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Effect of vermicomposting on concentration and speciation of heavy metals in sewage sludge with additive materials

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HIGHLIGHTS

- Vermicomposting with additive materials could accelerate stabilization of sludge.
- Total content of all heavy metals significantly reduced.
- Earthworm activity sequestered heavy metals during vermicomposting.
- Additive materials strongly affect heavy metal behaviors.

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ABSTRACT

The aim of this work was to evaluate the total content and speciation of heavy metals (As, Cr, Cd, Cu, Fe, Mn, Ni, Pb and Zn) during vermicomposting of sewage sludge by *Eisenia fetida* earthworm with different additive materials (soil, straw, fly ash and sawdust). Results showed that the pH, total organic carbon were reduced, while the electric conductivity and germination index increased after a combined composting – vermicomposting process. The addition of bulking agents accelerated the stabilization of sludge and eliminated its toxicity. The total heavy metals after vermicomposting in 10 scenarios were lowered as compared with the initial values and the control without amendment. BCR sequential extraction indicated that vermicomposting significantly decreased the mobility of all heavy metals by increasing the residual fractions. The activity of earthworms and appropriate addition of amendment materials played a positive role in sequestering heavy metals during the treatment of sewage sludge.

1. Introduction

Municipal wastewater treatment plants have produced significant amount of sewage sludge, land application is one of the most promising methods for handling with the dewatered sludge. However, the presence of organic and inorganic hazardous substances, including pathogenic organisms and heavy metals in sludge, can be harmful to the environment (Villar et al., 2016). Vermicomposting is a bio-chemical degradation process of organic materials (Fu et al., 2015), with the joint action of earthworm and microorganism under aerobic condition, most of the organic components can be effectively converted into valuable products, riching in nitrogen, phosphorus, potassium and humic substances (Lv et al., 2016).

Many studies focused on vermicomposting with different organic wastes, such like cattle dung (Lv et al., 2016), plant waste (Singh and Kalamdhad, 2013), municipal solid waste (Soobhany et al., 2015), and sewage sludge (Wang et al., 2013b; Zhao et al., 2010). For obtaining optimal earthworm activities, organic materials should be bearing physical-chemical properties, such as pH (5–8), moisture content (40–55%) and C/N ratio (around 30), at acceptable range (Lim et al., 2016). Hence, suitable organic waste or amendments is crucial to ensure a successful vermicomposting process. During vermicomposting, various bulking agents are used as amendment materials. Cow dung is the most commonly used for it is easier for earthworms to grow in (Lim et al., 2016); plant waste like soybean husk (Lim et al., 2011) and rice husk (Lim et al., 2012) could also be adopted in some instances; organic wastes with low carbon content can be mixed with lignocellulosic materials to improve the C/N ratio (Castillo et al., 2013); fly ash can also be used for further stabilization purposes (Wang et al., 2013a).

One crucial problem for the reuse of sewage sludge lies on its heavy metal content and transformation. The heavy metal behaviors during vermicomposting should not be neglected. Some research found a reduction of heavy metal contents after vermi-

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composting (Singh and Kalamdhad, 2013; Suthar et al., 2014), which was probably due to the bio-accumulation of heavy metals by the earworm tissues; on the contrary, a clearly higher total content was observed in some studies (Lv et al., 2016; Maňáková et al., 2014), which might be caused by the decreased volume of vermicompost. The determination of total heavy metal content variation do helped giving an overall pollution index, however, it's not useful for providing the risk of bio-availability, namely, the speciation. It is believed that the water soluble or exchangeable fraction of heavy metals is the most risky to plants and human being (Paré et al.). Sequential chemical extraction can be adopted to investigate the speciation of heavy metals during vermicomposting. As most studies focused on this topic reported, vermicomposting significantly reduced the exchangeable fraction of initial raw materials, greatly sequestered the water soluble ions and transformed them into the residual fraction (Lv et al., 2016; Singh and Kalamdhad, 2012, 2013). The mechanism for this sequestration was due to mineralization and humification effect of earthworms and microorganisms brought the heavy metals to an inert fraction. Notably, of all heavy metal speciation studied, the organic wastes used were either cow dung or green waste, and the heavy metal pollution caused by sewage sludge is much more severe than by these substances. Therefore, the speciation behavior of sewage sludge during vermicomposting should be drawing much more attention to.

