Philippine Journal of Science
149 (1): 179-188, March 2020
ISSN 0031 - 7683
Date Received: 13 Aug 2019

Efficiency of Combined Co-composting, Vermicomposting, and Drying in the Treatment of Cadmium, Mercury, Helminths, and Coliforms in Sludge from Wastewater Facilities for Potential Agricultural Applications

Maria Aileen Leah G. Guzman[1]*, May Ann A. Udtojan[1], Marylle F. Del Castillo[1], Emilyn Q. Espiritu[1], Jude Anthony N. Estiva[2], Jewel Racquel S. Unson[1], Joan Ruby E. Dumo[1], and Jay Roy E. Espinas[1]

[1]Department of Environmental Science, Ateneo de Manila University, Loyola Heights 1108 Quezon City, Philippines
[2]Aparri Engineering LLC, 131 Main St., Suite 180, Hackensack NJ 07601 USA

Sludge generated from wastewater treatment facilities has been applied in agriculture as soil conditioners. However, the incomplete and/or inappropriate treatment of wastewater may result in sludge that may still contain heavy metals, helminth ova, and coliforms posing a risk to both humans and the environment. This study assessed various pretreatment techniques such as co-composting, vermicomposting, and a combination of these on sludge samples to remove heavy metals (cadmium and mercury), helminth ova, and coliforms. Physico-chemical and biological analyses were used to compare untreated (*i.e.* raw) and treated sludge samples. The results showed that for the raw sludge, mercury (4.02 +/– 0.17 mg/kg) and cadmium (6.30 +/– 0.48 mg/kg) exceeded the limits specified under the Philippine National Standard (PNS) for Organic Soil Amendments of 2 mg/kg and 5 mg/kg, respectively. Laboratory examinations also revealed the presence of helminth ova (5 ova/g) and coliforms (10 CFU/g) in the samples. Sludge samples subjected to a combination of co-composting and vermicomposting resulted in the elimination of mercury and a significant reduction in cadmium concentration from 6.30 mg/kg to 1.12 mg/kg. No helminth ova were observed in the samples after further drying. However, both treated and untreated sludge samples had low nutrient content. The study highlights the need for raising public awareness and educating farmers on the potential risks associated with the use of raw sludge for agriculture.

Keywords: composting, heavy metals, helminths, sludge, total coliform, vermicomposting

INTRODUCTION

The management of sludge produced from wastewater treatment facilities is one of the most expensive challenges faced by the wastewater industry that engineers and regulators are trying to solve (Metcalf and Eddy 2003; Sinha *et al.* 2009). The production of massive quantities of sludge has led to the development of various disposal methods including the use of landfills, incinerators, and land application. Among these, the use of sludge for land application is proposed to be the most resourceful and economical alternative method for disposal. Sludge is a potential source of nutrients that can be used as a soil

*Corresponding Author: mguzman@ateneo.edu

conditioner or fertilizer (Stadelmann *et al.* 2001; Metcalf and Eddy 2003). Several studies have shown that sludge contains compounds that provide a rich source of organic matter, nitrogen, phosphorus, potassium, and other plant nutrients that may be of agricultural value (EC 2001; Usman *et al.* 2012). The high organic matter in sludge can improve the physical characteristics of soils such as its structure, water retention, and porosity (Hossain *et al.* 2017). Hence, it is environmentally friendly and also an economically efficient method of solid waste disposal.

However, the land application of sludge has been restricted due to the reported presence of toxic contaminants, such as heavy metals and microbial pathogens of which pose environmental and human health risks (USEPA 2000). Heavy metals are of major concern due to their non-biodegradable (Duruibe *et al.* 2007) and accumulative nature that can lead to a decline in soil fertility (Singh and Kalamdhad 2011). For instance, some crops such as tomatoes or lettuce grown in soils with high metal concentrations could directly transfer the heavy metals to humans if the crops are eaten raw (Cappon 1981). Similarly, pathogenic organisms such as helminths and coliforms can persist in soils and in plants for months to years (USEPA 1993, 2003). As such, these contaminants may expose humans to various diseases (*e.g.* long-term cadmium exposure can cause kidney damage while helminth ova can cause gastrointestinal infections) as they enter the food chain through crop consumption (WHO 1989; Schonning and Stenstrom 2004; Lesmana *et al.* 2009). These issues highlight the need for a more thorough understanding of the nature of sludge and to search for possible remediation measures to ensure its safe application in agriculture.

Various treatments have been suggested from the United States of America, the United Kingdom, Netherlands, France, *etc.* (USEPA 1994; EC 2001). However, when considering an economical and sustainable approach, composting technology is the most practical option (Nair *et al.* 2006). Most studies on sludge treatments were conducted in Pakistan, Ghana, and Malaysia – specifically on co-composting (Bazrafshan *et al.* 2006; Cofie *et al.* 2009; Hock *et al.* 2009). On the other hand, vermicomposting studies have been conducted in Malaysia, Florida, and Australia (VermiCo 2013; Eastman *et al.* 2001; Sinha *et al.* 2009) while integrated co-composting and vermicomposting studies have been conducted in Iran (Ndegwa and Thompson 2001; Alidadi *et al.* 2007). In the Philippines, there has been little to no studies about the characterization and toxic effects of sludge and its treatment. Only the study by Manguiat (1997) was found wherein the author studied sewage sludge from agro-industrial wastewater treatment plants and showed that the sludge passed both US and German standards on heavy metals. Furthermore, the author used irradiation, specifically gamma radiation, for pathogen control. The study also suggests that biological composting and alkaline stabilization using a combination of heat, high pH (12), and drying can be used as an alternative procedure for treating sludge.

