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Alleviation of heavy metal phytotoxicity in sewage sludge by vermicomposting with additive urban plant litter

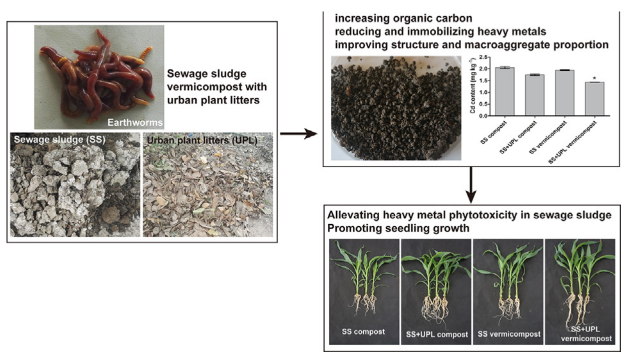
Daoming Wu [a], Xiaoli Yu [b], Shuangshuang Chu [a], Douglass F. Jacobs [c], Xiaohua Wei [d], Cai Wang [a], Fengling Long [a], Xiaoyang Chen [a], Shucai Zeng [a,]*

[a] *College of Forestry & Landscape Architecture, South China Agricultural University, Guangzhou 510642, China*
[b] *School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou 510006, China*
[c] *Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907-2061, USA*
[d] *Earth, Environmental and Geographical Sciences, University of British Columbia (Okanagan Campus), Kelowna, British Columbia V1V1V7, Canada*

HIGHLIGHTS

- The addition of urban plant litter promoted macroaggregate formation in sewage sludge.
- The plant litter and earthworm application reduced the bioavailability of heavy metal.
- The formation of oxidizable heavy metal contributed to their bioaccumulation in earthworms.
- Vermicompost of sludge and *Bauhinia purpurea* litter improved maize seedling growth.

GRAPHICAL ABSTRACT



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ABSTRACT

The handling of sewage sludge (SS) and urban plant litter (UPL) has become an important concern. Immobilizing heavy metals (HMs) is regarded as a necessary process for recycling SS in agriculture and forestry. Here, HM removal and HM phytotoxicity in SS during vermicomposting with different additive UPLs was investigated. The results show that vermicomposting with additive UPL significantly reduced the content of HMs, and increased organic carbon content and the proportion of macroaggregates in SS. This process also significantly immobilized HMs by mainly transforming extractable and reducible HMs into residual products. The litters of *Dracontomelon duperreanum* and *Bauhinia purpurea* increased oxidizable HMs in SS and the accumulation capacity of HMs of earthworms during vermicomposting. The Cd content in vermicomposts with the *B. purpurea* litter addition was decreased by 31% relative to the initial SS. Maize in vermicomposts with UPL additions, especially with *B. purpurea* litter, exhibited significan5tly higher seed germination rates, seedling biomass, root activity, and a lower accumulation of HMs than in SS compost without UPL additions. These results suggest that vermicomposting with additive UPL can alleviate the phytotoxicity of HMs in SS and provides a new method for simultaneously recycling SS and UPL.

Abbreviations: SS, sewage sludge; UPL, urban plant litter; HM, heavy metal; BCR, the European Community Bureau of Reference; AAS, atomic absorption spectrometry; SPAD, soil and plant analyzer development; TTC, triphenyl tetrazolium chloride.

* Corresponding author.
E-mail address: sczeng@scau.edu.cn (S. Zeng).

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1. Introduction

Sewage sludge (SS) and urban plant litter (UPL) production have increased rapidly with increasing urbanization, and their production represents one of the most significant challenges in urban development and environmental management, especially in China (Ministry of Housing and Urban-Rural Development of P. R. China, 2017). Agricultural and forestry applications are among the most available options for SS disposal because SS is rich in organic matter and nutrients (Fytili and Zabaniotou, 2008; Mohamed et al., 2018). However, the accumulation of contaminants (especially heavy metals, HMs) has become a key factor limiting the agricultural application of SS (Verlicchi and Zambello, 2015). A high accumulation of HMs, especially of Cd and Pb in plants can disrupt water and nutrient uptake, decrease chlorophyll, protein content and root activity, lead to reduced yield and quality, and even become a threat to human health after entering the human food chain (Aibibu et al., 2010; Kovacs and Szemmelveisz, 2017). Therefore, immobilizing or removing HMs is very important for recycling SS as a fertilizer or soil amendment (Fytili and Zabaniotou, 2008).

Vermicomposting of SS has been widely used to stabilize HMs in SS (Gogoi et al., 2015; Camargo et al., 2016). Speciation of HMs indicates that vermicomposting significantly decreased the mobility of HMs by transforming water soluble or exchangeable fractions of HMs into residual fractions (Lv et al., 2016; He et al., 2016; Goswami et al., 2016). Unfortunately, SS cannot be independently used in the vermicomposting process, and SS alone will harm earthworm growth due to its low C/N ratio and high salinity and content of HMs (Lim et al., 2016). Hence, to ensure successful vermicomposting of SS, several suitable external materials should be applied to mitigate the toxicity of SS. Recently, many authors reported that vermicomposting with amendment materials, such as cow manure, rice and wheat straw, biochar, fly ash, mushroom substrate waste and sawdust, could effectively reduce HMs in SS (Gogoi et al., 2015; He et al., 2016; Meng et al., 2017; Suleiman et al., 2017). Nevertheless, little is known regarding the effects of UPL on earthworm growth and immobilization of HMs during vermicomposting of SS.

