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Development of a small-scale composter and its application in composting of biodegradable waste generated from a government institution

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Abstract

Laws that govern solid waste management in the Philippines promote composting as an environment-friendly technology. Generally, biodegradable waste constitutes a big portion of solid waste. Composting, therefore, is a potential solid waste management option. This study aimed to develop a small-scale composter for the biodegradable waste generated within the Department of Science and Technology (DOST), Taguig City, Metro Manila. Waste analysis and characterization study showed that DOST canteen and offices generate an average of 65.63 kg solid wastes per day. Biodegradable waste constitutes 73% of these wastes. The remaining wastes are composed of residual (15%), recyclable (10%), inert (1%) and special (1%) wastes. A drum-type motorized composter was fabricated with a feeding capacity of 50 kilogram (kg). Feedstock consisted of 2 parts biodegradable waste, 1 part dried yard waste, and 2 parts inoculant. Thermophilic condition was achieved during active composting and took about 8 days to three weeks. Compost products had a total NPK (nitrogen, phosphorus, potassium) of 4.55 to 5.81% and organic matter of 47 to 52%. The small composter was found effective in the conversion of biodegradable materials into compost. This composter can be an alternative technology for community-based management of solid biodegradable waste.

Key words : Composting, solid waste management, small-scale composter

INTRODUCTION

The "Ecological Solid Waste Management Act" or Republic Act (R.A.) No. 9003 provides the legal framework for the country's systematic, comprehensive and ecological solid waste management program that ensure protection of public health and the environment [1]. It underscores the need to create the necessary institutional mechanisms and incentives, as well as imposes penalties for acts in violation of any of its provisions. Being a government institution, the Department of Science and Technology (DOST) recognizes that part of its moral obligation is to manage its own wastes properly to ensure that it complies with all regulatory requirements. In the performance of its functions, DOST generates solid wastes such as food waste, yard waste, and even wastes from its Research and Development Laboratories. Generally, more than 50% of these solid wastes are biodegradable and therefore can be utilized for composting.

The Industrial Technology Development Institute (ITDI) of DOST previously developed a bioreactor composting technology to provide a viable alternative technology to the worsening solid waste disposal problem in the country. It is an in-vessel composting technology for the treatment and disposal of the organic fraction of municipal solid wastes [2]. It has three main components: 1) bioreactor, the machine that is energy-efficient and durable, where aerobic composting of substrate takes place; 2) solid microbial inoculant, which consists of thermophilic, locally isolated microorganisms that accelerate the rise of composting temperature; and 3) composting process, which follows the internationally accepted principles of aerobic composting to provide optimum conditions for rapid decomposition of organic solid wastes. To comply with the R.A. 9003, several Local Government Units (LGUs) all over the Philippines have been using the bioreactor composting technology in their Material Recovery Facilities (MRFs). The bioreactor technology was also applied in other types of wastes including water hyacinths [3], tannery fleshing wastes [4], and various fruit wastes.

At present, the bioreactor is being commercialized using two types of machines, namely stirred-tank bioreactors and rotary-tank bioreactors [2]. The stirred-tank type has been commercialized more extensively with mostly LGUs as technology adaptors. The available nominal capacities for stirred-tank bioreactors are 1,000 kilogram per day (kg d^{1}) and 500 kg d^{-1}. On the other hand, rotary-tank bioreactor caters to technology adaptors requiring input capacities of 2,000 kg d^{-1} or higher. Unlike the stirred-tank reactor, rotary type does not require shredding of wastes prior to feeding and tolerates less efficient segregation. Both reactor configurations are operated on a semi-continuous schedule, i.e. daily withdrawal and feeding. Active composting occurs inside the reactor, and further degradation of raw compost is done in the curing area for a minimum of one month. The resulting product from the bioreactor technology can be used as soil conditioner or compost.