In response to this need, this study aimed to investigate the potential of sludge as a safe and cost-effective alternative soil conditioner. Specifically, the research aimed to: (a) determine the physicochemical characteristics and composition of the sludge obtained from various sources; and (b) describe the effectiveness of various sludge treatment processes for heavy metal, helminth ova, and coliform removal.

MATERIALS AND METHODS

Description of Sites

The sludge samples used in the study were obtained from two wastewater treatment facilities on the island of Luzon in the Philippines. One is a septage treatment plant while the other is a sewage treatment plant.

The septage treatment plant is a local government-owned and -controlled corporation with a 30 m^3 daily septage capacity. It only provides septage service to its domestic water customers. The desludging service cycle is every five years on a regular basis (BWD 2012). The septage treatment process separates the solid (sludge) and the liquid (effluent) components of the raw septage. The sludge is disposed of as earth fill and soil enhancer whereas the effluent is used in irrigation and re-used within the wastewater treatment facility (*e.g.* for cleaning, landscaping, *etc.*) according to the treatment facility staff.

The sewage treatment plant is originally designed as an oxidation ditch system with a treatment volume capacity of 8,600 m^3 of wastewater per day. Only 20% of its design capacity, however, was being treated (JICA 1991). It was initially constructed to service domestic areas connected to the sewage system but later included commercial areas that were constructed within the vicinity. The plant also accepts septage from areas that are not connected to the sewage line. Sewage is directly loaded into the oxidation ditches. Part of its full function is the inclusion of sludge thickeners and sludge drying beds to process sludge as a by-product of the wastewater treatment process. The dewatered sludge is dried in drying beds and then sold as an alternative agricultural fertilizer/ soil conditioner (Robinson 2003; CEPMO 2014).

Sample Collection and Preparation

The sample size and the method of analysis were determined using the Publicly-Owned Treatment Works

Sludge Sampling and Analysis Guidance Document (USEPA 1989). The sampling of sludge from the two wastewater facilities was conducted once during the wet season. The sludge was dewatered using a dewatering machine and drying beds resulting in 72% and 10% moisture content, respectively. Composite sludge samples were randomly collected from each treatment facility and placed in bags. Seven (7) bags each weighing approximately 10 kg were obtained from the septage treatment plant and one bag weighing approximately 20 kg of sludge samples from the sewage treatment plant was collected. These were immediately transported to the laboratory for processing and analyses.

Physico-Chemical Characterization of the Sludge Samples

The raw sludge samples (*i.e.* with 72% and 10% moisture content) were analyzed for various parameters using standard methods. The heavy metals arsenic, cadmium, chromium, and lead were analyzed using USEPA Method 3050B; while mercury was analyzed using the cold-vapor technique. These were quantified using atomic absorption spectrophotometry. In compliance with the PNS for Organic Soil Amendments (PNS/BAFS 183:2016), the carbon-nitrogen ratio was computed, total nitrogen was analyzed using the Kjeldahl method, total phosphorus using USEPA Method 265.3, organic matter and moisture content using the loss-on-ignition method, pH using a portable soil pH meter, temperature using a thermometer, and color consistency and odor using sensory observations.

Microbiological Characterization of the Sludge Samples

The raw sludge samples were subjected to microbiological characterization based on the total helminths (expressed as ova/g) following the Standard Methods for the Recovery and Enumeration of Helminth Ova in Wastewater, Sludge, Compost, and Urine-diversion Waste in South Africa (Moodley *et al.* 2008). Total coliform was determined using the pour plate method of the Philippine Coconut Authority laboratory.

Optimization of the Sludge Treatment

In order to comply with local standards for the use of sludge in agriculture (PNS/BAFS 183:2016), prior treatment is necessary to remove pathogens and heavy metals that may be present in sludge. Several treatment strategies were employed to determine which of these would produce the desired results. Each treatment was prepared in triplicates along with a control set-up of pure sludge. The sludge samples with 10% moisture content were hydrated to raise the moisture level to 60% using distilled water (here referred to as "reconstituted" sludge or RS). The other sludge samples with 72% moisture were used as is in the succeeding stage.

Co-composting. For the RS, co-composting (CC) experiments were performed in plastic bins containing a 2:1:1 ratio of vegetable scraps, RS, and soil – with a final weight of 2 kg. Holes were drilled at the bottom of the bins to allow adequate drainage. The interior of the bins was lined with aluminum foil so as to reach an internal temperature of 35–65 °C. The internal temperature was checked daily using a thermometer. The daily moisture content of the co-composting materials was monitored and maintained at 60%. The manual turning of co-composting materials was done once a week to aerate and homogenize the mixture. The sludge samples with 72% moisture were mixed with vegetable scraps in a 1:2 sludge-to-vegetable-scraps ratio, with a total weight of 3 kg. The mixtures were composted for 30 d, similar to the procedure followed with the RS.

