SOIL LEAD IMMOBILIZATION USING PHOSPHATE ROCK

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Abstract. Phosphate compounds of lead (Pb) are highly insoluble and their formation in contaminated soils would aid immobilization of Pb. The goal of the current research was to evaluate the immobilization of Pb by various treatments of phosphate rock on contaminated agricultural soils typical of Taiwan, and to determine the optimal amount of phosphate rock for use in field application. Samples of contaminated soil, each containing Pb concentrations ranging from 346 to 1873 mg kg⁻¹ were collected from arable land near a ceramic products manufacturing factory. Both batch immobilization experiments and in situ remediation were completed using phosphate rock additives. Results of the batch experiments demonstrate that the phosphate rock was effective in reducing Pb extractable by 0.1 M HCl, with a minimum reduction of 33–97% after 8 days of reaction, for initial Pb concentrations up to 1873 mg kg⁻¹. HCl-extractable Pb did not decrease after an additional 2-day reaction with a greater phosphate rock loading. It was also found that the reaction time had less effect on Pb immobilization than the amount of phosphate rock added. Results from in situ remediation experiments indicate that soil-extractable Pb was reduced by 93% (mean; range 85.2–97.2%), which is comparable with the results of the batch study. Additionally, the soil pH was increased from 6.25 (mean; range 5.96–6.76) to 7.2 (mean; range 6.92–7.53) after remediation. Based upon the HCl-extractable Pb content and the amount of phosphate rock added, various linear log-linear regression curves were obtained. These predictive equations have been used for field application. Our field results demonstrate that phosphate rocks have a potential to cost-effectively treat Pb-contaminated soils in Taiwan.

Keywords: immobilization, Pb-contaminated soil, phosphate rock

1. Introduction

Lead contamination is of great environmental concern due to the effect of lead on human health. Lead concentrations in uncontaminated soils range from 2 to 200 mg kg⁻¹ (Lindsay, 1979). The upper background levels of Pb concentrations in Taiwan’s natural soil average 18 mg kg⁻¹ (0.1 N HCl extractable Pb content) and 50 mg kg⁻¹ (total Pb content) (Chen and Huang, 1992). In Taiwan, a soil is generally considered contaminated with Pb when its total Pb concentration exceeds 100 mg kg⁻¹ according to reports published by the Environmental Protection Administration of Taiwan in 1992. In addition, the cleanup standard for Pb is 120 mg kg⁻¹ on a 0.1 N HCl extractable Pb-content basis (the current EPA-ROC action level for Pb) (EPA-ROC, 2000). It should be noted that several researchers (Chen et al.,
1992; Liu, 1998; Sah, 1998) have reported that the ratio of 0.1 M HCl extractable content to aqua regia content of Pb in their investigated soils in Taiwan ranges from 26.1 to 55.5%. Therefore, the 120 mg kg\(^{-1}\) standard with HCl is about 216–460 mg kg\(^{-1}\) using aqua regia (Lin, 2002).

About 250 ha of agricultural soils contaminated with heavy metals were identified by the Environmental Protection Administration of Taiwan (EPA-ROC) in 2002. Of these soils, the highest Pb contents were up to 11,400 mg kg\(^{-1}\) (0.1 M HCl extractable Pb content) (Liao, 1998). As a result of such severe Pb contamination, considerable attention and resources are being focused on remediating Pb-contaminated soils. According to the Soil and Groundwater Pollution Remediation Act 2001 by EPA-ROC, remediation action is considered when the total soil Pb content exceeds 1000 mg kg\(^{-1}\) (EPA-ROC, 2001). Current technologies for contaminated soil remediation are usually costly and/or cannot permanently prevent the toxic element from entering into the biosphere. Thus, as an alternative remediation technique, \textit{in situ} immobilization of Pb in contaminated soils with phosphate rocks amendments has received a great deal of attention in the past several years (Ma \textit{et al.}, 1995; Zhang \textit{et al.}, 1997). This approach is based on the formation of geochemically stable lead phosphate minerals from the reactions of labile soil-Pb forms with the added solid phosphate minerals such as phosphate rocks. Phosphates of Pb have low solubilities, generally several orders of magnitude less soluble than the analogous carbonates and sulphates. Due to its low water solubility (\(K_{sp} = 10^{-71.6}\)), it is believed that the problems of phosphate leaching and runoff will not be concerned (Ma \textit{et al.}, 1995). Cotter-Howells and Caporn (1996) also indicated treatments with highly soluble P may increase the risk of P-induced eutrophication. Therefore, less soluble P such as phosphate rock may reduce such a risk. The technique for conversion of soil-Pb to the more stable pyromorphite (less bioavailable form) is easily accomplished by addition of phosphate rocks to the soil. This can be accomplished by mixing by cultivation of phosphate chemicals or minerals into soils. Field applications of lead immobilization at contaminated sites using phosphate additives to reduce soil Pb bioavailability and increase long-term stability have been demonstrated by Cao \textit{et al.} (2002) and Eusden \textit{et al.} (2002). Cao and his co-workers showed a long-term stability for lead immobilization, and suggested application of combined H\(_3\)PO\(_4\) with phosphate rock may provide an appropriate remedial alternative for \textit{in situ} Pb immobilization.

The aim of this work was to further investigate the use of phosphate rock as a soil additive to immobilize the labile soil lead at a Pb-contaminated site in Taiwan. The effectiveness of the treatment was assessed by reacting Pb-contaminated soil with phosphate rocks in a batch study, and examining the extractable Pb content. Based upon the extractable Pb content in soils and the amount of phosphate rock added under the laboratory-controlled conditions, empirical curves were obtained by regression analysis. These predictive equations can be used for field application.