Since the minimum capacity of ITDI bioreactor is 500 kg d^{-1}, a smaller scale in-vessel composter is needed to cater for wastes generated in households, schools, or small communities and institutions. In this study, a drum-type composter was designed and fabricated to utilize the biodegradable waste, such as food waste and garden waste, generated within DOST compound. The project was initiated with the Waste Analysis and Characterization Study (WACS) of DOST-generated waste. High quality compost products were obtained after composting operations that can be applied in ornamental plants and greening program.

MATERIALS AND METHODS

Waste analysis and characterization study (WACS)

WACS was conducted to determine the 1) composition of solid waste generated in DOST offices and canteen, and 2) daily amount of different kind of solid wastes including biodegradable wastes, which will serve as basis for the design of in-vessel composter. Wastes were collected daily for five days from DOST main building, attached agencies and DOST canteen. WACS procedure was based on the reports of Monsada *et al.* [5] and Esguerra *et al.* [6]. All collected wastes were brought to the Environment and Biotechnology Division, Industrial Technology Development Institute (EBD-ITDI) and total weight was recorded. Total volume of garbage pile was determined by multiplying the total area by the height of garbage pile.

Wastes were unpacked, mixed, and divided into four quadrants by conical quartering. Two quadrants (2 and 4) were selected and sorted based on the following types: biodegradable, recyclable (plastics, glass, bottles, paper, and metals), residual (polystyrene foam, sando bags, foil packs, other residuals), inert (ceramics, bricks, stones, ash, broken plates, other inert), and special wastes (battery, tissue and cloth with blood, fluorescent lamps, other special wastes). Sorted garbage was weighed and percent composition (kg waste/kg of total waste X 100%) was calculated. Bulk density was determined using one of the two remaining quadrants (1 or 3). Computation for bulk density was based on the following formula: bulk density = kg waste / (area of container X height of waste) [5-6].

Design and fabrication of small-scale composter

The amount of biodegradable waste served as basis for determining the capacity of composter. The small-scale composter was designed and drafted using Solid Works Software 2013. Figures 1 shows the 3-D assembly drawing of the composter. A 200 liter (L)-capacity blue plastic drum (high density polyethylene) was used for the fabrication of composter. The composter has three basic parts: 1) the drum which holds the composting mixture, 2) a metal stand to support the container and allow the drum to rotate, and 3) a gear motor for rotating the drum and allow mixing of materials. The composter drum has an opening for loading and unloading of materials. The opening was made of plastic cut portion of the drum. Attached to the opening were metal locks and hinges. The composter drum has aeration holes at both sides. Inside the drum were angular bars that act as baffles. Attached to opposite sides of the drum were metal shafts welded to round plates. The welded plates with shaft were attached to the drum by several bolts and nuts. The stand, to support the composting drum, was fabricated using angular bars. Metal frame supports and pillow blocks were installed at the left side of the composting drum. The gear motor was attached to the side of the metal support for rotation of the composter. Two wheel pulleys, 2 and 6 inches, were attached to the gear motor shaft and composter shaft, respectively. A V-belt was fixed to the two pulleys.

Seed compost

Seed compost was produced by collecting degraded materials from an existing compost pile, and from decaying household and yard wastes. These degraded materials were mixed with yard waste and fresh biodegradable waste at a ratio of 1:2. The substrate was allowed to decompose by simple pile-type method for two months. The resulting seed compost was characterized for its nutrient content.

Start-up operation

In-vessel composting was initiated by propagating the initial seed compost needed for actual operation. Raw materials for start-up operation consisted of pulverized rice bran (locally termed as *darak*), dried yard waste and seed compost at a ratio of 2:2:1. The total weight of raw materials was 20 kg (8 kg -rice bran, 8 kg -dried yard waste, and 4 kg -seed compost). Rice bran served as nutrient source for microorganism, whereas yard waste served as carbon source. Yard wastes consisted mainly of dried leaves collected around ITDI. Prior to loading, water was added to the mixture to achieve 50 to 60% moisture content. A simple squeeze method was used in adjusting the moisture content[2]. Propagation of seed compost lasted for two days and the resulting material was used as inoculant for composting operation.

