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The Vertical Movement of Cadmium, Nickel and Lead Through Undisturbed Cores Having a Surface Amended of Sewage Sludge

[1]J. Nouri , [2]B. J. Alloway and [3]P.J. Peterson,
[1]Department of Environmental Health Engineering, School of Public Health, Tehran , University of Medical Sciences, P.O.Box, 14155-6446, Tehran, Iran. [2]Department of Soil Science, University of Reading, Whiteknights, P.O.Box 233, Reading, RG6 6DW, U.K.,
[3]King's College London, Strand, London WC2R 2LS , England, U.K

Abstract: An experiment over a period of 14 months was carried out on duplicate undisturbed cores of 3 soils, with different textures using one sludge in order to obtain more information on the vertical movement of heavy metals through sludge treated soil. Over the first 8 months the pH values were in this order : sandy silt loam > sandy clay> loamy sand of both control and sludge amended soils. The rainwater pH values during the first 8 months were acidic, but during the following six months, they increased loan alkaline value. At the end weathering, it was found that only the amended surface and upper layers contained elevated concentrations of heavy metals. Thus the nature of soil was an extremely important factor in the downward movement of constituents. It appears that a guideline for sludge application to land the pH of soils should be maintained at or above 6.5 . Groundwater pollution was likely to be the greatest in highly permeable sandy soils and these should not be used for the application of heavy metals. Soil water influenced the chemistry of surface waters and this affected the survival of fresh water fauna and flora.

Key words: Sewage sludge , movement , heavy metals , soil , leachate

Introduction

In most soil environments sorption is the dominating speciation process and thus, largest fraction of heavy metals in a soil is associated with the solid phase of the soil phase (Frost and Griffin, 1977; Essington and Mattigod, 1991). Pollution problems arise when heavy metals mobilized into the soil solution and taken up by the plants or transported to the surface or ground waters .The properties of the soil are thus, very important in the attention of heavy metals in the environment. Sorption of heavy metals is also strongly pH–dependent. In general, sorption increases with increasing pH (Alloway, 1998 and Alloway and Jackson, 1991). That is, lower the pH value more will be the metal mobilization. When pH value is less than 5, mobility is enhanced as a result of the increased proton concentration. At pH value above 7, some heavy metals tend from hydroxy complexes which will increaset he solubility of the metal in question (Brallier *et al.*, 1996). Apart from pH value, the other soil properties determining the speciatio n of heavy metals are; the content of organic matter; chemical composition of soil water; redox poten tial; the cation exchange capacity (CEC); temperatur e and soil texture, which reflect the particle size distribution of the soil and thus, the content of fine particles like oxides and clay (Alloway and Jackson, 1991 and Alloway, 1998).

The application of sewage sludge has an impact on the soil itself as well as on the uses of the soil (Keefer and Singh, 1986). The biggest concern in effects of sludge application on soil properties in the amended zone is that increasing the total metal contens of soils and plants (Hooda *et al.* 1997; and Sims and Kline, 1991) and finally, the other affected factor is an increase in the total content of nitrogen and carbon.

Materials and Methods

In order to obtain more detailed information on the vertical movement of heavy metals through sludge treated soil profiles, an experiment was carried out on duplicate undisturbed cores of three soils with different textures using one sludge. The experiment carried out in London in 1990. Sections of plastic drainpipe having a diameter of 6.5 cm and length 36 cm, were hammered into the ground with a wooden mallet and dug out with a spade.

The soil textures were determined by the pipette method using the British size limits and were found to be loamy sand; sandy slit loan and sandy clay.

The soils were held in the pipe sections with 0.5 mm nylon mesh covering the end, above which there was a pad of washed glass- wool. The surface layers were amended with air dried sewage sludge from the Deephams works (Enfield). They were placed on a flat roof five floors up, and exposed to the weather for more than a year. Three control columns were used without sludge amendments. The sludge application rate was 286 g air dried sludge per tube, which was equivalent to about 100 t ha^{-1}. Eluates from each tube and total precipitation werecollected, bulked together and analyzed for the periods 0-6 months, further 6- months, and further 8-14 months. Aliquots of 25 ml eluates and rainwater were filtered (Whatman 42) and the filtrate digested with nitric acid, cadmium, nickel and lead were then determined in the solutions. At the end of the experiment, the soils were pushed out of the pipes and cut into six 5 cm sections. Small subsamples from these sections were extracted with water and ammonium acetate (1M., pH 7). The metal concentrations in the extracts were determined and the pH of each section was measured.

