Malaysia	Middle	0.81	Hoornweg and Thomas (1999)
Phillipines	Middle	0.30 - 0.70	World Bank (2001)
Singapore	High	1.10	Hoornweg and Thomas (1999)
Thailand	Middle	1.10	Hoornweg and Thomas (1999)
Vietnam	Low	0.55	Hoornweg and Thomas (1999)

2. Current status of solid waste management practices

Unlike most developed countries, inadequate management of solid wastes still exists in many parts of the world. As the public slowly recognizes the importance of proper solid waste management, the global scientific society with the collaboration of external support is striving to further improve solid waste management, especially in developing countries. However, several factors such as economic, financial, institutional, social and technical constraints faced by both recipient and external support party deters the effort for proper solid waste management (Ogawa, 2008). The current solid waste management system is deemed inefficient due to problems such as uncontrolled open dumping and burning without pollution control and encourages the breeding of pests (Ogawa, 2008). According to Terazono et al. (2005), Asian countries such as Indonesia, Malaysian and Thailand are not stringent in solid waste management due to the fact that no strict laws were practiced on waste management.

2.1 Characterization of waste

Waste can be classified into categories based on its source. In general, solid wastes is divided into four main categories known as agricultural waste, construction and demolition solid waste, municipal solid waste (MSW) and industrial waste. Sources of municipal wastes are mostly from households, industries and hospitals while industrial solid and scheduled wastes are from chemical, fabrication, manufacturing and power plants. Agricultural wastes are generated from dairy farms and orchards. The common concrete, dirt and construction wastes are categorized under construction and demolition solid waste. Generally, MSW could be considered as the most complex solid waste stream, as opposed to more homogenous waste streams, resulting from industrial or agricultural activities (Sim and Wu, 2010).

2.2 Waste treatment and disposal

Current primary methods of solid waste management include practices such as composting, waste incineration, landfilling, recycling, reduction at source and others. Apart from composting, methods such as incineration are commonly used to destroy toxic waste, recover energy and reduce volume of waste (Kumar, 2011). However, its high cost and the need for supplementary fuel for combustion of wet and low combustible waste marks it as an unsustainable option. Although landfilling is a typical method for disposal of solid wastes, it is proven to have negative impact on the environment (Gebreegziabher et al., 2012).

Landfill sites are known to produce leachate that carries both organic and inorganic contaminants. In addition, the landfilled organic fraction of solid wastes produces greenhouse gases that must be collected and burned to reduce their impact on global warming and eliminate odour nuisances (Sim and Wu, 2010). Moreover, unregulated incineration and uncontrolled landfilling are harmful to the environment due to generation of air, ash and water pollutant, creating a necessity for sustainable options to be adopted in solid waste management. A qualitative analysis in terms of strengths and weaknesses of each waste treatment technology for managing (biodegradable) solid wastes was reported by Zaman (2013a).

3. Composting or/and vermicomposting of biodegradable solid wastes

3.1 Composting

Composting is regarded as a biological process which converts organic waste into a stable form either through aerobic or anaerobic decomposition (Talyan et al., 2008). During the past decade, a number of studies were generated to monitor the efficiency of composting through process activity parameters which led to an agreeable specific method to evaluate the quality and maturity of end composts from diverse types of organic waste (Melis and Castaldi, 2004). The main difference between anaerobic and aerobic decomposition is characterized by the type of gases and amount of energy released during composting. The amount of energy released during aerobic composting through exothermic reaction is higher as compared to anaerobic decomposition (chemical reduction). The microorganisms in aerobic composting produce gases such as CO_2, NO_2 and NO_3, while CH_4 and CO_2 are released during anaerobic decomposition (Talyan et al., 2008). Composting of biodegradable solid wastes is deemed useful for its utilizable end product as nutrient-rich organic fertilizers or for land application (United Nations, 2000). Waste composition found in developing countries is especially suitable for composting owing to its higher portion of compostable in the waste stream (Narayana, 2009). This process can be an alternative option to landfilling as it is able to lessen the likelihood of pollution and extend the life of landfills (Singh et al., 2011). It does not smell or attract pests and flies, when it is performed under controlled conditions. In fact, it helps to recycle nutrients from organic wastes back to the soil with the use of its end product. According to Singh et al. (2011), evaporation and decomposition during composition can help reduce 50 % of weight in waste, owing to its high moisture content in organic waste. However, composting may exert higher operating and maintenance costs as compared to open landfilling because (1) higher compost cost as compared to the commercial fertilizers; (2) improper separation of the inert materials such as plastics and glass, which degrade the quality of final compost material for agricultural purposes; (3) and poor operation and maintenance of composting facilities (Talyan et al., 2008).

