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EVALUATION OF HEAVY METAL CONTENT IN IRRADIATED SLUDGE, CHICKEN MANURE AND FERTILIZED SOIL IN INDONESIA

N. HILMY, S. SUWIRMA, S. SURTIPANTI, HARSOJO
Centre for Application of Isotopes and Radiation,
Jakarta, Indonesia

Abstract

The contents of heavy metals, Hg, Cd, Cr, Cu, Ni, Pb, Zn and Co, were determined in two irradiated sludges, chicken manure and fertilized soil. Sludge I was collected from a treatment plant in Jakarta city, Sludge II from a sludge reservoir in a Jakarta suburb, chicken manure was obtained from a farm south of Jakarta, and the soil had been treated with phosphate fertilizer since 1967. The sludges and chicken manure were collected during the rainy and dry seasons, and the heavy-metal contents were determined by atomic-absorption spectrometry and neutron-activation analysis. The results obtained are compared with data from Canada, and are discussed in terms of permissible limits in the environment.

1. INTRODUCTION

The disposal of sewage is becoming a major problem in industrialized and developing countries because of increasing volumes of sludge and treated municipal wastewater (sewage effluent). Health risks and increasing concern for the environment call for alternatives in waste management. One of the most readily available methods of utilizing and disposing of these wastes is by application to crop land. However, with increasing industrialization and modernization, heavy metals and other toxic materials now contaminate municipal sewage materials, and it is becoming increasingly apparent that land application must be restricted to levels that will prevent ground- and surface-water pollution and accumulation of toxic substances in the environment [1]. Sewage sludge contains xenobiotic chemicals and heavy metals that can accumulate in the soil and then be taken up by crops, which, in turn, may become toxic to humans. The levels of these toxic substances in a sludge depend very much on its origin.

Due to free-radical formation, the radiolysis of sludge may alter the form and distribution of heavy metals contained therein. It is known that metals in sludge are generally present as mineral particulates and colloids, due to cation exchange, sorption, precipitation as carbonates, phosphates and sulphides, complex formation and chelation. Irradiation produces high-energy excitation and ionization of molecules, lethal penetration of cell tissue and the formation of free radicals that create strong oxidation conditions in the sludge matrix [2, 3].

In Indonesia, sewage sludge and chicken manure are being used to provide nutrients for crops and animal feed. To ensure safety, toxic substances must be kept at acceptable levels. At present, there is no specific regulation governing the use of sludge or chicken manure as fertilizer in Indonesia.

This report examines the heavy metals in two irradiated sewage sludges collected from the city of Jakarta and its suburbs, and also in chicken manure, phosphate fertilizer (triple super phosphate [TSP]) and fertilized soil. The concentrations of heavy metals, determined by atomic absorption spectrometry and neutron activiation analysis, are shown in Table I [4, 5, 6, 7].

TABLE I. HEAVY METAL CONCENTRATIONS IN SEWAGE SLUDGE, CHICKEN MANURE, PHOSPHATE FERTILIZER AND FERTILIZED SOIL

Sample	Hg	Cd	Cr	Cu	Ni	Pb	Zn	Co
	(ppm)							
Sludge I	2.50[a] ±0.10	1.52 ±0.40	13.4 ±1.1	100 ±10.0	14.2 ±10.0	18.0 ±12.0	630 ±20.0	20.0 ±0.02
Sludge II	1.35 ±0.09	0.88 ±0.20	10.4 ±0.30	50.0 ±2.0	14.4 ±0.4	12.8 ±1.2	450 ±60.0	24.4 ±2.4
Chicken manure	0.03 ±0.01	0.51 ±0.88	0.06 ±0.08	30.0 ±2.0	15.7 ±1.3	0.01 ±0.01	250 ±10.0	ND[b]
P fertilizer	0.09 ±0.01	8.4 ±5.8	0.27 ±0.13	10.2 ±5.5	15.4 ±7.9	4.6 ±1.4	240 ±100	2.51 ±1.7
Fertilized soil	-	2.76 ±0.10	86.9 ±33.9	21.3 ±5.5	22.0 ±2.0	29.9 ±3.3	22.2 ±1.06	50.9 ±44.2
Permissible conc. in soil	-	1.00	250	2-100	3-1000	2-2000	10-100	1-13

[a]Mean ± standard deviation (n = 5).
[b]Not detected.