Vermicomposting. For the RS, vermicomposting (VC) experiments were performed using a set-up similar to that of CC as described previously, with a final weight of 2 kg before the addition of 50 g of *Eudrilus eugeniae* (African Nightcrawler) earthworms to each bin. To prevent the earthworms from escaping, a plastic net was placed over each bin. At the end of the treatment, earthworms were sieved to separate them from the vermicompost. After weighing the worms, the worms were subjected to heavy metal analysis.

For the sludge with a 72% moisture level, the final weight was 3 kg. Vermicomposting was performed following the same procedures done to the RS with the addition of 60 g African Nightcrawler earthworms to each bin instead of 50. The difference in the number of worms used was based on the weight of the composting materials. Vermicastings were manually harvested after 30 d.

Combined co-composting and vermicomposting. For the RS, combined co-composting-vermicomposting (CV) experiments were performed by first co-composting the sludge with the vegetable scraps as described previously for 28 d, followed by vermicomposting as described previously. For the sludge with 72% moisture, vermicomposting of sludge was mixed with market waste on a 1:2 sludge-to-scraps ratio. The mixtures were composted for 20 d in bins with holes and mixed for proper aeration. After 20 d of co-composting, 60 g of earthworms were added and the vermicasts were manually harvested after 10 d.

Combined co-composting and vermicomposting with subsequent oven-drying. For the sludge with 72% moisture, co-composting and vermicomposting

Table 1. Summary of initial sludge characteristics obtained from the two wastewater treatment facilities.

Physico-chemical and microbiological properties	Sewage treatment plant	Septage treatment plant	PNS-BAFS standards (2016)
Color	Brown	Black	Brown to black
Odor	No foul odor	No foul odor	No foul odor
Consistency	Not friable	Friable	Friable
pH at 30 °C	6.84 ± 0.06	6.61 ± 0.04	Not regulated
Moisture content	10.62 ± 0.04	72.3 ± 0.01	10–35%
Organic matter	25.52 ± 0.60	83.5 ± 0.10	≥ 20%
Total N-P_2O_5-K_2O	1.28 ± 0.08 (N) 0.04 ± 3.01E–03 (P_2O_5) 0.35 ± 0.03 (K_2O)	0.04 ± 0.01 (N) 5.2 ± 0.01E06 (P_2O_5) 0.001 ± 0.6 (K_2O)	2.5 – < 5%
Arsenic	1.18 ± 0.17	0.118 ± 0.10	20 (mg/kg)
Cadmium	6.30 ± 0.48	0.0163 ± 0.40	5 (mg/kg)
Chromium	20.19 ± 1.09	Not analyzed	150 (mg/kg)
Lead	23.37 ± 2.16	0.0204 ± 0.01	50 (mg/kg)
Mercury	4.02 ± 0.17	Not analyzed	2 (mg/kg)
Total coliform	< 10 ± 0	< 10 ± 0	< 10 (cfu/g)
Total helminths	1 ± 0	5 ± 1	Not regulated (ova/g)

Each value represents the mean ± SD (n = 3).
Sewage treatment plant – sludge samples with 10% moisture content
Septage treatment plant – sludge samples with 72% moisture content
PNS/BAFS 183:2016 – Philippine National Standard / Bureau of Agriculture and Fisheries Standards for Organic Soil Amendments

Table 2. Summary of the characteristics of sludge subjected to various treatment strategies.

Parameter	Control		Co-composting (CC)		Vermi-composting (VC)		Co-composting and vermi-composting (CV)		PNS-BAFS standards (2016)
	Sewage treatment plant	Septage treatment plant	Sewage treatment plant	Septage treatment plant	Sewage treatment plant	Septage treatment plant	Sewage treatment plant	Septage treatment plant	
Color	Brown	Black	Brown	Black	Brown	Black	Brown	Black	Brown to black
Odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor	No foul odor
Consistency	Not friable	Slimy	Friable	Friable	Friable	Friable	Friable	Friable	Friable
Temperature	30 °C	28 °C	37 °C – 30 °C	41 °C – 28 °C	28 °C – 25 °C	28 °C	33 °C – 29 °C	40 °C – 28 °C	–
pH	6.07 ± 0.12	6.61 ± 0.04	6.80 ± 0.07	6.91 ± 0.13	7.11 ± 0.10	6.66 ± 0.4	7.02 ± 0.01	6.80 ± 0.11	Not regulated
Moisture content (100%)	7.93 ± 0.29	22.3 ± 21.6	8.85 ± 0.19	20.6 ± 12	4.20 ± 0.14	27.9 ± 0.01	4.21 ± 0.37	26.7 ± 6	10–35
Organic matter (%)	24.70 ± 0.79^{a}	47.2 ± 10	31.50 ± 1.69^{a}	13.3 ± 3.8	17.68 ± 0.57^{b}	23.8 ± 0.03	17.13 ± 0.68^{b}	13.9 ± 1.6	≥ 20
	1.29 ± 0.15^{a}	0.04 ± 0.01	1.12 ± 0.13^{a}	0.016 ± 0.004	0.51 ± 0.007^{b}	0.025 ± 0.001	0.49 ± 0.05^{b}	0.0001 ± 0.00	
Total N-P_2O_5-K_2O	0.057 ± 0.02^{ac}	5.2E06 ± 0.0	0.086 ± 0.043^{cd}	0.000047 ± 4.2E06	0.0056 ± 0.003^{b}	0.000057 ± 7.8E05	0.017 ± 0.005^{ab}	0.000028 ± 3.9E05	2.5 – <5%
	0.354 ± 0.007^{b}	0.001 ± 0.6	0.356 ± 0.004^{b}	0.003 ± 0.004	0.37 ± 0.003^{a}	0.003 ± 0.01	0.36 ± 0.009^{b}	Not detected	
Total coliform	< 10 ± 0	< 10 ± 0	4.3E3 ± 2.5E02	< 10 ± 0	1.5E04 ± 5.0E03	< 10 ± 0	< 10 ± 0	< 10 ± 0	< 10cfu/g
Total helminths	Not detected	13 ± 3	1 ± 0	18 ± 5	1 ± 0	19 ± 4	Not detected	26 ± 16	Not regulated