In-vessel composting

Feedstock consisted of 2 parts biodegradable waste, 1 part dried waste, and 2 parts inoculant. The total mixture (50 kg) composed of 20 kg biodegradable waste (vegetable scrap waste from canteen, food left-over), 10 kg dried yard waste, and 20 kg inoculant. Biodegradable waste and yard waste were shredded using a multipurpose electric shredder (Mazma, TMICORP INC., Sta. Cruz, Manila) to reduce particle size. Composting feedstocks were mixed well and moisture was adjusted to 50-60% by squeeze method[2]. Initial mixture was characterized for total nitrogen, total phosphorus, total potassium, total organic matter, total organic carbon, and pH. The composter was rotated for 8 hours (h) daily at 6 revolutions per minute (rpm). Substrate retention time was 4 to 5 days inside the composter. After which, raw composts were unloaded and transferred to curing area for further degradation and maturation of materials. Part of this raw compost was used as inoculant for the next in-vessel composting operations.

Pile composting and curing

Partially degraded materials in piles were regularly turned and temperature of substrate was daily monitored. During active pile composting, moisture was maintained at 50-60% by adding water. Compost was considered mature when the temperature of the pile was nearly ambient[2]. Mature composts were sieved using wire screen (9 mm^2) and then submitted for nutrient analysis to an accredited laboratory.

Analytical procedure

Temperature of piles was monitored using dial thermometer (Cole-Palmer Instrument Co., USA). Grab samples were analyzed for pH, moisture, and ash[7]. Composts were submitted to the Philippine Coconut Authority (PCA), Diliman, Quezon City for nutrient analyses. Total nitrogen, phosphorus, and carbon were determined using UV-Vis spectrophotometer, total potassium by flame photometer, and total organic matter by gravimetric method (PCA).

Data analyses

Means of waste characterization data such as total weight, total volume, and bulk density were obtained after five days WACS. Three composting operations were done to determine the efficiency of fabricated composter. Means and standard deviations were used for characterization parameters of initial mixtures such as total organic matter, total organic carbon, moisture, total nitrogen, and pH.

RESULTS

Waste analysis and characterization study (WACS)

Wastes used in WACS were collected from office waste, canteen waste, toilet waste, and yard waste. Normally, building cleaners or janitors daily collect these garbage in the afternoon using black plastic bags and dump these wastes at designated areas. Unsegregated wastes are then picked-up by garbage hauling trucks once a week.

Table 1 shows the waste generation per day, total volume, and bulk density for five-day WACS of DOST waste. The average waste generation was 65.6 kilogram per day (kg d^{-1}) with an average volume of 0.68 cubic meters (m^3). Highest amount and volume of waste was observed at day 1 (Monday) due to the accumulated wastes during weekend. Bulk density of solid waste ranged from 106.7 to 166.2 kg m^{-3} with an average of 122.2 kg m^{-3}.

The composition of wastes by type is shown in Figure 2. The largest proportion was biodegradable waste (73%), followed by residual wastes (15%), and recyclable (10%). The lowest proportions were inert and special wastes with both 1% composition. Much of the biodegradable wastes were vegetable scraps and food wastes from DOST canteen (48%) and soiled paper (41%) from offices; the remaining portion of biodegradable materials came from yard wastes (11%). Based from the total collected wastes of 66 kg d^{-1} and 73% of which was biodegradable waste, the potential material for composting averaged to 48 kg d^{-1}. Residual wastes were mainly composed of used plastic or sando bags (79%) and the rest were foil packs (13%), polystyrene foam (1%), and other residual wastes (7%). Recyclable materials were made up of 40% used papers, 22% glass bottles, 19% metals, 17% plastic bottles, and 2% other recyclables.

