Research article

Management of Municipal Sewage Sludge by Vermicomposting Technology: Converting a Waste into a Bio fertilizer for Agriculture

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Abstract This paper reports on the feasibility of utilization of vermicomposting technology using the earthworm *Eudrilus eugeniae* for managing municipal sewage sludge by conversion into beneficial bio-fertilizer. Sewage sludge was used at various concentrations 1, 5, 10, 15, 20, and 25% to test for avoidance behavior of the earthworm. The mix of sewage sludge with cassava wastes and cow dung was subjected to compost treatment with and without earthworm treatment for 30 days. During the study period data was collected on the surviving earthworms, biomass together with chemical analysis of wastes before and after treatment. The results indicate that 5% concentration of sludge mixed with cassava waste was ideal for *Eudrilus eugeniae* to treat. There was a decrease in pH, organic carbon concentration, C:N ratio, and an increase in electrical conductivity (EC), nitrogen, potassium and phosphorus concentrations in all the vermireactors. Total Kjeldhal nitrogen (TKN), available phosphorus and potassium concentrations were increased compared to compost without earthworm treatment at 50, 24, and 10% respectively. The heavy metal concentrations (Cr, Cu, Cd, Pb and Hg) in final vermicomposts were lower than in initial feed mixtures. The earthworm biomass was increased 40-90% and could survive 60% from the beginning. Therefore, the present study showed that vermicomposting of municipal sewage sludge into bio-fertilizer is feasible and provides a safe, simple, economic and practical alternative method to resolve the problem of management of sewage sludge.

Keywords waste management, safe fertilizer, agriculture

INTRODUCTION

In Thailand, municipal sewage sludge from domestic wastewater treatment is generated in large quantities, is hazardous and creates problem for safe disposal due to the presence of certain soil contaminants, such as organic compounds, heavy metals, and human pathogens. Sewage sludge generated in huge quantities has led to indiscriminate and inappropriately timed application of untreated sludge to agricultural fields as fertilizer because of its nutrient content, especially nitrogen and phosphorus. The problem of sludge disposal and management exists in other developing countries and probably prevails also in other parts of the world. Indiscriminate disposal of sewage sludge on agricultural fields induces soil and plant toxicity and creates depressive effects on the metabolism of soil microorganisms by drastically modifying physico-chemical and biological environments of soil. Therefore it is absolutely essential for sewage sludge to undergo additional stabilization treatment prior to agricultural use (Hait and Tare, 2011).

The organic matter and high nutrient contents of municipal sewage sludge have promoted its application to agricultural land as an organic fertilizer. However, heavy metals in domestic and industrial wastewater are concentrated in sewage sludge at high levels with the total content ranging from 0.5 to 2% on a dry weight basis and at 6% in extreme conditions (Gupta and Garg, 2008). Therefore, concerns for the safe application of sewage sludge are mainly focus on the heavy metal contamination that can arise. Copper and cadmium often have high concentrations in sewage sludge and may affect the health of people and animals through the food chain if sludge is applied improperly. Methods for decreasing the contents and bioavailability of these elements in sewage sludge are worthy of research. Unlike organic compounds, metals cannot be degraded (Lasat, 2000). To decrease the contents and bioavailability of heavy metals usually requires their removal. Such an approach can be prohibitively expensive. Also, the metal removing process often employs stringent physicochemical agents, which can dramatically inhibit soil fertility with subsequent negative impacts on the ecosystem. Another method is to use chemical immobilization amendments to reduce metal bioavailability. The addition of chemical immobilization amendments may only immobilize lethal levels for restricted periods of time and introduce other harmful chemicals. Phytoremediation is recognized as the most commercially and environmental friendly technology available (Lasat, 2000), but up to now, only a limited number of plants have been found to have the phytoaccumulation ability and much less can be used for field phytoremediation because of low biomass production. There is a need for ecologically as well as economically sustainable technologies which enable recovery of recyclable constituents from sewage sludge as it is rich in nutrients and has high organic matter content. Vermicompost technology is ecologically and economically sustainable and has been widely used for processing of sewage sludge over the years (Sinha et al., 2010). Therefore, this study aimed to assess the feasibility of utilization of vermicomposting technology by using the earthworm (*Eudrilus eugeniae*) for ameliorating the municipal sewage sludge by conversion into beneficial bio fertilizer.

