

Immobilization of cadmium and lead in biosolids as affected by lime, red mud, fly ash and bentonite addition

Thammared Chuasavathi^{A,B}, Nanthi S. Bolan^B and Ravi Naidu^{A,B}

^ACRC CARE, University of South Australia, Mawson Lakes, SA, Australia, Email Thammared.Chuasavathi@postgrads.unisa.edu

^BCentre for Environmental Risk Assessment and Remediation, University of South Australia, Mawson Lakes, SA, Australia, Email Nanthi.Bolan@unisa.edu.au

Abstract

Biosolid samples from the Bolivar Wastewater Treatment Plant (South Australia) were blended with lime (1%, 3% and 5%; w/w basis), red mud, fly ash and bentonite (5%, 10% and 20%; w/w basis) and incubated under aerobic condition at room temperature for seven months to examine the effects of various additives on: (i) the redistribution of metals in the biosolids and (ii) the mobilization of metals and their subsequent release to pore water. Both the NH_4NO_3 extractable concentration of Cd (Cd_{NN}) and Pb (Pb_{NN}) from biosolids and the concentration of these metals in pore water was lower in all amendments than biosolid alone. The effect of amendments on the immobilization of biosolid-derived Cd and Pb varied with both the nature and level of amendments addition. The immobilization of Cd and Pb in biosolids and pore water increased with increasing level of amendment addition and red mud was most efficient in the immobilization of Cd and Pb. For example, red mud at the highest rate of application decreased Cd_{NN} and Pb_{NN} from 1.73 and 11.018 $\mu\text{g}/\text{kg}$ (biosolid alone) to 0.24 and 1.12 $\mu\text{g}/\text{kg}$, respectively. It decreased the pore water concentration of these metals from 8.88 and 4.82 $\mu\text{g}/\text{L}$ (biosolid alone) to 1.34 and 1.68 $\mu\text{g}/\text{L}$, respectively.

Key Words

Biosolids, heavy metal, lime, red mud, fly ash, bentonite.

Introduction

Millions of tons of biosolids are generated worldwide every year. As an option of disposal, application of biosolids to land has been proved to be quite effective, especially in reviving degraded soils and also as a cost effective soil amendment for growing agricultural crops. Biosolids possess an abundant supply of nutrients and organic matter that improve soil chemical, physical and biological properties. However, biosolids can cause some environmental risk because they are usually a potential source of heavy metals when applied to soil. Thus, there is a need to develop suitable treatment methods for biosolids to overcome this problem. One effective approach might be co-composting of biosolids with other waste resources, such as lime, red mud, fly ash and bentonite, which can immobilize heavy metals, thereby reducing their mobility and bioavailability. The overall objective is to produce co-additive products by mixing biosolids with other waste by-products that are effective in the immobilization of heavy metals and to compare the effectiveness of various co-compost blends on the immobilization of metals in biosolids.

Methods

The immobilization of Cd and Pb in biosolid amended with lime, red mud, coal fly ash and bentonite (Table 1) was investigated in laboratory incubation experiments. Biosolid samples from the Bolivar Wastewater Treatment Plant in South Australia were used for this study. Two incubation experiments were conducted; one to examine the effect of various additives on the redistribution of metals in the biosolids and the other to examine the effect of these additives on the mobilization of metals and their subsequent release to pore water. The experimental treatments were comprised of control (only biosolid without any additive), addition of lime (1%, 3% and 5%; w/w basis), red mud, fly ash and bentonite (5%, 10% and 20%; w/w basis). All treatments were duplicated and incubated under aerobic condition at room temperature for seven months. Pore water samples were collected at 0, 1, 2, 3, 5 and 7 months of incubation using a rhizon extraction technique. The concentration of heavy metals in the pore water samples was measured to examine the solubility and mobility of metals. Similarly, biosolid subsamples were taken at various intervals to monitor the redistribution of metals and these samples were analyzed for pH (1:5 biosolid: water), dissolved organic carbon (DOC) and 1M NH_4NO_3 extractable Cd and Pb.

Table 1. Some chemical characteristics of biosolids and other by-products.

