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Research Note

Modeling Heavy Metals (Cr, Ni, Pb) Transport in Soil Under Sewage Sludge Application

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ABSTRACT
The purpose of this study is to assess the possible contamination of the groundwater by heavy metals derived from sewage sludge through a plot study. For this purpose, two 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. The first plot was irrigated with pipe water as control plot. The second one with sewage sludge from Shoush wastewater treatment Plant where is located in the south of Tehran. Soil samples were taken from the topsoil to 100 cm depth, each sample for every 10 cm depth from each plot. Cr, Ni and Pb concentration was measured as a function of depth after 150 days. Hydrus-1D was calibrated for heavy metals transport in the site. Modeling and experimental results were nearly the same. Simulation results for plot 2 indicated small risk of groundwater contamination. However high concentration of heavy metals near the soil surface raises a concern about leaching as macro pore and preferential flow. Simulation results for plot 2 indicates that in Hydrus -1D adsorption parameters were estimated in order to allow a deeper transport of heavy metals which had actually occurred duo to macro pore flow.

KEYWORDS: Hydrus 1D, heavy metals, sewage sludge, transport, wastewater

INTRODUCTION

The agricultural use of sewage sludge is widely recommended, since it contains organic matter and is rich in macro and micro nutrients [1], [2]. However elevated concentrations of trace metals on land receiving sewage sludge are of public concern because of possible phyotoxicity or increased movement of metals in the food chain[3] pollution of surface and groundwater is also a concern [4], [5],[6]. Even low concentrations of heavy metals are toxic because there is no good mechanism for their elimination from the body. There is also the possibility of transfer of these metals into environmental media, most especially shallow groundwater systems through leaching [4], [7]. The results of packed-column studies may be overly optimistic in predicting soil immobilization of metals, bypass flow via preferential flow paths in field soils may allow significant metals transport to groundwater [8], [9] 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 [3],[10], [11]. 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 [12]. Mathematical models can predict pollution of groundwater and assists researchers to find situation of metals in different depth.

Theoretical background

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 flow in the liquid phase[12]. 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:

(1)

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

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 hydraulic conductivity[13], [14].

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, Feddes et al(1978) defined S as

$S(h)=\alpha(h)Sp$ (2)

Where h is the osmotic head, which is assumed here to be given by a linear combination of the concentrations of all solute presents[14], [15].

MATERIALS AND METHODS

Two 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 [16]. Some chemical physical properties of the soil measured before the sludge and effluent application and the results are summarized in table 1. A pvc drainage pipe was installed in one meter depth of each plot to collect the leached water [4],[17]. The first plot was irrigated with pipe water as control plot, second plot with sewage sludge from Shoush Wastewater Treatment Plant in south of Tehran. 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 heavy metals were measured. In September 2008 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 50 soil samples were taken from each plot. 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. Heavy metals concentration in the soil samples were obtained by determining metal concentration in a 4 N HNO_3 extract (70 º C) by atomic absorption spectrometry [4], [16], [18]. The concentration heavy metals in the sewage sludge also were measured before each period of irrigation.

Table1. Some physical and chemical properties of the silt loam soil in the study area

Plot number	pH	CEC meq/lit	$CaCO_3$ percent	Organic matter percent	Soil moisture percent	Soil porosity percent
1	7.76	36.62	12.25%	0.36	35.7934	0.52
2	7.94	44.25	11.25%	0.37	40.9814	0.52
Mean	7.85	40.43	11.75%	0.365	38.3874	0.52

1. Inputs of Model

From main process window, part of simulate, water flow and solute transport parameters was selected. For geometry information, cm unit was considered as length.

Number of soil materials: 1

Number of layers for mass balances: 1

Decline from vertical axes: 1 ($\cos 0^0 = 1$)

Depth of the soil profile: 100 cm

Time information: Day was selected as time unit. Time discretization: start 0 irrigation time: 150 days

Soil Hydraulic model: Van Genuchten-Mualem

Hysteresis: No hysteresis

Soil catalog : loam

2. Water flow parameter

Qr Residual soil water content: 0.078

Qs Saturated soil water content: 0.43

Ks Saturated hydraulic conductivity: 0.01733

l: Tortuosity parameter in the conductivity function 0.5

n: Parameter in the soil water retention function 1.56

Water flow boundary condition:
- Upper boundary condition: constant flux, heavy metals concentration in sewage sludge
-Lower boundary condition: free drainage, heavy metals concentration in leached water
-Constant boundary flux: 150 lit (water for irrigation), 7 days, plot size: 2* 10:0.00416 cm/day
-Solute transport: 7 kinds of metals, 150 days, absorption coefficient: 1.7
-Profile information: 19 different of depth in the simulated zones
Water content in the simulated zones was shown in table2
Roots of plants such as radish, lettuce and spinach considered as the material balance