Start-up operation

Start-up operation was done to reproduce the initial seed compost. The characteristics of raw materials used for start-up operation is shown in Table 2. The seed compost used had a total NPK of 7.8%, total organic matter of 54.6%, carbon to nitrogen (C:N) ratio of 13:1, blackish, and with no foul odor. The initial mixture (rice bran, yard waste, and seed compost) had a moisture content of 55.14%, total organic matter of 80.98%, and pH of 6.30. After two days in the composter, the substrate had a pH of 4.93, moisture of 55.68% and organic matter of 71.6%. This material was used as inoculant in the composting operations.

Characteristics of raw materials for composting

The biodegradable waste used during composting operations consisted mainly of vegetable scraps and leftover foods. Biodegradable waste had high moisture content (81.4 to 83.6%), pH of 5.0 to 5.5, and total organic matter of 91.0 to 93.2%. Dried yard waste (bulking materials) composed of fallen leaves and had low moisture content (9.1 to 10.0%), pH of 5.4 to 5.6, and total organic matter of 84.6 to 90.0%. The characteristics of initial mixtures are presented in Table 3. Moisture content of initial mixture was adjusted by adding water to achieve 50-60% moisture.

Table 1: Amount of wastes generated within DOST*

Day	Total weight (kg d^{-1})	Total Volume (m^3)	Bulk density (kg m^{-3})
1	97.45	1.083	111.55
2	69.29	0.504	110.03
3	61.75	0.619	166.25
4	65.10	0.798	106.69
5	34.55	0.412	116.34
Average	65.63	0.683	122.17

* DOST - Department of Science and Technology, Taguig City, Metro Manila, Philippines

Table 2: Characteristics of raw materials for start-up operation

Parameters	Rice bran	Dried yard waste	Seed compost
Total Nitrogen, %	2.62	1.17	1.92
Total Phosphorus, %	0.83	0.08	2.54
Total Potassium, %	1.25	0.0008	3.36
Organic Matter, %	91.22	86.02	54.58
Organic Carbon, %	33.40	32.62	27.71
pH	6.32	5.55	8.12

Table 3: Characteristics of initial mixtures used in composting operations

Parameters	Initial mixtures		
	Run 1	Run 2	Run 3
Moisture, %	54.96 ±1.00	50.05 ±0.66	57.09 ±0.77
Total Organic Matter, %	63.23 ±0.99	70.75 ±0.02	72.29 ±0.57
Total Organic Carbon, %	29.98 ±0.12	32.61 ±0.69	35.62 ±0.04
Total Nitrogen, %	1.99 ±0.03	2.19 ±0.08	1.74 ±0.02
pH	6.0 ±0.32	6.95 ±0.14	6.38 ±0.14

Table 4: Compost analysis from three composting operations

Parameters	Composts				Standard*
	Run 1	Run 2	Run 3	Average	
Total Nitrogen, %	2.04	2.32	1.91	2.09	
Total Phosphorus, %	1.46	1.19	0.58	1.07	
Total Potassium, %	2.31	1.95	2.07	2.11	
Total NPK, %	5.81	5.46	4.55	5.27	2.5 - <5: Compost 5 – 7: Organic fertilizer
Total Organic Matter, %	47.99	51.65	46.69	48.78	≥20
Color	dark brown	dark brown	dark brown		dark brown to black
Odor	none	none	none		no foul odor

* BAFS-DA. 2013. Philippine National Standard for Organic Fertilizer. Bureau of Agriculture and Fisheries Standards, Department of Agriculture. PNS/BAFS 40:2013