Material	pH	EC ($\mu\text{s}/\text{cm}$)	OM (%)	N (%)	P (-----mg/kg-----)	K (-----mg/kg-----)	Cd (-----mg/kg-----)	Cu (-----mg/kg-----)	Pb (-----mg/kg-----)
Biosolids	6.64	8680	43.4	0.85	800	2285	1.23	359.6	51.6
Lime	8.73	420	-	-	-	-	0.03	4.21	2.34
Red mud	9.1	13750	-	-	-	-	0.14	10.1	44.0
Fly ash	9.86	1360	0.01	0.02	272	530	0.24	74.9	46.1
Bentonite	7.2	897	-	-	-	-	0.18	6.9	46.3

Results

The NH_4NO_3 extractable concentration of Cd (Cd_{NN}), which represents bioavailable Cd was lower in all amendments than biosolid alone. The effect of amendments on the immobilization of Cd present in biosolids varied with both the nature and level of amendments addition. The Cd_{NN} concentration decreased with increasing level of amendment addition, indicating that immobilization of Cd increased with application rate. For example, at the highest rate of application, red mud, lime, fly ash and bentonite in biosolid sub-samples decreased the Cd_{NN} concentration from 1.73 $\mu\text{g}/\text{kg}$ (biosolid alone) to 0.24, 0.65, 0.67 and 0.59 $\mu\text{g}/\text{kg}$, respectively (Figure 1), thereby achieving 83.4, 38.1, 53.5, and 59.1% immobilization of bioavailable Cd (Cd_{NN}). In biosolid pore water, at the highest rate of application, red mud, lime, fly ash and bentonite decreased the Cd level from 8.88 $\mu\text{g}/\text{L}$ (biosolid alone) to 1.344, 2.152, 3.065 and 2.036 $\mu\text{g}/\text{L}$, respectively (Figure 2), thereby achieving 81.8, 70.9, 58.6 and 72.5% immobilization of bioavailable Cd.

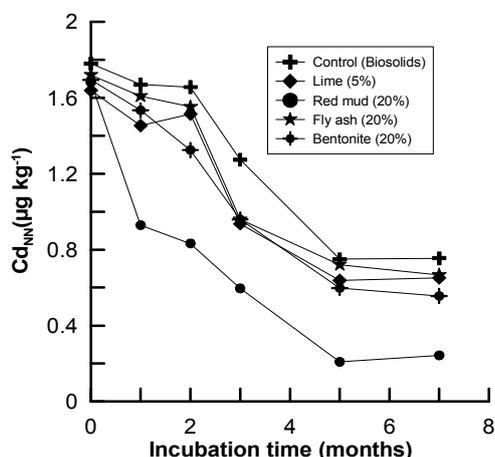


Figure 1. The effect of lime, red mud, flies ash and bentonite on the NH_4NO_3 extractable Cd.

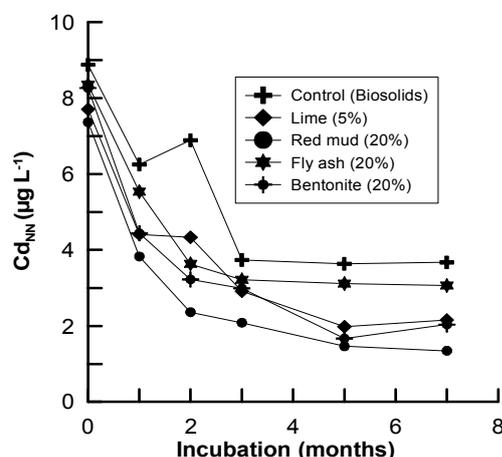


Figure 2. The effect of lime, red mud, fly ash and bentonite on Cd in biosolids in biosolid pore water.

The effect of amendments on biosolid-derived Pb varied with both the nature and level of amendments addition. The immobilization of Pb increased with increasing application rates for all amendments. For example, at the highest rate of application, red mud, lime, fly ash and bentonite in biosolid sub-samples decreased the Pb level from 11.018 $\mu\text{g}/\text{kg}$ (biosolid alone) to 1.118, 1.232, 1.743 and 1.334 $\mu\text{g}/\text{kg}$, respectively (Figure 3), thereby achieving 87.8, 86.6, 81.0 and 85.47% immobilization of bioavailable Pb (Pb_{NN}). In biosolid pore water, at the highest rate of application, red mud, lime, fly ash and bentonite decreased the Pb level from 4.822 $\mu\text{g}/\text{kg}$ (biosolid alone) to 1.804, 2.667, 2.787 and 2.684 $\mu\text{g}/\text{kg}$, respectively (Figure 4), thereby achieving 55.1, 33.6, 30.6, and 33.2% immobilization of bioavailable Pb.