3.2 Vermicomposting

Vermicomposting was widely introduced more than a decade ago with comprehensive research by noted researchers such as Clive Edwards, Mary Appelhof and Rhonda Sherman; who are pioneers in the vermicomposting process. Not to be mistaken for the term ‘vermiculture’, vermicomposting is a novel solid waste treatment process in which earthworms are utilized to manage and convert organic wastes into useful organic fertilizers with the aid of microorganisms by promoting microbial activity (Domínguez and Edwards, 2004). The biodegradation of biosolids and organic residues takes place in an aerobic environment with optimum biological activity and symbiotic interactions between earthworms and microorganisms (Garg and Gupta, 2009). Vermicompost or vermicast is the main product of vermicomposting, where it has great fertilizer value with high humus content suitable for agriculture application (Lim et al., 2012). The brittle humus-like product is originated from the fragmentation and ingestion of organic waste in the earthworm digestive system, specifically in the gizzard. During vermicomposting process, organic waste is ingested into the stomach of the earthworm by its mouth. Then, the load will pass through its gizzard where it will be ground by ingested stones and released as vermicast when it exits the intestine. The gut of the earthworm works as a bioreactor, where the fragmentation and grinding of substrate, bioconversion of substrate and mineralization of different elements present in substrate takes place (Palsania et. al., 2008). A portion of these organic wastes are converted into biomass and respiration produce such as additional earthworms and carbon dioxide, apart from the vermicompost itself. However, proper selection of the suitable earthworm species is essential for an optimized biodegradation process. The selection criteria for a suitable earthworm species in vermicomposting include high reproductive rates, high consumption of organic matter and high tolerance to various environmental factors. Thus, among the earthworm species, epigeic earthworms are the most suitable in vermicomposting process. Example of epigeic earthworms are *Eudrilus eugeniae, Eisenia foetida* and *Perionyx excavatus.* Their habitat, temperature tolerance, life span and other characteristics are given in Table 2. (Garg and Gupta, 2009). Other characteristics of several epigeic earthworms are shown in Table 2. The efficiency of these epigeic species in converting various biodegradable solid wastes into vermicomposts is well documented by various authors (Table 3).

Table 2: Characteristics of ideal earthworms (epigeic species) for vermicomposting

Characteristics	*Eisenia foetida*	*Eudrilus eugeniae*	*Perionyx excavatus*
Active phase	All year long	All year long	All year long
Location	Temperate zones	Tropical Africa and South America	Tropical countries
Moisture (%)	65-90	65-90	65-90
Temperature (^oC)	18-25	20-25	25-30
Age of cocoon production (weeks)	5-9	7-10	15-18
No. of young/cocoons	2-4	2-3	1
Incubation period (weeks)	3-4	4	4
Vermistabilization time (weeks)	6-8	3-4	4-5

References: Domínguez and Edwards (2004) and Singh et al. (2011)