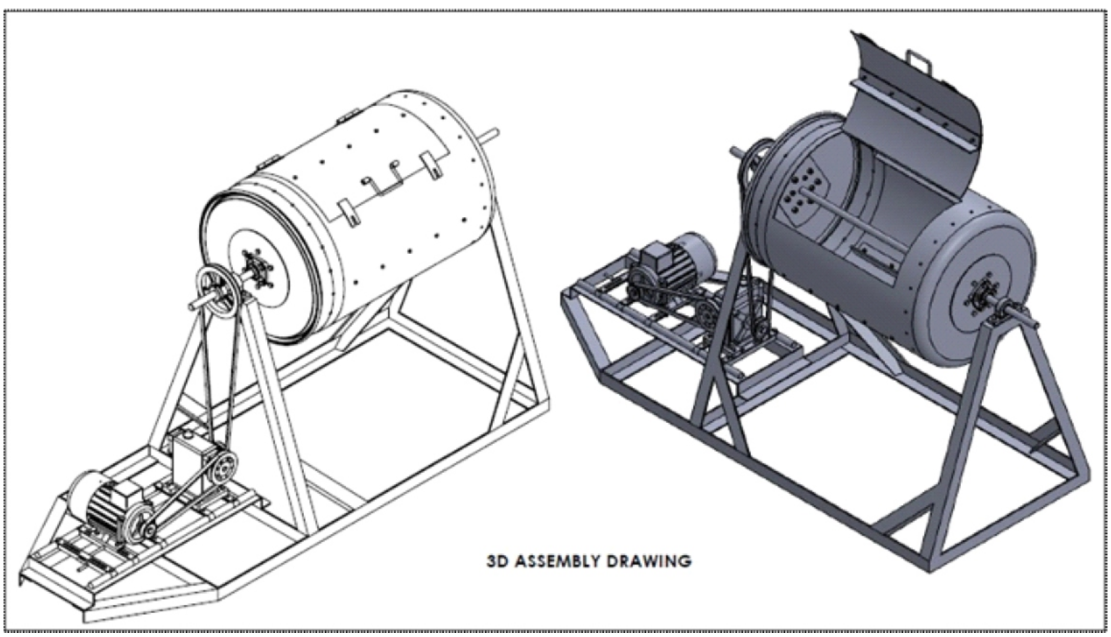

Figure 1. The 3-D assembly drawing of the small-scale composter

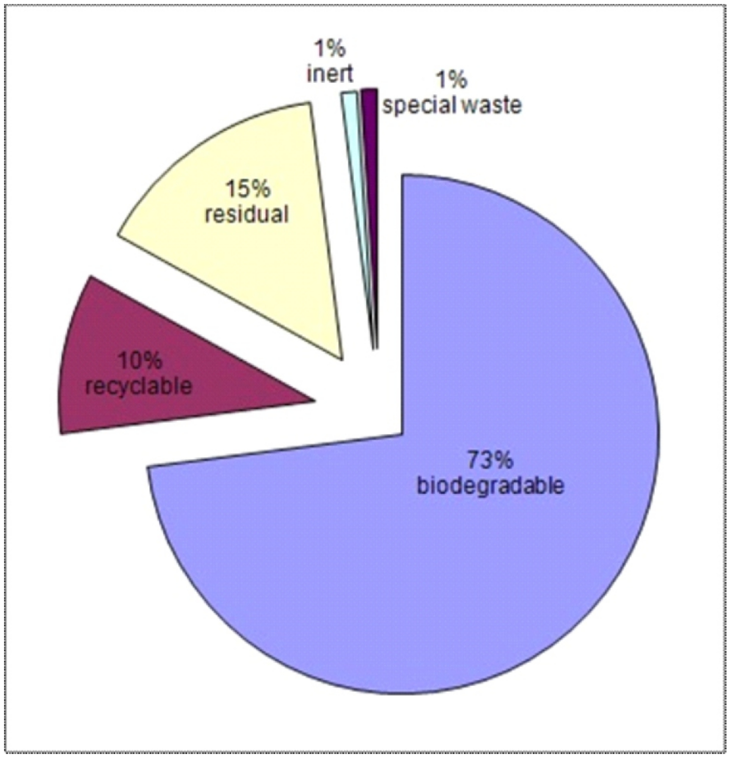

Figure 2. Percent composition of DOST-generated wastes

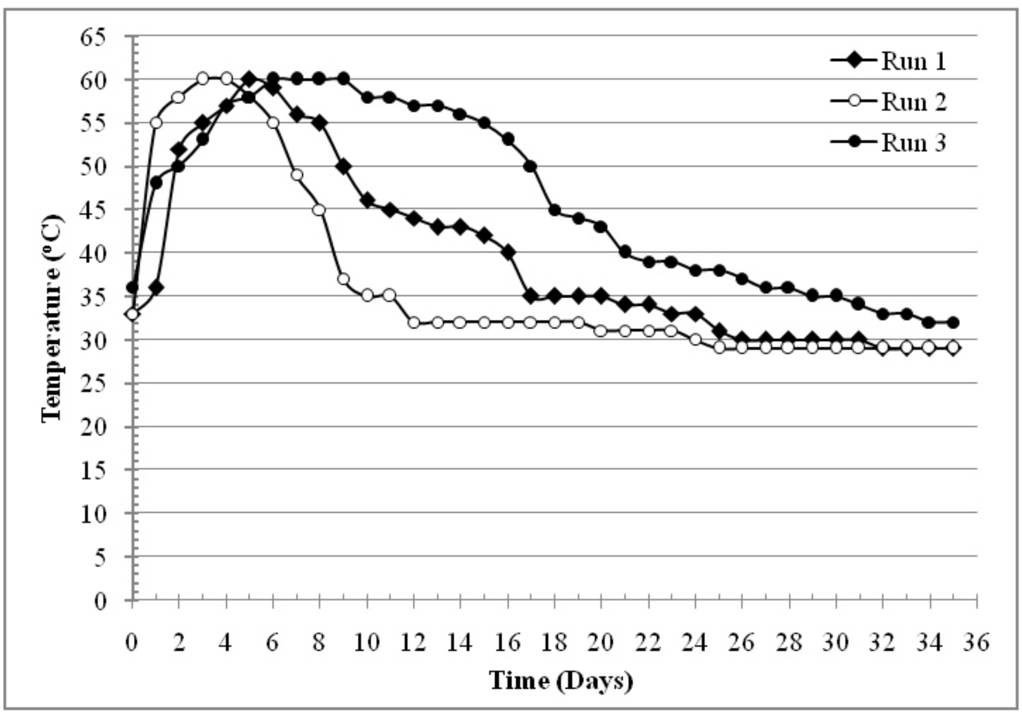

Figure 3. Temperature profile during composting operations

Temperature profile during composting operations

Three composting runs were conducted and the temperature profile during the composting operations is shown in Figure 3. Thermophilic condition was observed after 1 to 2 days of loading the initial mixture into the composter. High temperature condition was recorded for 8 days to 3 weeks during in-vessel and pile composting. Temperature of 55°C and higher was observed for 6 to 12 days during the active composting period. Curing or maturation stage lasted for two weeks in all composting runs. Substrate pH was acidic during the initial 1 to 3 days of composting and pH became basic thereafter. Lowest pH observed during the initial composting phase was 5.36 while highest pH recorded during active composting was 9.12. Recorded temperature in the composting area was 23 to 33°C for runs 1 and 2, and 27 to 35°C for run 3.

Compost analysis

Composts produced from the three composting runs were dark brown, humus-like, and without foul odor. Analyses of composts showed high nutrient content with a total NPK of 4.55 to 5.81% and an average NPK of 5.27% (Table 4). Final compost products had organic matter (OM) ranging from 48 to 52%. A reduction of 15 to 26% organic matter was noted from the initial compost mixture of 63 to 72% OM (Table 3).

