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Effects of readily dispersible colloid on adsorption and transport of Zn, Cu, and Pb in soils

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Abstract

Soil colloids (<0.002 mm) were extracted from three types of soils to make the colloid-bound forms of Zn, Cu, and Pb solution. The clay mineral types and composition of the colloids, the adsorption characteristics of the colloids, and the effect of readily dispersible colloid on the transport of metals and the quality of the soils and groundwater were studied. The results showed that the adsorption capacity of Cu, Zn, and Pb was greater for the Aquic Vertisols (Shajiang Black soil) as compared to the Udic Luvisols (Brown soil) and Usdic Luvisols (Cinnamon soil), due to the difference of clay content and clay mineral composition in the different soils. The adsorption capacity of Pb was much higher than that of Zn and Cu for the same soils, which would contribute to the chemical properties of metals and specific adsorption characters of the colloids. The mobility of Zn in soils was greater than that of Cu and Pb, while similar trend was found in the transportation processes for Zn and Cu. The concentration of Zn and Cu in leachates increased as the leaching solution volume increased, but the migration of Pb was negligible, and the concentration of Pb could not been detected in leachates even after 7.5 pore volume leaching solution. The influence of mobility on Zn and Cu transport was different for different type of colloids. The mobility caused by readily dispersible colloids from Aquic Vertisols was greater as compared to that of Udic Luvisols and Usdic Luvisols. Analysis of soils after column leaching indicated that Zn was distributed much deeper than Cu, but Pb was almost not migrated, and mainly accumulated in the soil surface. Therefore, Zn had greater tendency for the groundwater pollution than Cu and Pb, and Pb tends to contaminate the surface soils.

Keywords: Soil readily dispersible colloid; Adsorption characteristics; Heavy metals; Mobility; Groundwater quality

1. Introduction

Information regarding the mobility of applied chemicals in soils is essential for environmental assessment of their potential leaching to groundwater supplies (Gorder and Dahn, 1981; Poirria et al., 1972; Selim and Zhu, 2002). The transport of potentially harmful substances, such as heavy metals and pesticides, through the soil profile into the groundwater has been a major environmental concern (Emmerich et al., 1982; Davies, 1994; Seta and Karathanasis, 1996; Vinten et al., 1983). However, any efforts toward describing and predicting contaminant transport cannot succeed if major pathways and mechanisms for transport are not well understood (Seta and Karathanasis, 1997a; Thomas and Phillips, 1979; Zhang et al., 2000).

Most approaches to describe contaminant transport into groundwater as a two-phase system: the contaminant migration in the mobile aqueous phase and the immobile solid phase (Davis, 1982; Guo and Chorover, 2003). Based on this approach, many contaminants, which are less soluble in water but have a strong tendency to bind to the solid phase, are assumed to be immobile and, therefore, present little danger to the groundwater (Sauerbeck, 1991; Seta and Karathanasis, 1997b; Van Olphen, 1977). Recent research results, however, suggest that readily dispersible colloidal particles in the solid phase may also be mobile in subsurface environments and thus transport significant amounts of contaminants to groundwater (Guo and Chorover, 2003; Selim and Zhu, 2002). Calculations of colloid facilitated transport are affected by the inability to predict the physicochemical dynamics of colloids in the groundwater zone (Prima et al., 2002; Selim and Zhu, 2002; Seta and Karathanasis, 1997c).

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Table 1
Selected properties of soils used in this study

Soil type	Location (County in Shandong)	Depth (cm)	pH (1:1)	Organic matter ($g\ kg^{-1}$)	Sand ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)	CEC ($cmol\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Total Zn ($mg\ kg^{-1}$)	Total Cu ($mg\ kg^{-1}$)	Total Pb ($mg\ kg^{-1}$)
Udic Luvisols	Qixia	0–20	4.94	10.1	47.0	38.0	15.0	Tr	15.1	0.96	61.3	30.7	35.5
Usdic Luvisols	Taian	0–20	7.05	15.3	37.5	50.3	12.2	Tr	13.4	0.91	66.6	37.2	43.4
Aquic Vertisols	Dongping	0–20	8.13	13.1	14.8	65.2	20.0	50.8	24.35	0.89	69.0	8.9	22.2