Each value represents the mean ± SD (n = 3).
Results sharing the same letter are not significantly different at $p < 0.05$.
C – control (untreated soil); N – nitrogen; P – phosphorus; K – potassium;
Sewage treatment plant – sludge samples with 10% moisture content
Septage treatment plant – sludge samples with 72% moisture content

were performed as previously described for 30 d. The vermicasts were then subjected to further oven-drying at 57 ˚C for 1 h (USEPA 1994).

At the end of each treatment, physicochemical and microbiological analyses were conducted to compare the sludge characteristics before and after the treatments, as well as the effectivity of each treatment in removing the helminths and heavy metals. Furthermore, after the experiments, the earthworms that were used in the treatments were disposed of following the guidelines described in the Department of Environment and Natural Resources (DENR) Administrative Order 36, Series of 2004 (DAO 2004-36) for disposing of hazardous waste.

RESULTS AND DISCUSSIONS

Physico-chemical and Microbiological Characterization of the Sludge

The initial visual examination of the sludge collected from the two wastewater treatment facilities during the wet season showed that both samples met the required color and odor (Table 1). However, the sludge sample from the sewage treatment plant was not friable while the moisture content of the sludge sample from the septage treatment plant was too high (72.3 ± 0.01% moisture). Hence, both sludge samples failed to meet the requirement for consistency and moisture content, respectively.

The results of the initial chemical analyses, expressed as mean ± standard deviation (SD), showed that the average concentrations of the organic matter (sewage treatment plant, 25.52 ± 0.60%; septage treatment plant, 83.5 ± 0.10%) of both samples were within the required level set by the PNS for Organic Soil Amendments (*i.e.* ≥ 20%). However, the nitrogen and potassium level of both sludge samples failed to meet the established limit for soil conditioner (2.5 – <5%), while the total concentration of Hg (4.02 ± 0.17 mg/kg and Cd (6.30 ± 0.48 mg/kg) from the sewage treatment plant exceeded the prescribed standard. Microbiological results showed that the total coliform count of both samples met the standard, but helminth ova were detected in both sludge samples. The results of this study highlight the need for additional treatment to remove heavy metals, and helminths.

After the 8-wk treatment process, changes in the physicochemical properties of the initial samples were observed. The end product of each treatment was observed to be much darker in color, odor-free and visually homogenous as compared to their initial condition. The resulting pH values (6.02–7.11) were found to be slightly acidic to neutral. This could be attributed to the production of organic acids from microbial metabolism as well as the production of humic and fulvic acids during decomposition (Ndegwa and Thompson 2000; Dominguez and Edwards 2004; Suthar and Singh 2008).

For the sludge samples from the sewage treatment plant,

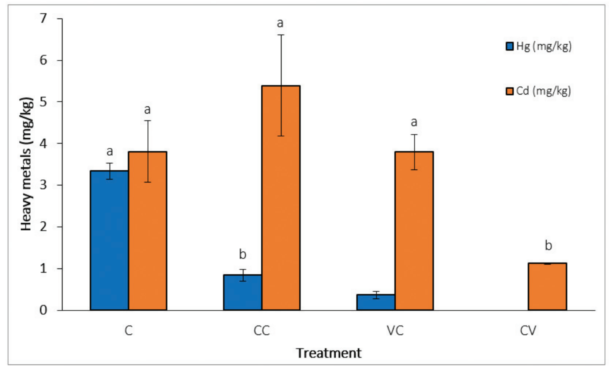

Figure 1. Average heavy metal concentration (mg/kg), expressed as mean ± SD, in the treated sludge samples after treatment. Each value represents the mean ± SD (n = 3). Results sharing the same letter are not significantly different at $p < 0.05$. C – control (untreated soil); CC – co-composting; VC – vermicomposting; CV – co-composting + vermicomposting.

a 27.5% significant increase ($p < 0.05$) in organic matter content was found after CC (31.50 ± 1.69%) whereas a 28.4% and a 17.13% significant loss ($p < 0.05$) was detected after VC (17.68 ± 0.57%) and CV (17.13 ± 0.68%), respectively (Table 2). Results for the sludge samples from the septage treatment plant showed a significant loss ($p < 0.05$) in organic matter content of 67.5%, 41.8%, and 66% after CC (13.3 ± 3.8%), VC (23.8 ± 0.03%), and CV (13.9% ± 1.6), respectively (Table 2). Partial mineralization and humification are chemical changes that occur because of organic matter bio-oxidation (Fornes *et al.* 2012). Greater reduction in organic matter content indicates better degradation and mineralization, giving more stable products (Ndegwa and Thompson 2001). Hence, VC and CV treatments can be used to efficiently stabilize sludge.