1.1. Cadmium

There is no evidence of an essential role of this element in plant growth. Cd is readily absorbed and consequently is detectable in most plants. Soil contamination with Cd is believed to be a serious health risk. The concentration of Cd in top soil is high in the vicinity of Pb and Zn mines (2-144 ppm) [8]. Sewage sludge and phosphate fertilizer are also important sources of Cd. The maximum permissible rate of Cd addition to soil depends on the soil pH. At high pH, Cd exhibits higher mobility than in acid environments. The background value of Cd in soils is usually between

0.07 and 1.10 ppm, and should not exceed 1.5 ppm [8]. Cd content in the sludge collected from the treatment plant in Jakarta city (Sludge I) was 1.52 ppm and 0.88 ppm in the sludge reservoir in a Jakarta suburb (Sludge II). The mean concentrations of Cd were 1.20 ppm in the sludge, 0.51 ppm in chicken manure, 8.37 ppm in phosphate fertilizer, and 2.76 ppm in fertilized soil. The sludge and chicken-manure levels were lower than than those reported for sludges Canada (Table II). The risk of high absorption of this metal by plants can be controlled by using a low amount of sludge in the soil-sludge mixture.

1.2. Copper

Copper is very soluble and its ions are released in acid environments. Therefore, it is among the more mobile of the heavy metals. Contamination of soil results from utilization of Cu-containing fertilizer in agriculture or from municipal wastes or industrial emissions. Another possible source is the corrosion of Cu alloys (electric wires, pipes etc.).

The addition of Cu to cultivated soils through fertilizer, chemicals and waste has recently been extensively investigated. The most important aspect of Cu contamination is its accumulation in surface soils. The threshold value of 100 ppm Cu has been exceeded in several cases [8]. In root tissue, Cu is found in complexed forms, although it is most likely to be taken up in dissociated forms. In this investigation the concentrations of Cu in Sludge I, Sludge II, chicken manure and fertilized soil were 100, 50, 30 and 21 ppm, respectively. Although the Cu levels in the sludges and chicken manure were higher than in the phosphate fertilizer (10 ppm), they were generally lower than those reported for soil and sludges in Canada (Table II).

TABLE II. HEAVY-METAL CONCENTRATIONS IN SOIL AND SLUDGES IN CANADA [2]

Sample	Hg	Cd	Cr	Cu	Ni	Pb	Zn	Co
	(ppm)							
Soil	0.01-0.3	0.0-0.7	3-3000	2-100	10-1000	2-200	10-300	-
Sludge	0.1-50	3-3000	40-8800	200-800	20-5300	120-300	700-4900	- -
Sewage sludge	-	<0.5	24	335	9.7	88	151	1.7

1.3. Lead

The natural Pb content of soil originates from the parent rock. All soils are likely to contain it, especially in the top horizon. There are much data available in the literature on soil Pb, but it can be difficult to separate background levels from anthropogenic amounts in surface soil. Davies [9] stated that 70 ppm is an upper background limit for Pb in normal soils.

Lead is not an essential element, although it is found in all plants. Some species tolerate high levels, whereas others show retarded growth at 10 ppm in solution-culture studies. The concentrations in Sludge I, Sludge II, chicken manure and fertilized soil were 10.0, 12.8, 0.01, and 19.9 ppm respectively - i.e. higher in the sludges than in phosphate fertilizer (5 ppm) but lower than reported by Chuaqui et al. [2] (Table II). The levels of soil Pb that are toxic to plants, not easy to predict, generally range from 100 to 500 ppm [8].

1.4. Mercury

The concentrations of Hg in Sludge I, Sludge II, chicken manure and phosphate fertilizer were 2.5, 1.35, 0.03 and 0.09 ppm, respectively. Levels were higher in the sludges than in phosphate fertilizer, but generally lower than levels found in soils and sludges in Canada (Table II). The accumulation of Hg in soil is controlled mainly by organic-complex formation and by precipitate formation. Mobility of Hg requires dissolution and biological degradation of organo-mercury compounds.

Sewage sludge and other wastes, and phosphate fertilizer are possible sources of Hg contamination in soil. The behaviour of Hg in soil is of interest since its ready bioavailability creates an important health hazard. It is readily taken up from solution culture and transported within plants. The affinity that protein sulphydryl groups have for Hg apparently is the key disrupting metabolic process. Toxic effects in young barley were observed at Hg levels of 0.01 ppm and a concentration of 3 ppm was severely toxic [10]. Volatilized elemental Hg and methylated derivatives are known to be very toxic for plants.