Sampling of total precipitation: Total precipitation, comprising rainwater and dust, was collected monthly in a bottle fitted with a polythene funnel (15 cm diameter). The bulk rainwater samples were screened through terylene mesh to remove insects and the bottle kept in a dark and cool place to inhibit the growth of algae. The samples were not acidified because this would probably have affected the ratio of soluble to in soluble forms of the elements (Cawse and Peirson, 1972). The insoluble fraction was excluded and only the fraction passing through a Whatman No. 42 filter paper was analyzed.

Results

The concentrations of metals eluted from the columns indicated that the mobility of cadmium, nickel and lead decreased over a period of time after the sludge amendment (Tables 1-3 ; Figs. 1-3). The pH of the upper part of the amended column was markedly lower than that of the corresponding portion of the control column. However, there is a possibility that some rainwater drained down the sides of

Table 1: pH values and metal concentrations in leachates undisturbed cores Months (0-6) (values in $\mu g\ ml^{-1}$)

		pH	Cadmium	Nickel	Lead
(a)	Control	6.5	0.002	0.01	0.065
	Sludge amended	5.1	0.035	0.86	0.58
(b)	Control	6.4	0.005	0.02	0.22
	Sludge amended	6.3	0.041	1.63	0.54
©	Control	6.7	0.005	0.01	0.004
	Sludge amended	5.8	0.038	0.58	0.68
Rainwater		4.3	0.0015	0.012	0.13

(a) Loamy sand (b) Sandy silt loam © Sandy clay
* Measurements are for soluble metals in rainwater.

Table 2: pH values and metal concentrations in leachates undisturbed cores Months (6-8) (values in $\mu g\ ml^{-1}$)

		pH	Cadmium	Nickel	Lead
(a)	Control	7.0	0.0025	0.045	0.16
	Sludge amended	6.0	0.03	0.3	0.58
(b)	Control	7.4	00.04	0.05	0.085
	Sludge amended	7.2	0.028	0.25	0.56
©	Control	7.3	0.004	0.023	0.004
	Sludge amended	6.6	0.038	0.23	0.58
Rainwater		4.1	0.0012	0.01	0.11

(a) Loamy sand (b) Sandy silt loam © Sandy clay
* Measurements are for soluble metals in rainwater.

Table 3: pH values and metal concentrations in leachates undisturbed cores Months (8-14) (values in $\mu g\ ml^{-1}$)

		pH	Cadmium	Nickel	Lead
(a)	Control	6.6	0.003	0.004	0.19
	Sludge amended	6.9	0.01	0.028	0.22
(b)	Control	6.9	0.004	0.005	0.08
	Sludge amended	6.8	0.009	0.017	0.22
©	Control	7.2	0.006	0.0025	0.01
	Sludge amended	6.8	0.015	0.03	0.29
Rainwater		7.4	0.0019	0.005	0.065

(a) Loamy sand (b) Sandy silt loam (c) Sandy clay
* Measurements are for soluble metals in rainwater.

the soils after dry periods when some shrinkage may have occurred. It is suggested that, as in the previous experiment with saturation extracts of sludge- soil mixtures, there was an initial flushing out of water-soluble forms of the metals and bases and/or the gradual formation of insoluble organic complexes. In the sandy silt loam columns the increase in cadmium and nickel concentrations were higher than in other two soils, but lead values were lower. The pH values of the sludge amended column-sections were lower than the non-amended controls (Fig. 4), probably due to the nitrification of the large amount of NH_4-N released from the sludge, the pH increased with depth. The pH values of the eluates from the control columns varied with soil texture and initial base status. Over a period of 8 months the pH values were in the order: sandy silt loam > sandy clay > loamy sand for both control