The total N content of the final product of each treatment found in the sludge samples from the sewage treatment plant ranged from 0.49–1.12%. Significant loss ($p < 0.05$) was found after VC (0.51 ± 0.01%) and CV (0.49 ± 0.05%) but no significant reduction was measured after CC (1.12 ± 0.13%). On the other hand, the total N found in the sludge samples from the septage treatment plant ranged from 0.01–0.02%. Significant loss was found after CC (0.016 ± 0.004%), VC (0.025 ± 0.001%), and CV (0.0001 ± 0.004%). The significant reduction in total N content after treatment could be due to mineral N leaching because of frequent application of water (Cogger *et al.*

Table 3. Average change in accumulated metal concentration in earthworm tissues, expressed as mean ± SD (n = 3).

Heavy metal (mg/kg)	Initial concentration	After VC	% accumulated metals after VC	After CV	% accumulated metals after VC
Cd	0.79 ± 0.08[a]	1.89 ± 0.87[ab]	20.40	3.0 ± 0.24[b]	40.84
Hg	0.02 ± 0[a]	1.31 ± 0.80[ab]	39.31	2.94 ± 0.80[b]	86.98

Results sharing the same letter are not significantly different at $p < 0.5$.
VC – vermicomposting; CV – co-composting + vermicomposting

2000) during vermicomposting to maintain optimum moisture content. A similar result was reported by Fornes *et al.* (2012) in which heavy irrigation resulted to greater leaching of the total N content and most macronutrients in vermicomposting and integrated composting systems as compared to composting alone.

An increase in available P concentration was detected after CC (0.086 ± 0.043%) of sludge from the sewage treatment plant and after VC (0.000057 ± 7.8E05%) of sludge from the septage treatment plant. While decreases in the available P were noticed after VC (0.0056 ± 0.003%) and CV (0.017 ± 0.005%) from the samples taken from the sewage treatment plant and after CC (0.000047 ± 4.2E06%) and CV (0.000028 ± 3.9E05%) from the samples taken from the septage treatment plant. The result of the VC treatment showed a significant decrease ($p < 0.05$) in P concentration. This may be linked to phosphate leaching brought about by frequent watering during VC. The decrease in available P was consistent with the findings of Ndegwa and Thompson (2001).

The total K concentration following all composting treatments generally increased as compared to the control, with the VC treatment showing a statistically significant increase ($p < 0.05$) in K concentration. This could be attributed to the addition of soil, which was found to contain 0.37% K. The increase in the total K concentration seen after the VC (sewage treatment plant, 0.37 ± 0.003%; septage treatment plant, 0.003 ± 0.01%) treatment might have been due to the acid production by the microorganisms present in the gut of earthworms which could solubilize the insoluble potassium (Kaviraj and Sharma 2003). Similar findings were reported by Tripathi and Bhardwaj (2004), Gupta and Garg (2008), and Suthar and Singh (2008).

Results of the Heavy Metal Analyses

Heavy metal contents of the final products showed an increase of 41.6% in Cd concentration after CC (mean ± SD = 5.39 ± 1.22 mg/kg) but this result did not differ significantly from the Control (mean ± SD = 3.81 ± 0.74 mg/kg). A 70.5% significant reduction ($p < 0.05$) on Cd concentration was found after CV (mean ± SD = 1.12 ± 0.02 mg/kg) (see Figure 1). The results for the total Hg level showed a decrease after CC. The combined composting also demonstrated a significant ($p < 0.05$) and 100% removal of Hg among all the treatments (see Figure 1).

Several studies have shown that earthworms can accumulate heavy metals from organic waste through their skin and gut (Suthar and Singh 2008; Sinha *et al.* 2009; Suthar *et al.* 2014; Soobhany *et al.* 2015). However, only a few studies focused on the use of *Eudrilus eugeniae* as vermiworms for the removal of toxic heavy metals from specific waste (Graft 1982; Iwai *et al.* 2013; Soobhany *et al.* 2015) due to their narrow temperature tolerance compared to *Eisenia fetida* (Reinecke *et al.* 1992). In this study, a large increase in the concentration of heavy metals was measured from the body tissues of *Eudrilus eugeniae* relative to the initial concentration. For Cd, the concentration increased by 1.1 mg/kg after VC and 2.21 mg/kg after CV. For Hg, the concentration increased by 1.29 mg/kg after VC and 2.92 mg/kg after CV (Table 3). Specifically, a significant increase ($p < 0.05$) in heavy metal concentrations was measured from the earthworm tissues after the CV treatment. Earthworms subjected to the CV treatment accumulated 40.84% and 86.98% of the total Cd and Hg in their system, respectively. This could be due to the palatability of waste mixtures in the combined treatment as evidenced by the remarkable increase in earthworm biomass. It is worth mentioning that the CV system was the treatment that also exhibited a significant decrease in organic matter decomposition.