Application of these amendments increased pH of biosolids both in solid phase and pore water, but it decreased the concentration of soluble Cd and Pb in biosolid and pore water. The DOC concentration in the biosolids also decreased with the amendment addition in the solid phase and pore water, except for lime and fly ash. In a separate DOC sorption experiment, it was noticed that red mud sorbed the highest amount of DOC followed by bentonite (Figure 5). The decrease in bioavailable Cd and Pb in biosolids and pore water resulting from co-composting with amendments may be attributed to the increases in pH and decrease in DOC concentration (Figure 6). The pH has a significant controlling effect on the chemical behavior of metals and heavy metal cations are more mobile under acid conditions (Bolan *et al.* 2003a and Merrington *et al.* 2002). The reduction in DOC in biosolids after application of all amendments may be a contributing factor to the availability and mobility of biosolid-borne metals. DOC can mobilize metals by forming strong complexes with metals in biosolid pore water solutions, whereas solid organic matter can immobilize metals (Bolan *et al.* 2003b; Bradl 2004 and Basta *et al.* 2005).

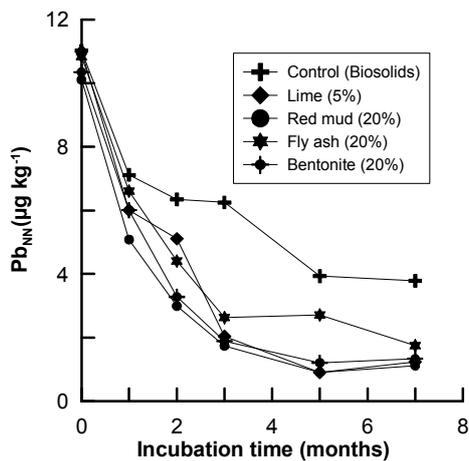


Figure 3. The effect of lime, red mud, flies ash and bentonite on the NH_4NO_3 extractable Pb.

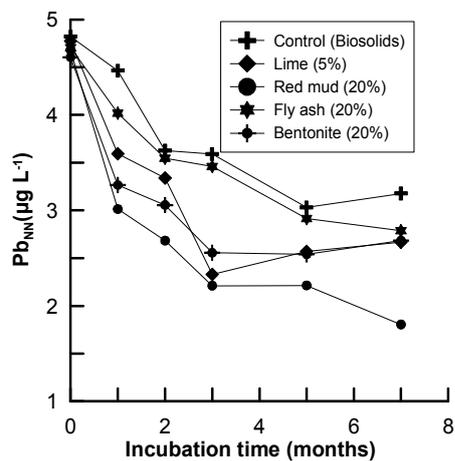


Figure 4. The effect of lime, red mud, fly ash and bentonite on Pb in biosolid pore water in biosolids.

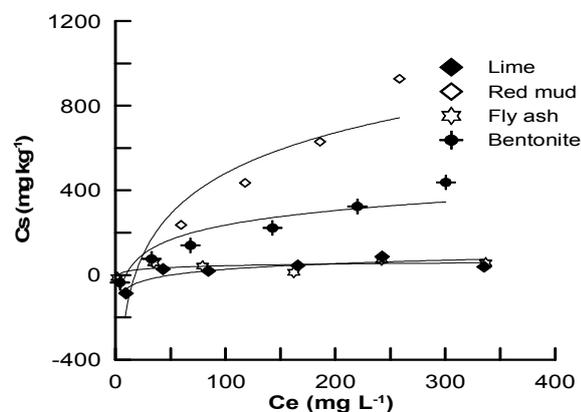


Figure 5. DOC sorption curves for lime, red mud, fly ash and bentonite.

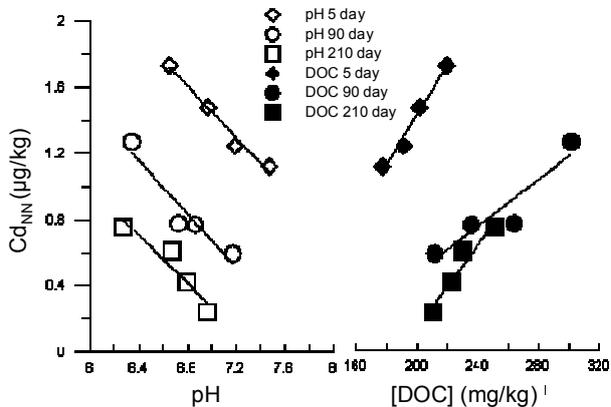


Figure 6. Relationships between pH and NH_4NO_3 extractable Cd (A) and DOC and NH_4NO_3 extractable Cd (B) in biosolid amended with various levels of red mud.

Conclusions

It was found that red mud was more effective than lime, coal fly ash and bentonite in reducing the availability of Cd and Pb. This may be attributed to the high pH and surface reactivity of red mud, thereby resulting in the immobilization of metals. The DOC concentration in biosolids decreased with increasing red mud application, thereby decreasing the DOC-induced mobilization of metals.

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