Table 3: Vermicomposting of different biodegradable solid wastes

Wastes	Earthworm	Final C/N ratio of vermicompost	Vermistabilization time (days)	Reference
Soybean husk and papaya	*E. eugeniae*	16.14	63	Lim et al. (2011)
Tomato crops	*E. andrei and E. foetida*	10.70	63	Fornes et al. (2012)
Tomato-plant waste and paper-mill sludge	*E. fetida*	15	168	Fernández-Gómez et al. (2013)
Separated digestate and wheat straw	*Eisenia*	14-16	~150	Hanc and Vasak (2014)
Palm oil mill effluent and rice straw	*E. eugeniae*	9.64	42	Lim et al. (2014b)
Rice straw and cow dung	*E. eugeniae*	7.97	60	Shak et al. (2014)
Empty fruit bunches and cow dung	*E. eugeniae*	18.53	84	Lim et al. (2014a)

Note: C/N ratio of less than 20 indicates the maturity of the organic wastes (Domínguez and Edwards, 2004)

3.3 From composting to vermicomposting of biodegradable solid wastes: comparison of process

Composting and vermicomposting are regarded as important technologies for solid waste management for its remedial benefits to agricultural soil by improving soil structure, high moisture retention and nutrient holding ability as well as abundance in microbial activity (Singh et al., 2011). Similarly, the effectiveness of composting and vermicomposting are both regulated by similar parameters. Yet, the conditions for these parameters differ for both processes to achieve favourable results or efficiency as summarized in Table 4. According to Norbu (2002), greater reduction of volatile solid and carbon to nitrogen ratio were observed in vermicomposting as compared to composting. In addition, exchangeable nutrients are higher in vermicompost, although elemental concentration was higher in compost (Norbu, 2002). It can be deduced that vermicomposting produces organic fertilizer with richer nutrient availability as compared to conventional composting. Compost from conventional composting tends to contain higher amount of ammonium, while vermicompost contains higher amount of plant-available form of nitrogen known as nitrates, which is beneficial to plant growth. However, the nutrient content and duration of process can differ based on the quality of feed material to earthworms. In most cases, a short period of composting can be applied to pre-compose waste before applying it to the vermicomposting process. Recently, most processes and studies have been combining both processes to decompose solid waste. For example, a study led by Fornes et al. (2012) compared the physical and chemical characteristics of tomato crop waste for composting, vermicomposting and a combination of both processes. It can be deduced that composting, vermicomposting and a combination of both are suitable options for organic waste management and valuable for horticultural purposes. Recently, Ravikannan et al. (2013) also indicated that a combination of composting and vermicomposting of sugar mill waste with municipal solid waste produced high quality organic fertilizer.

Table 4: Comparison between composting and vermicomposting process

Parameters	Composting	Vermicomposting
Type of process	Thermophilic stage (45 to 75 ^{o}C)	Only mesophilic stage
Type of waste	Similar decomposition rate for adequate degradation of waste	Not hard, oily, salty, too acidic or alkaline
C/N Ratio	Between 20 to 50	30:1 (ideal proportion)
pH	No specific requirement for pH	Between pH 5 to 8
Moisture Content	Coarse waste material (70-75 %)[a] Fine waste material (55-65 %)[a]	Suitable range between 65 to 80 % with optimal values highly dependent on the type of waste applied to the process
Duration	Lengthier	Shorter (in some cases lengthier than composting)
Product characteristics	Texture of compost is coarser. May contain pathogens and heavy metals	Finer in texture with pathogens and heavy metals removed

Source: [a] Verdonck (1988) and Singh et al. (2011)

4. Conclusion

The arising issues connected to land disposal and incineration has led to high consideration of low cost methods such as composting and vermicomposting as options for solid waste management of nontoxic waste. Although composting can be regarded as a feasible option for solid waste management, vermicomposting is also a suitable alternative based on the high nutritive value and time efficient process. By combining both composting and vermicomposting, an improved process can be made as an option for biodegradable solid waste management. In fact, the combination between composting (thermophilic process) and following by vermicomposting enhanced the end quality concerning P, Mg, and Ca contents, but reduced K content. High P and Ca content together with higher organic matter stability could be key factors for the use of vermicomposts in the acid and infertile soils of the tropics (Sierra et al., 2013).

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