Percent accumulation of metal in the earthworm tissues was calculated from the equation:

$$\% \text{ Metal Accumulation} = \frac{(\text{Metal in ET After Treatment} - \text{Metal in ET Before Treatment})}{\text{Metal in the Initial Wastes}} \times 100 \quad (1)$$

Percent removal efficiency is calculated from the equation:

$$\% \text{ Removal Efficiency} = \frac{(\text{Metal in the Initial Wastes} - \text{Metal in the Compost})}{\text{Metal in the Initial Wastes}} \times 100 \quad (2)$$

Therefore, the combined treatment of co-composting and vermicomposting (*i.e.* CV) can be used to effectively remove heavy metals – specifically Cd and Hg from sludge – as shown in Table 4. These results are consistent with findings from other studies using different metals, organic wastes, and earthworm species (Suthar and Singh 2008; Sinha *et al.* 2009; Iwai *et al.* 2013).

Table 4. Percent removal efficiency of co-composting, vermicomposting, and combined co-composting and vermicomposting.

Heavy metal	% removal efficiency		
	CC	VC	CV
Cd	0.20	29.82	79.07
Hg	75.00	89.14	100.00

In terms of the helminth ova and coliform levels found in the sludge from the sewage treatment plant, total coliform after the CV treatment was below 10 CFU/g and no helminth eggs were detected. This is in contrast with the other treatments (CC and VC) in which helminth eggs were detected and a large increase in the concentration of total coliforms was measured after CC and VC. Moreover, sludge from septage treatment plant after CC, VC, and CC exhibited below 10 CFU/g total coliform count but the total helminth count exceeded the allowable limits (Table 2) – hence the need to further dry the treated sludge to significantly reduce the helminth ova present (USEPA 1994).

For CC, the temperature only reached 37 °C on its 5th day and decreased subsequently while the VC temperature stayed below 30 °C. According to USEPA (2003), composting can significantly reduce helminth ova and coliforms provided that the temperature of sewage sludge is raised to 40 °C or higher for 5 d and the compost piles exceeds 55 °C within 4 h during the 5-d period. This suggests that the temperature in both treatments (CC and VC) was not high enough to kill the helminth ova and coliforms; thus, raising the possibility of coliform multiplication or re-activation.

However, a more detailed temperature specification for the composting system was noted by Jenkins (1999). Based on his study, complete pathogen reduction in a composting system can be assured if the temperature is attained at 62 °C for 1 h, 50 °C for 1 d, 46 °C for 1 wk, or 43 °C for 1 mo. Unlike the other treatments, the temperature for the CV treatment reached 50 °C on its first day, thereby resulting in low coliform count and elimination of helminth ova. These findings indicate that the CV treatment is more effective in terms of reducing heavy metal concentrations (Cd and Hg), helminth ova and coliforms than a single composting treatment in sludge with 10% moisture. While a combination of co-composting or vermicomposting followed by further drying is the best treatment to completely eliminate helminth ova in sludge with 72% moisture.

CONCLUSION

There is a need to characterize sludge prior to agricultural application. This study shows that the raw sludge samples from either type of treatment plant did not completely meet the minimum requirements set in PNS/BAFS 183:2016. High concentrations of Cd and Hg in sludge from the sewage treatment plant were found to exceed the maximum allowable level. Moreover, the presence of helminth ova in sludge from the septage treatment plant indicates that raw sludge cannot be recommended for land application as a soil conditioner. Thus, there is a need for further treatment prior to its use in land application to prevent risks to both the environment and human health. The findings of this study showed that a combination of co-composting and vermicomposting was significantly more effective than a single composting treatment in terms of eliminating Hg and significantly reducing the concentration of Cd. For the 72% moisture sludge, further drying was necessary after the combined treatment in order to eliminate the pathogens (coliforms and helminths). Moreover, caution needs to be observed with regards to the proper disposal of earthworms used in the treatments as stated in DAO 2004-36 to avoid contamination.

Further and more intensive work is necessary to investigate the beneficial effect/s of vermicompost to plants. As this study produced vermicomposts with low levels of nutrients, composting of sludge with nutrient-rich organic waste materials is highly suggested to maximize its full potential for soil amendment. It is also suggested to investigate seasonal comparison and the tolerance of earthworms to heavy metals such as those found in this study to determine their maximum efficiency in bioremediation.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Asian Development Bank, the Accelerated Science and Technology Human Resource Development Program of the Philippine Department of Science and Technology, and the Ateneo de Manila University for their generous funding support. Special thanks to Stella Tansengco Shapero and Kevin Paolo Bartolome for their valuable assistance in the conduct of this research.

REFERENCES

ALIDADI H, PARVARESH AR, SHAHMANSOURI MR, POURMOGHADAS H, NAJAFPOOR AA. 2007. Combined compost and vermicomposting process in the treatment and bioconversion of sludge. Pak J Biol Sci 10(21): 3944–3947.

BAZRAFSHAN E, ZAZOULI MA, BAZRAFSHAN J, BANPEI AM. 2006. Co-composting of Dewatered Sewage Sludge with Sawdust. Pak J Biol Sci 9(8): 1580–1583.