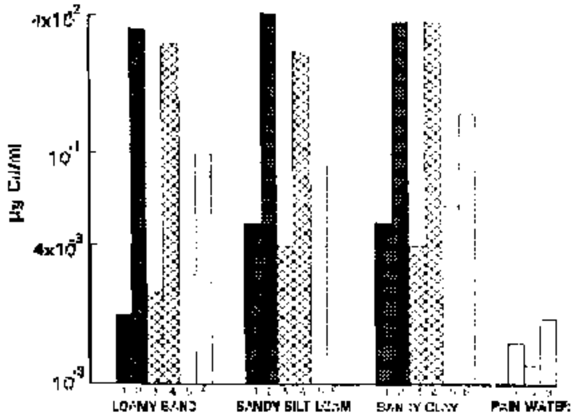

Fig. 1: Variation in cadmium concentration of undisturbed soil cores
1 Control, after 6 months
2 Amended sludge, after 6 months.
3 Control, after further 6-8 months.
4 Amended sludge, after further 6-8 months.
5 Control, after further 8-14 months.
6 Amended sludge, after further 8-14 months.
Rain - water after 6 months (7), further 6-8 months (8) and further 8-14 months (9).

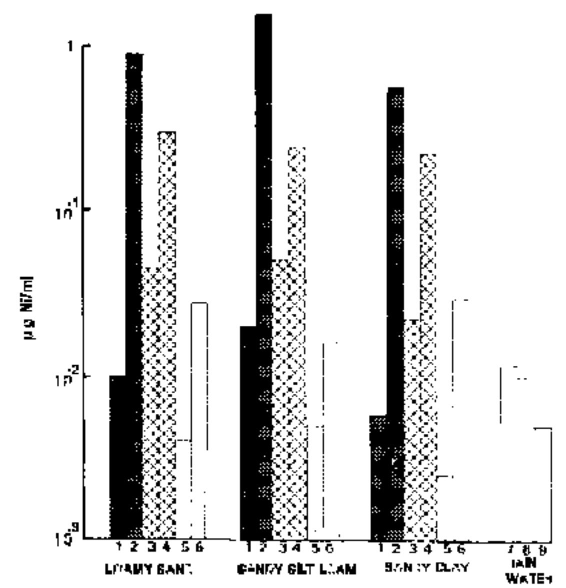

Fig. 2: Variations in nickel concentration of leachate of undisturbed soil cores
1 Control, after 6 months
2 Amended sludge, after 6 months.
3 Control, after further 6-8 months.
4 Amended sludge, after further 6-8 months.
5 Control, after further 8-14 months.
6 Amended sludge, after further 8-14 months.
Rain - water after 6 months (7), further 6-8 months (8) and further 8-14 months (9).

and sludge amended soils. The rainwater pH values were acidic (pH 4.3 - 4.1) during the period which included the coldest months (the first 8 months). However, over the

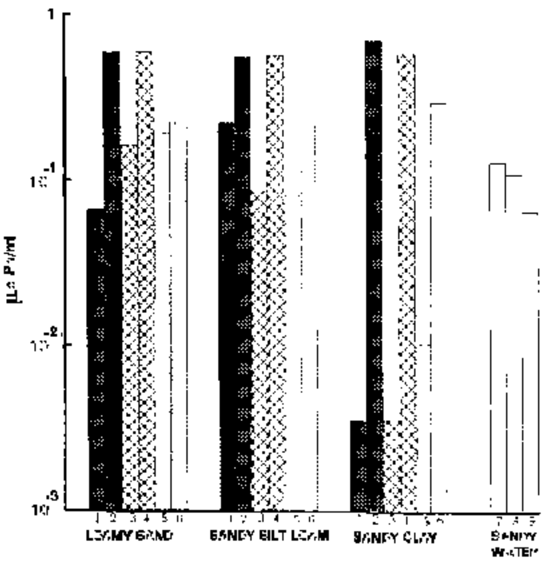

Fig. 3: Variations in lead concentration of leachate of undisturbed soil cores
1 Control, after 6 months
2 Amended sludge, after 6 months.
3 Control, after further 6-8 months.
4 Amended sludge, after further 6-8 months.
5 Control, after further 8-14 months.
6 Amended sludge, after further 8-14 months.
Rain - water after 6 months (7), further 6-8 months (8) and further 8-14 months (9).

