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Modeling of cadmium transport in the soil under sewage sludge application

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Key words: Cadmium, Hydrus 1D, groundwater, sewage sludge, transport.

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Abstract

The purpose of this study is to assess the possible contamination of the groundwater by Cd derived from sewage sludge through a plot study. For this purpose, four experimental plots, each size 2 by 10 m at Wastewater Treatment Plant-Shoush was prepared. A pvc drainage pipe was installed in one meter depth of each plot to collect the leached water. First plot was irrigated with pipe water as control plot, second plot with effluent from Shoush wastewater treatment Plant, third plot with sludge and pipe water, fourth plot with sewage sludge and effluent. Soil samples were taken from the topsoil to 100 cm depth, each sample for every 10 cm depth from each plot. Cd concentration was measured as a function of depth after 150 days. Hydrus-1D was calibrated for Cd transport in the site. Modeling and measured results were nearly the same. Simulation results for plot 2 and 4 indicated small risk of groundwater contamination. High concentration of Cd near the soil surface increases a concern about the crop for Cd uptake. Simulation results for plot 3 and 4 indicates that in Hydrus-1D adsorption parameters were estimated in order to allow a deeper transport of Cd which had actually occurred duo to macropore flow.

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Introduction

The agricultural use of sewage sludge is widely recommended, since it contains organic matter and is rich in macro and micro nutrients (Melo *et al.,* 2007). However elevated concentrations of trace metals on land receiving sludge are of public concern because of possible phytotoxicity or increased movement of metals in the food chain pollution of surface and groundwater is also a concern (Heckman, 1987; Jones, 1975).

Even low concentrations of heavy metals are toxic because there is no good mechanism for their elimination from the body. Excessive accumulation of heavy metals in agricultural soils through wastewater irrigation, may not only result in soil contamination, but also lead to elevated heavy metal uptake by plants and thus affect food quality and safety (Muchweti *et al.*, 2006). In addition, there is also the possibility of transfer of these metals into environmental media, most especially shallow groundwater systems through leaching (Moshood, 2009). Metal transfer from sewage sludge to soil and subsequently to groundwater represents one of the most critical long-term hazards associated with the application of these wastes to soils (Mcbride *et al.*, 1997).

With long-term use of sewage waste, heavy metals can accumulate to phytotoxic levels and results in reduced plant growth and/or enhanced metal concentrations in plants, especially in low pH soils, which when consumed by animals then enter the food chain (Chaney, 1994). Transport in soil systems is often further complicated by a multitude of coupled biogeochemical reactions, the presence of spatially and temporally variable flow velocities, and spatial heterogeneities at different scales (Mallants *et al.,* 2011). Very few modeling works have been conducted to study the transport of cadmium and other heavy metals in the field soils. One reason for, this is the difficulties in accounting for the complex processes controlling the fate and transport of heavy metals. The purpose of this study is to assess the possible contamination of the groundwater by Cd derived from sewage sludge through a plot study. Hydrus 1D was used for modeling transport of Cadmium in different layers of soil.

Materials and methods

Preparation of plots

Three experimental plots of agricultural land, each size 2 by 10 m on a silt loam soil at the south Tehran wastewater treatment plant were studied. The plots had been moldboard plowed and disked each time and thereafter. Some chemical physical properties of the soil measured before the sludge and effluent application and the results are summarized in table1. A pvc drainage pipe was installed in one meter depth of each plot to collect the leached water as shown in fig. 1. The first plot was irrigated with pipe water as control plot. The second plot was irrigated with effluent from wastewater treatment plant, third plot with sludge and pipe water, fourth plot with sewage sludge and effluent. The sludge was incorporated into 0-20 cm plow layer after application and disked and plowed before irrigation started.

Table 1. Some physical and chemical properties of the silt loam soil in the study area.

Plot number	pH	Soil moisture percent	Organic matter percent	CEC meq/lit	Texture	Nitrogen percent	PO4-P ppm	CaCO3 percent	Soil porosity percent
1	7.76	35.7934	0.36	36.62	Loam	1.4	20	12.25%	0.52
2	7.94	40.9840	0.37	44.25	Loam	1.3	20	11.25%	0.52
3	7.64	37.1495	0.49	42.62	Loam	1.5	22	10.75%	0.52
4	7.57	38.9744	0.42	41.50	Loam	1.4	19	10.5%	0.52
Mean	7.72	38.2225	0.41	41.24	Loam	1.4	20.25	11.8%	0.52

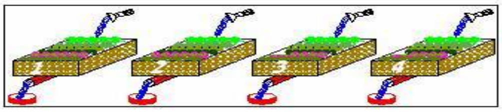

Fig.1. The plots with different irrigation.

Sampling and experimentation

Five months after the cultivation of crops sampling from the soils and crops was performed, also after and during each irrigation period leached water from each plot was sampled and Cd were measured. Soil samples were taken from the topsoil to 20 cm depth, each sample for every 3 cm depth and then from 20-100 cm depth each sample was taken for each 10 cm depth, overall 100 soil samples were taken from all plots. The soil samples were taken to the lab, all soil samples were air dried and ground to pass a No.14 u.s standard sieve through 1.4 mm mesh. 2 grams of each sample were taken for analysis. Cd concentration in the soil samples were obtained by determining metal concentration in a 4 N HNO3 extract (70 º C) by atomic absorption spectrometry (Black, 1965). The concentration Cd in the effluents and sludge also were measured before each period of irrigation.