METHODOLOGY

Earthworms and substrate: Earthworms, *Eudrilus eugeniae*, were randomly obtained from stock cultures maintained in the earthworm culture laboratory at Khon Kaen University. Stock earthworms were cultured in the laboratory on partially decomposed cow dung mixed with cassava waste. Sewage sludge with approximate water content of 75-85% was taken directly from the Si-Phaya Wastewater Treatment Plant in Bangkok, Thailand. The sludge was shade dried in the laboratory to remove excess water. The chemical characteristics of the sewage sludge and bulking materials are shown in Table 1.

A study of the toxicity of sewage sludge on the survival of earthworms: The study of the toxicity of sewage sludge on the avoidance behavior of earthworm was performed with different concentrations of sewage sludge at 1, 5, 10, 15, 20 and 25% using 10 earthworms in a plastic containers containing 100 g of (dry weight basis) substrate material; avoidance behaviour of earthworms was observed every day.

A study of the survival and the growth of earthworms affected by sewage sludge mixed with cassava industrial wastes: This study included 4 sub-experiments; 1. Vermicompost mixed with cassava pulp 2. Vermicompost+ 5% sewage sludge mixed with cassava pulp 3. Vermicompost with cassava peel 4. Vermicompost + 5 % sewage sludge mixed with cassava peel. This experiment used a “Completely Randomized Design” (CRD) with three replications. Ten earthworms were released into plastic pot containers containing 100 g (dry weight basis). The weight of earthworms was recorded before and after 30 days. After 7 days, the survival rate of earthworm was measured. Cassava waste was chosen in this study because cassava industry is main industry in this area and produces a considerable amount of waste per day.

Vermicomposting process

Experiment design: The vermicompost (VCP) (with earthworm) and compost (without earthworm) experiment was conducted in plastic buckets (35 cm diameter and 40 cm depth) and used cassava pulp, cassava peel and 5% sewage sludge in the process. The experimental design was CRD with 3 replications with the mixture at a rate of 75%: 25% (cassava industrial wastes: soil mixture). The 25% in soil mixture was composed of Nampong soil and cow manure. The moisture content in the mixture was adjusted to 70-80% of WHC (Water Holding Capacity) by water and 10 earthworms/1 kg were added to the mixed material which was covered with a dark net to prevent earthworm escape and direct exposure to light (Wang et al., 2012). The time of study were 0 and 30 days at room temperature between 28±2 ^{O}C

Chemical analysis: The weight of the system and chemical parameters of substrate were measured in all treatments before introducing earthworms and after vermicomposting for 30 days. The earthworms were separated by hand at the end of the period. The growth rate of composting earthworms in this system was then analyzed according to the method described by Suthar (2009).

(1) Analysis of sewage sludge and earthworms; A total of 40 g compost and vermicompost was collected from each container using multi-point sampling at random. The samples were homogenized, dried at 40°C in a ventilated oven, and then passed through 100-mesh sieves after grinding into small pieces. The pH of compost (CP) and vermicomposting (VCP) was measured using a digital pH meter in 1/2.5 (w/v) deionized water. Total organic carbon was determined by the partial-oxidation method (Walkley and Black, 1934). Total N (total nitrogen) was measured by the micro Kjeldahl method (Jackson, 1973; Bremner and Mlvaney, 1982). Total P (TP) was determined by digestion with acid (HNO_3: H_2SO_4:$HClO_4$ (5:2:1). The sample used 1:10 mixed acid (w/v). Water-soluble P (WSP) was measured in Deionized water extraction ratio VCP and CP 1:25 (W/V) and shaken for 2 hours. Exchangeable phosphorous (Exch. P) was determined using the Bray II extraction method (Schroth et al., 2003). The totals from P solutions were determined using the ascorbic acid molybdenum blue method by UV spectrophotometer (Murphy and Riley, 1962).

(2) Heavy Metal Analysis; Total heavy metals (Cr, Cu, Cd, Pb and Hg) concentrations were determined by the HF-HNO_3-$HClO_4$ digestion method and HNO_3-H_2SO_4 digestion method, respectively. The heavy metals were extracted using the diethylene-triaminepentaacetic acid (DTPA) extraction method. The heavy metal concentrations of all extracts were determined by atomic absorption spectrophotometry (AAS). About 20 g of initial earthworms in stock cultures and final earthworms at each treatment with equal weight were separated from containers and then kept in culture dishes in the dark for two days to empty their gut content, after which they were washed in distilled water to remove excess material from their bodies. Next, the earthworms were sacrificed by freezing and dried at 105 °C for 24 hours in a ventilated oven. Prior to analysis, the earthworms were cooled to room temperature, then ground and passed through a 20-mesh sieve. The metals concentrations (Cr, Cu, Cd, Pb and Hg) in earthworm tissue from different treatment groups were analyzed using the same method as described for sludge metal contents.

