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Journal of Hazardous Materials B139 (2007) 550–555

Journal of Hazardous Materials

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Disposal of domestic sludge and sludge ash on volcanic soils

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Available online 2 May 2006

Abstract

Column leaching experiments were conducted to test the ability of Chilean volcanic soils in retaining the mineral constituents and metals in sewage sludge and sludge ash that were incorporated into the soils. Small or negligible amounts of the total content of Pb, Fe, Cr, Mn, Cd, and Zn (0 to <2%), and more significant amounts of mineral constituents such as Na (7–9%), Ca (7–13%), PO_4 (4–10%), and SO_4 (39–46%) in the sludge and sludge ash were readily soluble. When they were incorporated on the surface layer of the soils and leached with 12 pore volumes of water over a 3 month period of time, less than 0.1% of the total amount of heavy metals and PO_4 in the sludge and sludge ash were collected in the drainage water. Cation exchange selectivity, specific anion adsorption and solubility are the processes that cause the reduction of leaching. The volcanic soils were capable of retaining the mineral constituents, P, and metals in applied sewage sludge and sludge ash and gradually released them as nutrients for plant growth.

Keywords: Sewage sludge; Sludge ash; Column studies; Volcanic soils

1. Introduction

Sewage sludge is the inevitable end product of municipal wastewater treatment processes worldwide. As the wastewater is being purified, the impurities removed from the water stream are being concentrated. The sludge stream thus contains many chemical and microbiological constituents usually in concentrated forms that may become potential sources of pollutants when the material is released. No matter how many treatment steps it undergoes, at the end, the sludge and/or its derivatives (such as sludge ash), require the ultimate disposal. For disposal, the sewage sludge may be land applied, land filled, incinerated, or ocean dumped. There is not an entirely satisfactory solution and all of the currently employed disposal options have serious draw backs. Land application however is by far the most commonly used method around the world. Approximately six million dry tons of sewage sludge is produced annually in the United States [1]. Recent report showed that the annual production of sewage sludge in member countries of the European Union may reach as much as 8×10^6 tons [2]. Significant amounts of sewage sludge produced in the United States and the western European nations have been applied on land. Dependent on the regions, 24–89% of the sludge produced in the US has been applied on land [1]. Bonnin [2] reported that 65% of the sewage sludge in France was land applied; the situations in other parts of the world are expected to be similar. Recently, European countries are studying more restrictive directives to sewage sludge applications on land.

As the residue of municipal wastewater treatment, sewage sludge represents the aggregation of organic matter, pathogens, trace elements, toxic organic chemicals, essential plant nutrients, and dissolved minerals originally dispersed in the wastewater and are captured and transformed by the wastewater treatment processes. Properly managed, the potential pollutants are assimilated via the biochemical cycling processes of the receiving soils in the land application. The practice provides soils with organic materials and offers the possibility of recycling plant nutrients, which in turn, improve the fertility [3] and physico-chemical properties of agricultural soils [4]. If not appropriately controlled, the potential pollutants released through the land application may degrade the quality of downstream water bodies, be transferred through the food chain to harm the consumers of har-

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doi:10.1016/j.jhazmat.2006.02.062

vests, and drastically alter the physical and chemical properties of the receiving soils. It is imperative that mass input provides adequate amounts of substances that are useful to plant development and the pollutant inputs are controlled to avert detrimental public health and environmental effects. Major countries such as the US, the European Union [5] and China [6] have enacted regulations or issued guidelines that limited the disposal options for a variety of reasons.

In Chile, the treatment works are gradually being brought online in recent years, before the collected wastewater was directly discharged and sewage sludge did not exist. With the commencement of wastewater treatment, sewage sludge and ash of the incinerated sewage sludge are accumulating in the metropolitan areas awaiting final disposals. In the sewage sludge used, the levels of heavy metals follow the sequence Zn > Mn > Cu > Cr > Pb > Ni > Mo > Cd (from 1780 mg/kg for Zn down to 5 mg/kg for Cd), being land application one of the primary options under consideration at this time.