Composting represents an effective method of transforming UPL into organic fertilizer and/or growth medium (Lim et al., 2016). However, traditional litter composting is time consuming and generates low quality products because plant litters are rich in lignocellulose and poor in nutrients (Gabhane et al., 2012). It is anticipated that SS mixed with UPL can provide an optimal material for earthworm activities and thus reduce composting time. In addition, the quality of the vermicomposting product can be increased by the SS amendment. However, plant litter traits (especially chemical) vary among plant species and may also directly affect earthworm activity (Schelfhout et al., 2017). Although several studies have reported the effectiveness of composting and vermicomposting on solid organic waste reclamation (Lazcano et al., 2008; Fornes et al., 2012; Soobhany et al., 2017), there have been very limited studies concerning the impact of different UPL on the variations of aggregate structure and HMs during vermicomposting of SS. Additionally, determining whether vermicomposting of SS with different UPL can generate products with varying physical-chemical characteristics is poorly understood.

Maize is considered an optimal species for the study of HM tolerance due to its fast growth and high HM sensitivity during germination (Deng et al., 2016). In this paper, the aim was to (i) investigate the feasibility of reducing and immobilizing HMs by composting or vermicomposting SS and different UPL; and (ii) analyze the phytotoxicity of different composting products by observing their effects on maize seed germination and subsequent seedling growth.

2. Materials and methods

2.1. Substrates and earthworms

The survival and growth of *Eisenia fetida* fed with leaf litter of different landscape plants was investigated in a preliminary food-choice experiment. The litters of ten common landscape plant species in South China were used as earthworm cultivation media including *Bauhinia purpurea*, *Dracontomelon duperreanum*, *Ficus virens*, *Hibiscus tiliaceus*, *Lagerstroemia speciose*, *Mangifera indica*, *Michelia alba*, *Neolamarckia cadamba*, *Roystonea regia* and *Zoysia japonica*. Subordinate function values in survival rate, cocoon production, net weight gain, relative feeding coefficient and relative activity coefficient followed a descending order by *B. purpurea*, *D. duperreanum*, *N. cadamba*, *Z. japonica*, *F. virens*, *R. regia*, *M. alba*, *H. tiliaceus*, *M. indica*, and *L. speciose* (Table S1). These data from subordinate function analyses indicate that the litters of *B. purpurea*, *D. duperreanum*, and *N. cadamba* were more favorable for *E. fetida* growth than the other UBL. Therefore, the leaf litters of *B. purpurea*, *D. duperreanum* and *N. cadamba* were chosen for further study. The litter of these plants was collected on the campus of South China Agricultural University (23°9′28.8″ N, 113°20′52.8″ E) and then oven dried at 70 °C to a constant weight. The SS was obtained from the Xintang Sewage Treatment Plant in Guangzhou, Guangdong Province, China, where the A^2/O biological procedure was adopted for wastewater treatment. The SS was spread out and air-dried at 28–32 °C for two months. The properties of SS and UPL are shown in Table S2. Adult earthworm *E. fetida*, which is known to bioaccumulate HMs, was used in vermicomposting. Before vermicomposting, the adult earthworms were kept in petri dishes with 10 mL deionized water for 24 h to empty their gut contents. Then, the earthworms of the same size (mean net weight 0.12 ± 0.01 g and mean length 4.02 ± 0.24 cm) were picked for vermicomposting.

2.2. Lab-scale composting and vermicomposting

A lab-scale composting and vermicomposting experiment (designed as shown in Table 1) was performed. The SS (0.5 kg per pot and four replicates for each treatment) with or without UPL was placed in plastic pots (12 cm in diameter and 15 cm in height, no hole in the bottom, and covered with a 0.25 mm sieve), watered to 80% of field capacity and left for two days for equilibration. After equilibration, forty adult worms were released to each pot in T6–T10 treatments. All of the pots were placed in an artificial climate chamber in the dark for 45 days at 25 °C. The moisture content of the mixture was maintained at 65% to 80% of field capacity by daily watering. After vermicomposting, the SS composts and vermicomposts were separated for oven drying at 60 °C for two days and collected for physical-chemical analysis and maize germination and growth tests.

Table 1
Experimental design.

Treatments	Sewage sludge (g)	Leaf litters (species, g)	C/N ratio	Earthworms (number of individual)
Composting				
T1	500	0	11.06	0
T2[a]	450	*Neolamarckia cadamba*, 50	13.40	0
T3	450	*Dracontomelon duperreanum*, 50	13.34	0
T4	450	*Bauhinia purpurea*, 50	12.91	0
T5	450	*Neolamarckia cadamba*: *Bauhinia purpurea*: *Dracontomelon duperreanum* = 1:1:1, 50	13.20	0
Vermicomposting				
T6	500	0	11.06	40
T7	450	*Neolamarckia cadamba*, 50	13.40	40
T8	450	*Dracontomelon duperreanum*, 50	13.34	40
T9	450	*Bauhinia purpurea*, 50	12.91	40
T10	450	*Neolamarckia cadamba*: *Bauhinia purpurea*: *Dracontomelon duperreanum* = 1:1:1, 50	13.20	40

[a] Sewage sludge: litter = 9:1 (W/W); medium mixed with this ratio is suitable for earthworms growth, and ensures more sewage sludge is decomposed by earthworms.