Statistical Analysis: One-way ANOVA was used to analyze the significant differences among different vermicomposters for studied parameters. Tukey's test was performed to identify the homogeneous type of vermicomposters for the various parameters. The probability levels used for statistical significance of tests were $p < 0.05$.

RESULTS AND DISCUSSION

Sewage sludge had negative impact on earthworm. Avoidance behavior of the earthworm *Eudrillus eugeniae* (% avoidance) when exposed to different concentrations of sewage sludge was showed in Table 2. However, when mixed sewage sludge with cassava waste, earthworms could survive in vermicompost at 5% sewage sludge and also increased weight. After 30 days, vermicompost with cassava pulp could increase nutrients and reduce Cr, Cu, Pb and Hg concentrations in sewage sludge by 2.31, 14.03, 1.80 and 33.75% , respectively and vermicompost with cassava peel could reduce Cu and Hg by 34.270 and 14.504%, respectively. The results are shown in Tables 1-6.

Cassava peel could help to reduce heavy metal by addition to vermicomposting and was better than cassava pulp. Vermicomposting resulted increase in total N (TN), total P (TP) and total K (TK) as compared to the initial compost material depending on different bulk material. The study showed that the vermicomposting significantly improved the availability of nutrients in sewage sludge. Moreover, vermicomposting considerably reduced the availability of heavy metal presumably by forming organic-bound complexes. The environmental conditions and characteristics of each material in general showed significant effect on the transformation and availability of nutrients and heavy metals (Hait and Tare, 2012). Cassava pulp is acidic with low electrical conductivity (EC) and is distinct from Cassava peel which has higher pH and EC (Table 1) and cow dung had both high pH and EC together with high available-P (Table 1).

Table 1 Physico-chemical characteristics of primary sewage sludge and bulking material for vermicompost

Material	pH	EC (μS/cm)	Avail-P (%)
Cassava pulp	4.21 ± 0.11	328.33 ± 22.30	0.002 ± 0.00
Cassava peel	6.72 ± 0.08	666 ± 26.66	0.010 ± 0.00
Soil	7.76 ± 0.03	543.33 ± 7.57	0.002 ± 0.00
Cow Dung	8.09 ± 0.12	5263.33 ± 234.59	0.033 ± 0.00
Sludge 100%	6.13 ± 0.03	1446 ± 44.51	0.020 ± 0.00
Sludge 5%	6.81 ± 0.06	553 ± 95.82	0.011 ± 0.00

Material	TP (%)	TN (%)	OM (%)	K (%)
Cassava pulp	0.083 ± 0.001	0.205 ± 0.008	70.072 ± 3.50	0.174 ± 0.006
Cassava peel	0.208 ± 0.006	0.133 ± 0.016	8.552 ± 0.45	0.213 ± 0.006
Soil	0.034 ± 0.002	0.044 ± 0.002	0.585 ± 0.07	0.038 ± 0.000
Cow dung	0.080 ± 0.001	0.927 ± 0.012	32.092 ± 3.90	1.719 ± 0.081
Sludge 100%	0.191 ± 0.001	2.710 ± 0.020	26.908 ± 0.95	0.088 ± 0.000
Sludge 5%	0.044 ± 0.003	0.119 ± 0.007	1.713 ± 1.31	0.048 ± 0.003

Table 2 Avoidance behavior of earthworm, *Eudrillus eugeniae* (% avoidance) exposed to different concentrations of sewage sludge

Concentration of sewage sludge (%)	% Avoidance of *Eudrillus eugeniae*
1	20
5	100
10	100
15	100
20	100
25	100

Table 3 Earthworm weight in different vermicomposting treatments

Treatment	Earthworm weight (g/earthworm)		
	0 day(g)	30 day(g)	Increased weight (%)
Vermicompost + cassava pulp	0.413	0.000	0.00
Vermicompost + cassava pulp +5% sludge	0.499	0.765	34.76
Vermicompost + cassava peel	0.433	0.475	8.83
Vermicompost + cassava peel +5% sludge	0.482	9.005	94.65

Table 4 Earthworm survival in different vermicompost treatments

Treatment	% survival
Vermicompost + cassava pulp	100
Vermicompost + cassava pulp +5% sludge	98
Vermicompost + cassava peel	96
Vermicompost + cassava peel +5% sludge	100