The agricultural soils in Central Chile where most of the country's population centers are situated are derived from parent material of volcanic origin, and account for approximately 69% of nation's arable land. The predominant minerals of these soils are allophane and ferrihydrite in the Andisols and kaolinite, halloysite and iron oxides in Ultisols. These soils are rich in iron oxides and organic matter contents, possess pH-dependent variable surface charge and high PO_4 accumulation. However, the soils have poor fertility; at the original acidic pH range of 4.5–5.5, they have low capacity for exchangeable cations (CEC) and a strong selectivity for K and Ca over Mg [7]. Phosphorus is strongly fixed by the minerals, thus is not readily available for plant absorption in these soils. To be productive, they require frequent adjustments of soil pH, replenishment of exchangeable Mg, and heavy PO_4 applications. When soil pH increases the CEC increases, P fixation decreases and K selectivity is reduced. On the other hand, when the soil organic matter increases, the K selectivity is also reduced [7]. Municipal sewage sludge and ash of the incinerated sewage sludge appear to possess the essential plant nutrients and dissolved minerals and the buffering capacity [8–11]. When land applied, they may replenish the depleting nutrient reservoirs in these soils under cultivations. If the added constituents are retained in the soils and absorbed by plants, the risk of contaminating the downstream water bodies may be minimized. In this study, the capacity of volcanic soils to retain chemical constituents in the land applied sewage and sewage sludge ash was investigated.

2. Materials and methods

2.1. Soils

The surface 0–25 cm depth layers of five volcanic soils located in the agricultural regions of the Southern Central Chile were collected. Namely, they were Collipulli, Diguillin, Nueva Braunau, Metrenco, and Ralún reflecting the localities from where soils were extracted. The samples were obtained from well drained and regularly cultivated fields. Collipulli and Metrenco are classified as Ultisols and Ralún, Diguillin, and Nueva Braunau as Andisols. General information on the climate and geography of the soils may be found in Escudey et al. [12]. Soil samples were screened in the field to pass a screen with 2 mm openings and stored at the field moisture content in a 4 °C cold room until used.

2.2. Experiments

Soils were packed to the depth of 25 cm into acrylic columns of 30 cm length and 10 cm of diameter, according to their respective field bulk densities. A filter paper disk was placed on the perforated plate at the bottom of each column to prevent the loss of solid materials. The sewage sludge was obtained from a domestic water treatment plant located in Santiago (Chile), the sewage sludge ash was obtained by heating the sewage sludge at 500 °C for 2 h. Dependent on the treatment, 30 g of air dried sewage sludge or the ash equivalent of 30 g of air dried sewage sludge were incorporated into the surface 5 cm of the packed columns. The experimental controls received neither the sludge nor the ash treatment. The columns, were placed in vertical position, flooded once a week with one pore volume of distilled water, and drained by gravity from top to bottom, for a period of 12 weeks. In addition, 30 g of sludge and the ash equivalent of 30 g of sludge were leached in the same manner. The drainages from each weekly leaching cycle were analyzed for pH, electrical conductivity, SO_4, PO_4, Na, K, Mg, Ca, Zn, Cu, Fe, Al, Ni, Cd, Pb, Mo, and Mn.

At the end of the leaching experiment, each soil column was cut open lengthwise and the profile was sectioned into five equal length segments for analysis of the soils' pH, electrical conductivity, and organic carbon, exchangeable cations, and P contents. A chemical fractionation of heavy metals was carried out in sludge and sludge ash, by using the methodology proposed by Chang et al. [13]. The sequential extraction with 0.5 M KNO_3, distilled water, 0.5 M NaOH, 0.05 M EDTA, and 0.5 M HNO_3 allows to estimate the exchangeable, sorbed, organic, carbonate and residual fractions of heavy metals.

2.3. Chemical determinations

The bulk density, exchangeable cations, total porosity, and organic carbon content of the soils were determined by methods outlined in methods of soil analysis (American Society of Agronomy, Madison, WI). Briefly, the bulk density [14] was determined by the average air dried weight of soils in undisturbed soil cores of the 0–25 cm soil profile in 5 cm (diameter) × 5 cm (height) brass rings; the exchangeable cations were determined as the concentrations of Na, K, Mg, and Ca in ammonium acetate extracts [15]; and organic carbon was determined by the Walkley-Black method [16]. The pH and electrical conductivity of soils were measured in soil suspensions with soil to water ratio of 1:2.5 w/v. The total elemental contents of Na, K, Mg, Ca, Zn, Cu, Fe, Al, Ni, Cd, Pb, Mo, Mn, P and S were determined by digesting the soils with a concentrated HNO_3–HCl–HF mixture in a microwave oven and measuring the concentrations by ICP–OES spectroscopy (Perkin Elmer Optima 2000 equipment, MECESUP USA9903).