Table2. Water content in the simulated zones

Sample number	Soil depth cm	Water content
1	Surface	0.17892
2	10	0.20313
3	20	0.19861
4	30	0.18987
5	40	0.17672
6	50	0.18018
7	60	0.31951
8	70	0.18572
9	80	0.19178
10	90	0.19178
Mean		0.20162
Standard Deviation		0.04228

RESULTS AND DISCUSSION
Average concentration of Cr, Ni and Pb in sewage sludge samples from Shoush treatment plant was 1.7, 2.6, 2.8 mg/l. In the modeling study, Hydrus-1D was used to simulate Cr, Ni and Pb 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. Figs 1, 2 and 3 show the predicted Cr, Ni and Pb concentration profile simulated by Hydrus for 150 days after application sewage sludge. After 150 days, the studied metals concentration reaches a depth of 40 cm in soil profile. Experimental and simulation results show good consensus. The experimental results were close to the measured one. Sorption behavior of heavy metals should consider and it could be described well using Freundlich isotherm.

CONCLUSION
Long term sewage sludge application scenarios showed that Cr, Ni and Pb can move to the deeper depths of soil profiles and enter the relatively shallow groundwater. Finally, the risk of groundwater contamination by heavy metals does not appear to be serious as the result of sludge application. It seems the risk of pollution of groundwater will appear if sewage sludge and wastewater continue as source water for irrigation. Consensus of modeling and experimental results show usage Hydrus model can predict situation of transport heavy metals in soil profile.

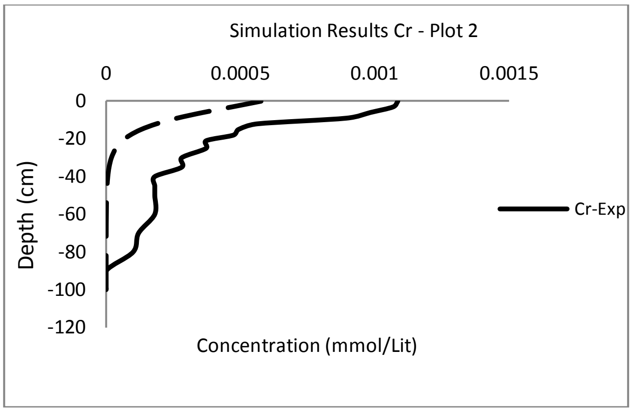

Fig 1. Experimental and simulation results of Cr concentration after 150 days plot 2

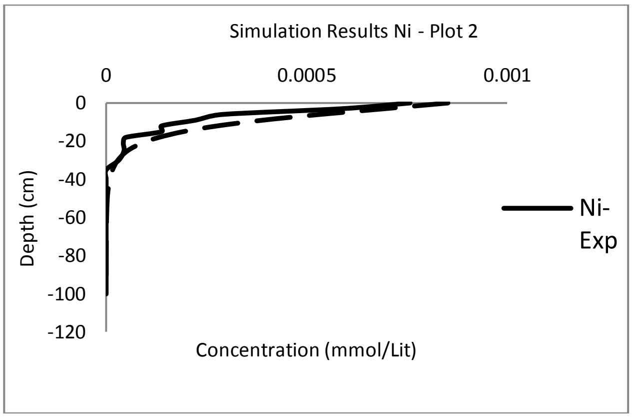

Fig 2. Experimental and measured results of Ni concentration after 150 days plot 2

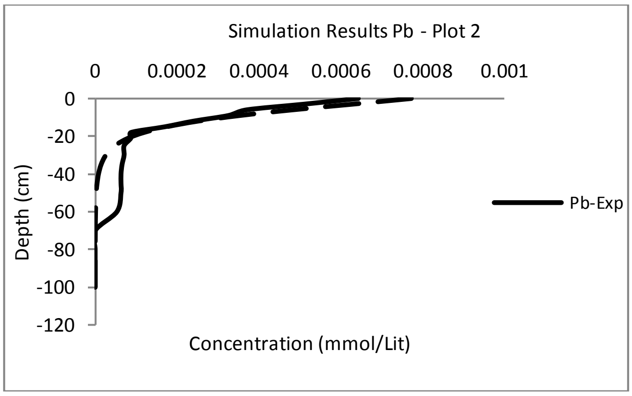

Fig 3. Experimental and simulation results of Pb concentration after 150 days plot 3

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