[BWD] Baliuag Water District. 2012. Septage Collection Scheme. Retrieved on 22 Apr 2017 from http://baliwagwd.com/contents/septage-collection-scheme/

CAPPON CJ. 1981. Mercury and Selenium Content and Chemical Form in Vegetable Crops Grown on Sludge-Amended Soil. Arch. Environ. Contam Toxicol 10: 673–689.

[CEPMO] Baguio City Environment and Parks Management Office. 2014. A Situationer: Wastewater Management in the City of Baguio. Retrieved on 24 Apr 2017 from http://www.unescap.org/sites/default/files/10-Waste%20water%20management% 20in%20the%20city%20of%20Baguio,%2 0Philippines%20.pdf

COFIE O, KONĚ D, ROTHENBERGER S, MOSER D, ZUBRUEGG C. 2009. Co-composting of faecal sludge and organic solid waste for agriculture: process dynamics. Water Res 43(18): 4665–4675.

COGGER CG, SULLIVAN DM, HENRY CL, DORSEY KP. 2000. Biosolids Management Guidelines for Washington State. Washington State Department of Ecology.

[DENR] Department of Environment and Natural Resources. 2004. DENR Administrative Order 36, Series of 2004: Revised Procedural Manual on Hazardous Waste Management.

DOMINGUEZ J, EDWARDS CA. 2004. Vermicomposting organic wastes: a review. In: Soil Zoology for Sustainable Development in the 21st Century. Hanna SH, Mikhail WZ ed. Cairo: Safwat H Shakir Hanna. p. 369–395.

DURUIBE JO, OGWUEGBU MO, EGWURUGWU JN. 2007. Heavy Metal Pollution and Human Biotoxic Effects. Int J Phys Sci 2(5): 112–118.

EASTMAN BR, KANE PN, EDWARDS CA, TRYTEK L, GUNADI B, STERMER AL, MOBLEY JR. 2001. The effectiveness of vermiculture in human pathogen reduction for USEPA biosolids stabilization. Compost Sci Util 9(1): 38–41.

[EC] European Commission. 2001. Disposal and recycling routes for sewage sludge Part 3. Retrieved on 22 Jul 2016 from http://ec.europa.eu/environment/archives/waste/sludge/pdf/ sludge _ disposal3.pdf

FORNES F, MENDOZA-HERNANDES D, GARCIA DE LA FUENTE R, ABAD M, BELDA RM. 2012. Composting versus Vermicomposting: A Comparative Study of Organic Matter Evolution Through Straight and Combined Processes. Bioresour Technol 118: 296–305.

GRAFT O. 1982. Vergleich der Regenswurmaten Eisenia foetida und Eudrilus eugeniae hinsichlich ihrer Eignung zur Proteinwinnung aus Abfallstoffen. Pedobiologia 23: 277–282.

GUPTA R, GARG VK. 2008. Stabilization of Primary Sewage Sludge During Vermicomposting. J Hazard Mater 153(3): 1023–1030.

HOCK LS, BAHARUDDIN AS, AHMAD MN, SHAH UKM, RAHMAN NAA, ABD-AZIZ S, HASSAN MA, SHIRAI Y. 2009. Physicochemical Changes in Windrow Co-Composting Process of Oil Palm Mesocarp Fiber and Palm Oil Mill Effluent Anaerobic Sludge. Aust J Basic & Appl Sci 3(3): 2809–2816.

HOSSAIN MZ, FRAGSTEIN PV, NIEMSDORFF PV, HESS J. 2017. Effect of Different Organic Wastes on Soil Properties and Plant Growth and Yield: A Review. Sci Agric Bohem 48(4): 224–237.

IWAI CB, TA-OUN M, CHUASAYATEE T, BOONYOTHA P. 2013. Management of Municipal Sewage

Sludge by Vermicomposting Technology: Converting a Waste into a Bio Fertilizer for Agriculture. Int J Environ Rural Dev 4(1): 169–174.

JENKINS J. 1999. The Humanure Handbook. A Guide to Composting Human Manure, Second Edition. Grove City, PA: Joseph Jenkins, Inc. Retrieved from https://humanurehandbook.com/downloads/H2.pdf

[JICA] Japan International Cooperation Agency. 1991. Basic Design Study Report on the Baguio Septage System Rehabilitation Project in the Republic of the Philippines [Supplementary Study].

KAVIRAJ S, SHARMA S. 2003. Municipal Solid Waste Management Through Vermicomposting Employing Exotic and Local Species of Earthworms. Bioresour Technol 90(2): 169–173.

LESMANA SO, FEBRIANA N, SOETAREDJO FE, SUNARSO J, ISMADJI S. 2009. Studies on Potential Applications of Biomass for the Separation of Heavy Metals from Water and Wastewater. Biochem Eng J 44: 19–41.

MANGUIAT IJ. 1997. Sewage sludge: turning an environmental pollutant into an agricultural resource. Retrieved on 28 Oct 2019 from http://agris.fao.org/agris-search/search.do?recordID=PH1998010123

METCALF AND EDDY, INC. 2003. Wastewater Engineering: Treatment, Disposal and Reuse, 4th ed. New York: McGraw-Hill Publishing Company Ltd.