There is very limited literature available on the mobility and speciation of heavy metals during vermicomposting of sewage sludge, which is the key factor for application of sewage sludge as a vermicompost. Therefore, the objectives of this study were to evaluate the total content and speciation of heavy metals (As, Cr, Cd, Cu, Fe, Mn, Ni, Pb and Zn) during vermicomposting adopting the sequential extraction method. Also, the impact of different additive materials (soil, straw, fly ash and sawdust) on the variation of heavy metal content, as well as the sequestration effect of vermicomposting, was investigated.

2. Material and methods

2.1. Substrates and earthworm

The sewage sludge was collected from the 2nd municipal wastewater treatment plant in Changsha city (Hunan province, China), which adopted the A^2/O biological procedure for wastewater treatment. The sludge collected was dewatered in the treatment plant. The sludge was firstly pre-composted for 15 days in the laboratory, applying the forced aeration. At the end of pre-composting, the temperature of the composting mass reached to below 35 °C. The sludge was removed from the reactor, mixed with different additive materials (soil, straw, fly ash and sawdust). The composition of materials in 10 different scenarios was shown in Table 1, where S5 was set as control with no amendment. Heavy metal content of different raw materials was shown in Table S1.

Table 1
Composition of vermicomposting materials in different scenarios.

Sample	Composition (g)				
	Sawdust	Fly ash	Straw	Soil	Pre-composted sludge
S1	6	20	2	12	160
S2	6	20	2	2	170
S3	6	0	2	32	160
S4	6	0	0	34	160
S5	0	0	0	0	200
S6	6	20	0	14	160
S7	6	20	0	4	170
S8	0	20	0	20	160
S9	0	20	0	10	170
S10	0	30	0	0	170

The earthworm species *Eisenia fetida* was used for the vermicomposting as adopted in many other researches (Kaur et al., 2010; Singh et al., 2010; Vig et al., 2011). *Eisenia fetida* exerted high tolerance toward toxic substances in sewage sludge, as well as high stabilization efficiency in the process (Duan et al., 2016). The earthworms used were bought from a earthworm farm in Yiyang, China, with an average weight of 0.05 g and the average length of 3.26 cm. In order to avoid the damaging effect of toxic substances, the earthworms were firstly allowed for a domestication procedure for 15 days. The earthworms were initially put in upland soil collected from Yuelu Mountain, Changsha. Soil was collected from 0 to 20 cm depth, dried and passed through a 2 mm sieve. The sludge was gradually added into the domestication container, as the sludge:soil ratio reached 3:1.

2.2. Vermicomposting experimental design

Vermicomposting was carried out in rectangular culture containers of 1 L capacity each. 200 g sludge mixtures for each scenario was filled in the container, an optimal of 1.60 kg worms/m^2 was adopted as worm stocking density, as previously studied by (Ndegwa et al., 2000). The bedding mixtures in all scenarios were moistened with distilled water to maintain the moisture content in their original range (as shown in Table 2). A plastic mesh blanket was covered on the top of each container to avoid sunlight and the escape of worms (Lv et al., 2016). The same series of each scenario without earthworms were kept under the same procedure and designated as control.

The vermicomposting container were kept in room temperature and in shadowed shelves for 25 days, as evidence showed that earthworms begin to discharge heavy metals into their surroundings within the interval of 10–15 weeks (Azizi et al., 2013; Malińska et al., 2016; Villar et al., 2016). After incubation, the samples were placed in sealed plastic bags and stored at 4 °C for further analysis.

2.3. Physical-chemical analysis

In order to analyze the water extractable substances in the samples, 10 g of sample (40 °C oven dried for 24 h) from each scenario was mixed with 100 mL of deionized water, and allowed to reach equilibrium at 25 ± 1 °C in a reciprocating shaker for 2 h, which was proven to be sufficient for the procedure (Yang et al., 2014). The solution and solid phase were then separated by centrifugation at 3000 rpm for 20 min, and filtered through a 0.45 μm membrane. The pH and EC (electrical conductivity) values were measured by pH meter and conductivity meter, respectively. TOC content was measured by the loss on ignition with samples oven dried for 4 h at 550 °C. Seed germination of *Lepidium sativum* was determined by growing in 4 mL of the aqueous extracts mentioned above in petri dishes for 48 h for calculating the germination index (GI) as according to (Villar et al., 2016). The properties of samples before and after vermicomposting were listed in Table 2.

Modified BCR sequential extraction procedure was adopted for measuring heavy metals (As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in all scenarios before and after vermicomposting (Nemati et al., 2011). The extractable, reducible, oxidable, residual fraction of heavy metals in each scenario were sequentially extracted, which were afterward determined by inductively coupled plasma optical emission spectroscopy (ICP-OES) method using an IRIS Intrepid II XSP Spectrometer (ThermoFisher, USA). All samples were measured in triplicate.