Table 5 Physico-chemical characteristics of initial waste mixtures, compost and vermicompost obtained from different vermicomposters (g/kg) by earthworm after 30 days

Treatment	pH			EC (μS/cm)		
	Initial 0 day	CP* 30 day	VCP** 30 day	Initial 0 day	CP* 30 day	VCP** 30 day
Vermicompost + cassava pulp	8.06 B	8.91 B	9.26 A	1712.67 A	2660.00 A	2019.00 D
Vermicompost + cassava pulp +5% sludge	8.31 A	9.06 A	8.96 B	1446.00 C	2666.67 A	2630.00 B
Vermicompost + cassava peel	8.07 B	8.38 C	7.62 D	1434.33 C	2306.67 B	2830.00 A
Vermicompost + cassava peel +5% sludge	8.00 B	8.12 D	7.79 C	1598.33 B	2280.00 B	2176.67 C

Treatment	TN (%)			OM (%)		
	Initial 0 day	CP* 30 day	VCP** 30 day	Initial 0 day	CP* 30 day	VCP** 30 day
Vermicompost + cassava pulp	0.160 C	0.310 B	0.210 D	12.872 A	21.148 A	6.219 C
Vermicompost + cassava pulp +5% sludge	0.351 A	0.524 A	0.343 B	14.016 A	17.364 AB	12.835 B
Vermicompost + cassava peel	0.136 D	0.206 C	0.261 C	9.590 BC	5.740 D	6.193 C
Vermicompost + cassava peel +5% sludge	0.207 B	0.300 B	0.594 A	7.974 C	5.934 D	11.814 B

Treatment	Avail-P (%)			TP (%)		
	Initial 0 day	CP* 30 day	VCP** 30 day	Initial 0 day	CP* 30 day	VCP** 30 day
Vermicompost + cassava pulp	0.012 D	0.023 A	0.018 C	0.015 B	0.575 D	0.496 C
Vermicompost + cassava pulp +5% sludge	0.017 A	0.023 A	0.024 B	0.036 A	0.978 A	0.819 A
Vermicompost + cassava peel	0.016 B	0.002 C	0.015 D	0.009 C	0.590 C	0.497 C
Vermicompost + cassava peel +5% sludge	0.015 C	0.019 B	0.025 A	0.034 A	0.699 B	0.785 B

Treatment	K (%)		
	Initial 0 day	CP* 30 day	VCP** 30 day
Vermicompost + cassava pulp	0.375 B	0.426 B	0.396 C
Vermicompost + cassava pulp +5% sludge	0.411 A	0.541 A	0.524 A
Vermicompost + cassava peel	0.304 C	0.280 C	0.332 D
Vermicompost + cassava peel +5% sludge	0.280 D	0.401 B	0.449 B

**CP = Compost without earthworm **VCP = Vermicompost with earthworm*
Mean values followed by different letters in the same column are statistically different (ANOVA; Tukey's test, $p < 0.05$)

Table 6 Heavy metal concentration (mg/kg) in initial sewage sludge and compost, vermicompost and earthworm after 30 days

Heavy metal	Heavy metal in initial sewage sludge (mg/kg)	[2/]S1		[2/]S2		[2/] Earthworm	
		CP*	VCP**	CP*	VCP**	S1	S2
Cr	73.533	9.736	9.516	9.680	5.237	2.051	2.351
Cu	667.628	40.242	35.290	36.798	27.406	7.746	4.815
Cd	1.189	0.088	0.108	0.079	0.086	0.172	0.172
Pb	113.904	11.249	11.050	7.724	7.884	2.351	1.786
Hg	4.450	0.321	0.240	0.150	0.131	0.038	0.048

**CP = Compost without earthworm **VCP = Vermicompost with earthworm*
S1= Vermicompost with cassava pulp *+5% sludge*. *S2=* Vermicompost with cassava peel *+5% sludge*
[1/]Test method*: In house method based on EPA 3052* [2/] *Manual on Fertilizer Analysis, APSRDO.DOA; 4/2551*

CONCLUSION

This study indicates that sewage sludge at 5% could be managed by earthworm treatment through vermicompost technology, which could be a potential technology to convert toxic organic waste into nutrient rich biofertilizer. The feasibility of using earthworms to mitigate the metal toxicity and to enhance the nutrient profile in sludge might be useful to improve the sustainability of land restoration practices on a low-input basis.

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