DISCUSSION

A drum-type motorized composter was developed to utilize the biodegradable waste generated in DOST into a useful product, compost. Based from WACS result, DOST generates about 48 kg d^{1} biodegradable waste. Therefore, small composter is enough rather than using the ITDI Bioreactor composting technology[2] with a minimum loading capacity of 500 kg d^{1}. Composting was initiated by start-up operation to propagate the seed compost. This was followed by in-vessel composting (4 to 5 days) using the fabricated composter, then active pile composting (2 to 3 weeks), and curing phase (two weeks). The use of composter hastens the initial degradation of materials through its slow rotation for 8 h d^{1}. No leachate and untoward odor was observed during the composting operations.

The efficiency of the composter was examined using biodegradable wastes collected within DOST. Temperature is an important parameter that affects the success of composting. The temperature profile of substrate (Figure 3) as observed in this study is typical in composting operation. Thermophilic condition was observed in all three composting runs indicating active microbial activity and proper condition. Active composting was observed for 1 to 3 weeks during in-vessel and pile composting. Heat generated during composting is due to the microbial action on organic materials. Initial decomposition of organic materials is carried out by mesophilic (moderate-temperature) micro organisms that rapidly break down the readily degradable compounds. The heat they produce causes the compost temperature to rapidly rise. As the temperature rises above 40°C, mesophilic microorganisms become less competitive and are replaced by thermophilic or heat-loving microorganisms. Faster decomposition occurs during thermophilic stage of composting (40-60°C)[8]. High temperature accelerates the breakdown of organic materials including fats, proteins, and complex carbohydrates. As the organic materials become depleted, compost temperature eventually decreases. Mesophilic microorganisms once again become active during the curing of the remaining organic matter. The U.S. Environmental Protection Agency (EPA) standard temperature to reduce the number of human and plant pathogens is 55°C and above for 3 to 15 days depending on the method of composting [9]. Temperature higher than 60°C slows down the composting process as beneficial microbes tend to die off [10]. Turning of pile when it gets too hot will help lower the temperature.

The change in pH observed in this study normally occurs during the composting process. Substrate pH is acidic during the initial stage of composting. This is due to the accumulation of organic acids as by-products of microbial degradation (bacteria and fungi) of organic materials. As composting proceeds, organic acids are broken down further resulting to increase in pH level. This happens during the thermophilic stage when decomposition and volatilization of organic acids and release of ammonia occur [11]. During the later part of composting, pH tends to become neutral as ammonia is either incorporated into the microbial growth or lost into the atmosphere. Mature compost generally has a pH between 6 and 8.

Composts produced in this study had high nutrient content (total NPK 4.5 to 5.81%) and can be classified as compost to organic fertilizer. Based from the Philippine National Standard for Organic Fertilizer[12], a product is considered compost or soil conditioner if the total NPK is between 2.5 to <5%, whereas organic fertilizer should have a total NPK between 5 to 7%. Organic matter content of composts produced in this study was 46 to 52%. Organic matter is metabolically oxidized by microorganisms into carbon dioxide and water during the composting process [13]. Reduction of organic matter during composting is an indication of biodegradation of materials [14]. Organic matter in compost helps improve water holding capacity and soil structure. Philippine standard requires 20% or higher organic matter in both compost and organic fertilizer [12].

Considering that waste management laws promote waste reduction at source and composting of biodegradable waste[1], the developed composter can serve as an alternative technology for management of small volume of biodegradable waste. This small-scale composter is very appropriate for the Material Recovery Facilities (MRFs) in barangays, villages, government agencies and academic institutions.

CONCLUSION

DOST canteen and offices generate an average of 65.63 kg solid wastes per day. Biodegradable waste constitutes 73% of these wastes which is about 48 kg d^{-1}. A small-scale motorized composter was fabricated using plastic drum with a feeding capacity of 50 kg. The composter was rotated 8 h d^{-1} with waste retention time of 4 to 5 days. Thermophilic condition was achieved during active composting. High quality composts were produced from three composting operations with total NPK ranging from 4.55 to 5.81%. The composter unit is portable, needs limited manpower, and easy to operate. The developed composter is very applicable in communities that generate small volume of biodegradable waste.

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