MOODLEY P, ARCHER C, HAWKSWORTH D, LEIBACH L. 2008. Standard Methods for the Recovery and Enumeration of Helminth Ova in Wastewater, Sludge, Compost and Urine-Diversion Waste in South Africa. Pretoria, South Africa: Water Research Commission.

NAIR J, SEKIOZIOC V, ANDA M. 2006. Effect of Pre-Composting on Vermicomposting of Kitchen Waste. Bioresource Technology 97: 2091–2095.

NDEGWA PM, THOMPSON SA. 2000. Effects of C-to-N Ratio on Vermicomposting of Biosolids. Bioresour Technol 75: 7–12.

NDEGWA PM, THOMPSON SA. 2001. Integrating Composting and Vermicomposting in the Treatment and Bioconversion of Biosolids. Bioresour Technol 76: 107–112.

[PNS] Philippine National Standards, [BAFS] Bureau of Agriculture and Fisheries Standards. 2016. PNS/BAFS 183:2016: Organic Soil Amendments.

REINECKE AJ, VILJOEN SA, SAAYMAN RJ. 1992. The Suitability of *Eudrilus eugeniae*, *Perionyx excavatus* and *Eisenia fetida* (Oligochaeta) for Vermicomposting in Southern Africa in Terms of Their Temperature Requirement. Soil Biol Biochem 24(12): 1295–1307.

ROBINSON A. 2003. Urban sewarage and sanitation: lesson learned from case studies in the Philippines. World Bank Water and Sanitation Program – East Asia and the Pacific.

SCHONNING C, STENSTROM TA. 2004. Guidelines for the Safe Use of Urine and Faeces in Ecological Sanitation. Sweden: Ecosanres, SEI.

SINGH J, KALAMDHAD AS. 2011. Effects of Heavy Metals on Soil, Plants, Human Health and Aquatic Life. Int J Res Chem Environ 1(2): 15–21.

SINHA RK, HEART S, BHARAMBE G, BHARAMBHATT A. 2009. Vermistabilization of Sewage Sludge (BIosolids) by Earthworms: Converting a Potential Biohazard Destined for Landfill Disposal into a Pathogen-free, Nutritive and Safe Biofertilizer for Farms. Waste Manag Res 28(10): 872–881.

SOOBHANY N, MOHEE R, GARG VK. 2015. Comparative Assessment of Heavy Metal Content During the Composting and Vermicomposting of Municipal Solid Waste Employing *Eudrilus eugeniae*. Waste Manage 39: 130–145.

STADELMANN FX, KULLING D, HERTER U. 2001. Sewage Sludge: Fertilizer or Waste? Retrieved on 24 Apr 2017 from http://library.eawag.ch/EAWAGPublications/openaccess/ Without_EAWAG_number/eawagnews/www_en53/en53e_printer/en53e_stadelm_p.pdf

SUTHAR S, SINGH S. 2008. Feasibility of Vermicomposting in Biostabilization of Sludge from a Distillery Industry. Sci Total Environ 394: 237–243.

SUTHAR S, SAJWAN P, KUMAR K. 2014. Vermiremediation of Heavy Metals in Wastewater Sludge from Paper and Pulp Industry Using Earthworm Eisenia Fetida. Ecotox Enviro Safe 109: 177–184.

TRIPATHI G, BHARDWAJ P. 2004. Decompostion of Kitchen Waste Amended with Cow Manure Using an Epigeic Species (*Eisenia fetida*) and an Anecic Species (*Lampito mauritti*). Bioresour Technol 92(2): 215–218.

[USEPA] United States Environmental Protection Agency. 1989. Publicly Owned Water Treatment Works Sludge Sampling and Analysis Guidance Document. Retrieved from http://greencriminology.org/glossary/publicly-owned-water-treatment-works-powts-us/ on 08 May 2019.

[USEPA] United States Environmental Protection Agency. 1993. Methods for Microbiological Analyses of Sewage Sludge. Washington, DC: Dynamic Corporation.

[USEPA] United States Environmental Protection Agency. 1994. Biosolids Management Handbook EPA Region VIII. Retrieved on 24 Apr 2017 from https://www.epa.gov/sites/production/ files/documents/handbook1.pdf

[USEPA] United States Environmental Protection Agency. 2000. Biosolids Technology Fact Sheet. Land Application of Biosolids. Washington, DC: Environmental Protection Agency.

[USEPA] United States Environmental Protection Agency. 2003. Control of Pathogens and Vector Attraction in Sewage Sludge. Cincinnati, OH: US Environmental Protection Agency.

USMAN K, KHAN S, GHULAM S, KHEN MU, KHAN N. 2012. Sewage Sludge: An Important Biological Resource for Sustainable Agriculture and Its Environmental Implications. Am J Plant Sci 3: 1708–1721.

VERMICO. 2013. Journal Publishes Study of Worms Reducing Human Pathogens in Biosolids. Retrieved on 17 Jan 2017 from http://www.vermico.com/journal-publishes-study-of-worms-reducing-humanpathogens-in-biosolids/

[WHO] World Health Organization. 1989. Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture [Technical Report Series 778]. Geneva.