Hydrus 1D program

We used Hydrus-1D program to model the experimental results. Hydrus implements a scaling procedure designed to simplify the description of the spatial variability in the unsaturated soil hydraulic properties in the flown domain. The Richard equation considers only water flowin the liquid phase (Moradi *et al*, 2005). One-dimensional uniform (equilibrium) water movement in a partially Saturated rigid porous medium is described by a modified form of the Richards equation using the assumption that the air phase plays an insignificant role in the liquid flow process and that water flow due to thermal gradients can be neglected:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[K(\theta)\left(\frac{\partial h}{\partial x} + \cos\alpha\right)\right] - S$$

Where h is the water pressure head, θ is the volumetric water content, t is time, x is the spatial coordinate, s is the sink term, α is the angle between the flow direction and the vertical axis, k is the unsaturated hyraulic conductivity (Simunek *et al*., 2008).

Root water uptake

The sink term, S, id defined as the volume of water removed from a unit volume of soil per unit time due to plant water uptake, S as $S(h)=\alpha(h)S_p$ Where h is the osmotic head, which is assumed here to be given by a linear combination of the concentrations of all solute presents(Simunek *et al*., 2006).

Results and discussions

Data of Analysis

Average concentration of Cd in effluents and sludge samples from Shosh treatment plant was 0.02 and 10.02 mg/l. In the modeling study, Hydrus-1D was used to simulate Cd concentration profiles with dispersivity. The modeling was based on the typical local irrigation scheme and climate data for 10 years. Hydraulics properties of soil were measured and they were considered for modeling.

Results of simulating

Figs 2, 3, 4 show the predicted Cd concentration profile simulated by Hydrus for 150 days after application effluents. After 150 days, the Cd concentration reaches a depth of 30- 60 cm in different plots. Process-based models that integrate these various processes can be valuable tools for investigating the mobility of a wide range of inorganic and organic contaminants subject to different hydrologic and geochemical conditions (Jacques *et al*., 2008) Experimental and simulation results shows good optimization. The experimental results were close to the measured one. Sorption behavior of cadmium should consider and it could be described well using Freundlich isotherm. Long term sewage sludge application scenarios showed that Cd can move to the deeper depths of soil profiles and enter the relatively shallow groundwater. Finally, the risk of groundwater contamination by Cd does not appear to be serious as the result of sludge application. It seems the risk of crop uptake appears to be more serious.

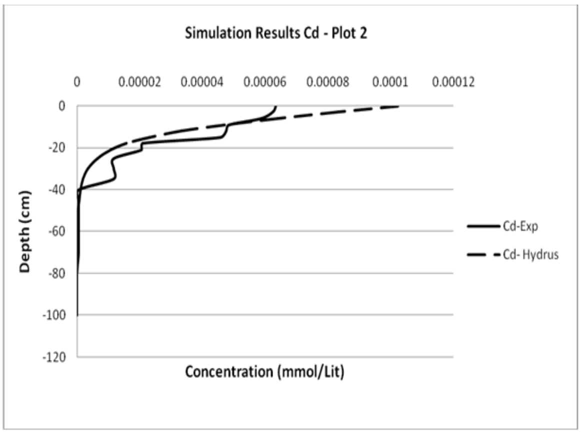

Fig. 2. Experimental and simulation results of Cd concentration in plot 2.

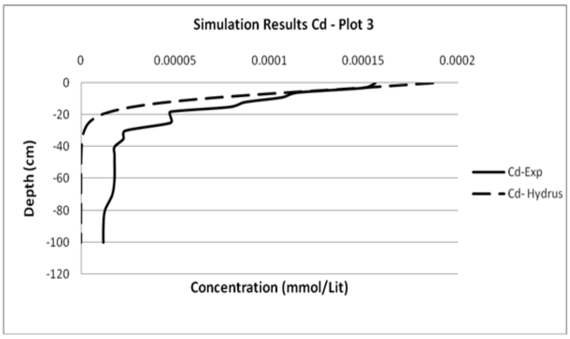

Fig. 3. Experimental and simulation results of Cd concentration in plot 3.

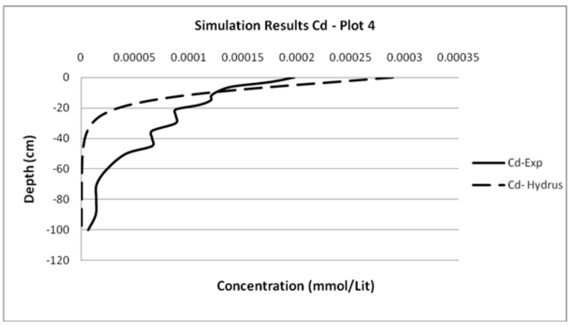

Fig. 4. Experimental and simulation results of Cd concentration in plot 4.

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