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Speciation of heavy metals during co-composting of sewage sludge with lime

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Abstract

During composting the humification of organic matter will have a significant effect on the physicochemical form of existence of heavy metals. Therefore the present study was conducted to investigate the effect of co-composting sewage sludge with lime on heavy metal speciation and the changes in DTPA extractable metals. Metal speciation was conducted to evaluate the redistribution of Cu, Mn, Ni, Pb and Zn in sewage sludge composted with lime. Sewage sludge was mixed with sawdust in 2:1 (w/w fresh weight) and then composted with lime at 0%, 0.63%, 1% or 1.63% (dry weight) for 100 days. The lime addition did not cause any changes in the different forms of Cu and Mn, but the composting process caused transformations of residual form of Cu and Mn into oxidizable and reducible form, respectively. For Ni, the reducible form was mainly transformed into residual form and lime addition decreased this transformation. Major transformation of different forms of Pb was not found, however the residual form of Pb increased with lime addition. The predominant residual form of Zn was mainly transformed into oxidizable form and the lime addition reduced this transformation. Addition of lime to sewage sludge during composting resulted in lower DTPA extractable metal contents. Therefore, lime is a suitable material to co-compost with sewage sludge to reduce the availability of heavy metals.

Keywords: Co-composting; DTPA extraction; Heavy metals; Sequential extraction; Sewage sludge; Lime

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1. Introduction

Composting followed by land application represents one of the most economical ways for the treatment and final disposal of sewage sludge because it combines material recycling and sludge disposal at the same time (Fang et al., 1999). Unfortunately, the presence of high levels of heavy metals often hinders agricultural land application of the composted sludge. The total heavy metal content in sewage sludge is about 0.5–2% on a dry weight basis (Wong and Henry, 1988), and in some cases, about 4% (Tyagi et al., 1991; Jain and Tyagi, 1992). Uptake of heavy metals by plants and subsequent accumulation along the food chain is a potential threat to animal and human health. Consequently, focus on the improvement of the composting process to minimize the mobility of heavy metals using various additives is receiving more attention (Wong et al., 1997; Ho and Qiao, 1998; Fang et al., 1999; Zorpas et al., 2000; Chiang et al., 2001). Lime is considered as one of the common amendment materials to co-compost with

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sewage sludge as it plays a role in heavy metal immobilization.

Assessment of the chemical speciation of heavy metals in composts enables one to evaluate their bioavailability and suitability for land application. Speciation of heavy metal involves the fractionation of its total content into exchangeable, acid extractable (carbonate bound), reducible (Fe–Mn oxides bound), oxidizable (organic bound) and residual forms. The exchangeable and acid extractable fractions are mobile fractions and easily available. The oxidizable and reducible forms will be leached out only under extreme conditions while the residual fraction is almost inert (Shrivastava and Banerjee, 1998). Different methods have been proposed for metal speciation (Tessier and Campbell, 1988) but the method developed by Tessier et al. (1979) is the one widely used for the purpose. Although several authors have studied the speciation of heavy metals in sewage sludge, much less is known about the transformation of metal species during composting. Hence the current study was aimed at evaluating the effect of composting on speciation of Cu, Mn, Ni, Pb and Zn in sewage sludge with lime as a co-composting material.

2. Materials and methods

2.1. Preparation of composting mass

Dewatered anaerobically digested sewage sludge, collected from Tai Po sewage treatment plant was mixed with sawdust as a bulking agent at 2:1 (w/w fresh weight) to obtain a C/N ratio of 30. The sewage sludge–saw dust mixture was then mixed thoroughly with lime (CaO) at 0%, 0.63%, 1.0% or 1.63% (w/w dry weight) using a concrete mixer. All treatments were done in duplicate and for each treatment 18 kg of the mixture was prepared and composted for 100 days in a bench-scale composting system (Fang et al., 1998). Air was supplied to the composting mass at $1\,\mathrm{l\,min^{-1}}$. and the moisture content was maintained between 60% and 70% throughout the composting phase. About 100 g of subsamples was taken periodically from each treatment for analysis.

2.2. Chemical analyses

The moisture content was determined by oven-drying at 105 °C for 24 h; while pH was measured in water extracts at 1:5 sample:deionized water (w/v). Total N and P contents in the compost were determined by Kjeldhal digestion and analysed by the indophenol-blue method for NH_4^+ and molybdenum-blue method for PO_4^{3-}. The total organic carbon was determined by the Walkley–Black titration method (Page et al., 1982). For the diethylene triaminepentaacetic acid–triethanolamine extraction (DTPA–TEA), compost samples of 1:5 (sample:extractant w/v) were shaken at 200 rpm for 2 h and centrifuged at 8000*g* for 5 min. After filtration, the supernatants were stored in polyethylene bottles before analysis. Selected chemical characteristics of the sewage sludge and sawdust used in this study are presented in Table 1.

2.3. Sequential extraction

The conventional method of Tessier et al. (1979) was used for the sequential extraction. The extraction was carried out in polypropylene centrifuge tubes of 50 ml capacity with an initial mass of 2.5 g oven dried (105 °C) fine fraction (<1 mm) of the samples. The following steps were adopted: (1) Exchangeable: 2.5 g of sample was extracted with 25 ml of 1 M $MgCl_2$ at pH 7.0 with agitation at 220 rpm for 1 h at 25 °C. (2) Acid extractable: Residue from (1) was extracted with 25 ml of 1 M NaOAc at pH 5.0 with agitation for 5 h at 25 °C. (3) Reducible: Residue from (2) was extracted with 25 ml of 0.1 M ($NH_2OH \cdot HCl$) in 25% acetic acid (v/v) for 6 h at 96 °C in a water bath with agitation. (4) Oxidizable: To the residue from (3), 5 ml of 30%, H_2O_2 at pH 2.0 was added at 30 min interval to prevent foaming (Gupta and Chen, 1975). The mixture was heated to 85 °C for 5 h, and after cooling, 2 ml of 3 M NH_4OAc in 20% HNO_3 (v/v) was added with

Table 1
Selected chemical properties of sewage sludge and saw dust

Parameter	Sewage sludge	Saw dust
pH	7.33 (0.10)[a]	5.55 (0.07)
EC ($\mathrm{dS\,m^{-1}}$)	1.82 (0.10)	0.02 (0.00)
Moisture content (%)	80.2 (1.00)	8.12 (0.35)
Total organic carbon (% of dry weight)	32.6 (1.21)	46.5 (2.78)
Total N (% of dry weight)	6.20 (0.14)	0.00 (0.00)
Total P (% of dry weight)	2.00 (0.18)	0.06 (0.002)
Total heavy metals (mg kg^{-1})		
Cu	112 (2.5)	2.13 (0.008)
Mn	110 (1.2)	<1.0
Ni	44.5 (0.2)	<1.0
Pb	52.5 (3.0)	<1.0
Zn	1009 (23)	9.27 (0.27)
DTPA–TEA extractable metals (mg kg^{-1})		
Cu	28.9 (0.72)	NA
Mn	23.6 (0.37)	NA
Ni	4.39 (0.07)	NA
Pb	18.5 (0.12)	NA
Zn	283 (4.65)	NA

NA-Not analyzed.

[a] Values in parentheses are standard deviation of the means ($n = 3$).