following six months, they increased to an alkaline value (pH 7.4). The acidity during the first nine months may have been due burning fossil fuels. At the end of the period of exposure to the weather, the columns were sectioned and extracted with water and 1 M ammonium acetate at pH 7.0 (using air dried soil). The results showed that only the amended surface and upper layers contained significantly elevated concentrations of extractable metals. The lower layers all had very low concentrations of water and ammonium acetate extractable metals, (<0.01 $\mu g\ g^{-1}$ with water and <0.1 $\mu g\ g^{-1}$ with ammonium acetate) which implied that the metals from the sludge either passed straight through the lower layers without being adsorbed in exchangeable forms, or were sorbed more strongly and not removed by these extractants.

Discussion

The eluates from sludge amended soils varied according to the texture of the soils and time. In all cases there was a decrease in metal concentration with time which could be due either to the initial depletion of soluble forms of metals as discussed in the previous experiment, or to the progressive sorption in the soil system as higher concentration were released. Sludge amended columns showed the greatest release and the eluates and sections from these columns had the lowest pH values. It is well known that the mobility of most elements in soils is largely dependent on the pH of the soil system and increases with decreasing of pH (Frost and Griffin, 1977; Tyler, 1978). It is important that future studies assess the influence of varying pH on the leaching of heavy metals. It may be understood why "guidelines" for sludge disposal specify that the pH should be above 6.5. The nature of the soil is an extremely important factor in the downward movement of constituents. Sandy soils have low adsorptive capacity and high permeability which allow rapid transmission of water, solutes and suspended soils, greater amounts of colloidal materials (clay and organic matter) increase the adsorptive capacity for trace elements and generally, the higher clay content reduces the permeability of soil water.

The sun of total eluate metal concentration in sludge amended columns showed that cadmium and lead concentrations were in the order:

Sandy clay> Sandy silt loam> Loamy sand

This implied that the sandy clay soil had a higher adsorptive capacity than sandy silt loam, with loamy sand having the lowest adsorptive capacity. The order was different for nickel concentrations:

Sandy silt loam> Loamy sand> Sandy clay

At high rates of sludge or effluent application the adsorptive capacity of soils can be saturated so that general statements pertaining to low rate of application cannot be applied. In general, it would appear that the advice in all "guidelines" for sludge application to land, that the pH of soils should be maintained at or above 6.5, is sound. Groundwater pollution is likely to be greatest in highly permeable sandy soils and these should not be used for the application of sludge having high concentrations of heavy metals. This is especially relevant to the sand Breckland soils which are underlain by permeable chalk and forms a very important aquifer for potable water supplies. The problem of acid rain is almost entirely manmade. That it is increasing arises from the steady growth in the burning of fossil fuels, especially in coal- fired power generation. Acid precipitation is produced when atmospheric moisture combines with the oxides of sulfur and nitrogen which are emitted when fossil fuels are burnt. Acid rain is a subtle form of pollution, it can damage aquatic and terrestrial ecosystems, manmade structures, and possibly human health, sometimes the damage is irreversible. In cold climates, atmospheric pollutants deposited during the winter generally accumulate in the snow, from which they are released in a concentrated form with the onset of thawing. This phenomenon can lead to sudden sharp increases in the acidity of a adjacent water bodies and soils. On the 10^{th} of April, 1974, in Pitlochry, Scotland, the rain falling in a heavy rainstorm had a pH of 2.4 – the lowest pH for a single downpour ever recorded (Sage, 1980). Increased acidity affects soil physico- chemical conditions, which in turn influence bacterial activity and plant growth (Nouri, 1980). Soil water influences the chemistry of surface waters, and this affects the survival of the freshwater fauna and flora.

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