1.5. Chromium

The determination of total Cr (Cr^{+3} and Cr^{+6}) concentrations in the samples are shown in Table I. The sludge levels were higher than those of phosphate fertilizer and chicken manure, but again lower than those obtained by Chuaqui et al. [2] (Table II).

Chromium may accumulate in surface soil due to pollution from industrial wastes and municipal sewage sludge. The Cr added to soils is usually accumulated in a thin surface layer. There is no evidence of an essential role of Cr in plant metabolism, although low concentrations in soil may give positive effects on plant growth [11]. The Cr content in plants is controlled mainly by its soluble content in the soil, and although most soils contain significant amounts, availability to plants is often limited. The rate of uptake depends on several factors. Usually, roots and leaves retain more Cr than does grain. Anderson et al. [12] reported toxicity in oats with a Cr content of 49 ppm when grown in a soil containing of 634 ppm. Turner and Rust [13] observed symptoms of toxicity with as little as 0.5 ppm Cr in nutrient culture, and 60 ppm in soil culture. The toxicity of Cr depends on its oxidation state and on the presence of readily-available forms.

1.6. Nickel

Nickel content was 14 ppm in Sludges I and II, 16 ppm in phosphate fertilizer, 16 ppm in chicken manure, and 22 ppm in fertilized soil. Soil treatments such as addition of lime, phosphate or organic matter are known to decrease availability of Ni to plants. The beneficial effects of Ni on plant growth indicate that it has an essential function in plants [14]. Generally, the range of excessive or toxic amounts of Ni in most plant species is from 10-100 ppm [8].

1.7. Zinc

Zinc is easily adsorbed by mineral and organic components of most soil types, with background levels normally in the range 17 to 25 ppm [8]. The processes involved in Zn adsorption are not completely understood; in acid conditions it is controlled by cation-exchange sites, and in alkaline conditions by chemisorption and organic ligands. Soil organic matter is known to be capable of binding Zn in stable forms, therefore accumulation in organic soil horizons and in some peats is common. Soluble organic complexes of Zn that occur in municipal sewage sludges are mobile in soil and available to plants, and therefore can create environmental problems.

In plants, Zn plays a role in the metabolism of carbohydrates, proteins and phosphates, and in the formation of auxins, RNA and ribosomes. There is evidence that Zn influences the permeability of membranes, and that it stabilizes the cellular components of higher plants and micro-organisms. The levels of Zn in descending order were, sludges > phosphate fertilizer > chicken manure; they were generally lower than those recorded by Chuaqui et al. [a] (Table II).

1.8. Cobalt

Cobalt occurs in two states Co^{+2} and Co^{+3}, and may also exist as a complex anion $Co(OH)_3$. During weathering, it is relatively mobile in oxidizing acid environments, but does not migrate in the soluble phase. Its mobility is related to the kind of organic matter in the soil. Cobalt concentrations usually range from 3 to 15 ppm. It can be taken up through the cuticle into the leaf; therefore foliar application in solution is effective in the correction of Co deficiency.

In legumes, Co deficiency inhibits the formation of leghaemoglobin and hence N_2 fixation. When taken up in excess by roots, it moves in the transpiration stream resulting in an enrichment at leaf margins and tips: common toxicity symptoms are white necrotic foliar margins and tips. Kitagishi et al. [15] reported that the addition of 25 and 50 ppm of Co to the soil was toxic to rice plants. The Co content in Sludge I, Sludge II, chicken manure, phosphate fertilizer and fertilized soil are 20, 24, undetectable, 2.5, and 51 ppm, respectively. The concentrations of Co in the sludges were higher than those in the chicken manure, the phosphate fertilizer, and the soil (Table 1).

2. CONCLUSIONS

Except for Ni, the heavy-metal levels in the sludges were higher than in chicken manure. And the heavy-metal contents in the sludges were lower than those reported in Canada by Chuaqui et al. [2], although similar to those reported by Bates et al. [3]. The concentrations in the fertilized soils in Indonesia are still within permissible levels [16], except for Cd. Based on the data presented, sewage sludges can be safely used to increase and sustain soil fertility and crop production in Indonesia.

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