The contaminant transport capacity of the readily dispersible colloids entering the aquatic system depends on solution chemistry and to a greater extent, on the colloids' physicochemical, mineralogical, and surface charge characteristics (Evangelou and Karathanasis, 1991; Melis et al., 1983; Seta and Karathanasis, 1997a; Tessens, 1984; Van Olphen, 1977). Relationships between these properties and mechanisms enhancing the potential of colloids to transport various pollutants have not been established. The objective of this study were (a) to evaluate the potential pollutant transport capacity of readily dispersible colloidal materials fractionated from representative soil samples with diverse mineralogy and soil properties; (b) to identify the physicochemical and mineralogical properties of colloidal materials which affect dispersivity and pollutant transport into groundwater; and (c) to assess the colloidal-facilitated transport of contaminants and distribution in soil profiles.

2. Materials and methods

Soil samples representing three main soil types in Shandong province were collected from Qixia, Taian and Dongping counties. Soil samples were air-dried and ground to pass through a 2-mm sieve. Particle distribution was analyzed following a micropipette method (Miller and Miller, 1987). Soil pH was measured with a pH meter in a 1:1(w/v) ratio of soil and water. Organic matter content was analyzed by the wet oxidation method (Walkley and Black, 1934). Total N was determined by the Kjeldahl method as described by Bremner and Mulvaney (1982). Cation exchange capacity (CEC) was determined by extracted soil using ammonium acetate and titrating distillated ammonium. Total Zn, Cu, Pb content in soils was determined by digest the soil in $HCl-HNO_3-HClO_4$, and the concentrations of Zn, Cu, Pb in the digested solution were measured by atomic adsorption spectroscopy (AAS). The mineralogy of the clay fraction was determined by X-ray diffraction (XRD) analysis, using a computer-controlled XRD system equipped with scanning motor and graphite crystal monochromator (Karathanasis and Hajek, 1982). Samples were scanned at 35 kV and 20mA using CuKα radiation.

Readily dispersible colloids were generated from three soil types; Brown soil (Udic Luvisols), Cinnamon soil (Usdic Luvisols) and Shajiang Black soil (Aquic Vertisols) with deionized water (D-H_2O) without addition of dispersing agents, shaking overnight, and centrifuging. The suspension was decanted through a 50-μm sieve and allowed to stand at least 2 days until the lager particles settle down and then passed through a 10-μm nylon screen. Prior to use, the colloid suspension was diluted with D-H_2O to obtain the desired concentration and spiked with Zn^{2+}, Cu^{2+} and Pb^{2+} icons.

Soil columns were generated by picking air-dried soils (passed through a 2-mm sieve) into PVC pipes (5.0 cm in diameter × 20 cm long). Prior to use, soil columns were saturated upward with D-H_2O to remove air pockets. Then a pulse of spiked colloid suspension with each metal into each column at a constant flux. The column effluent was collected and analyzed periodically. The concentrations of Zn, Cu, Pb in the effluents were measured by atomic adsorption spectroscopy (AAS).

The sorption and desorption of the metals were determined by the following procedure: a 5-g soil sample was weighted into a 50-mL centrifuge tube. Twenty-five milliliter solution containing 0, 40, 80, 120, 160, 200, or 300 μg Zn, or Cu mL^{-1}, or containing 0, 400, 800, 1200, 1600, or 2000 μg Pb mL^{-1} was added to each soil sample, respectively. Each tube with suspension was shaken for 24 h at room temperature. After centrifugation at 1800×*g* for 15 min, the supernatant was filtered through a 0.45-μm membrane. The concentrations of Zn, Cu, Pb in the filtered solution were determined using atomic adsorption spectroscopy (AAS). The amount of Zn, Cu, Pb sorbed by soils was calculated from the difference in metal concentration between the initial P solution and equilibrium metal concentration in the solution.

The distribution of residue of Pb in soil columns was determined by cutting the columns into four 5-cm parts. The soils of each part were air-dried and ground to pass through a 2-mm sieve. The soils were extracted using DTPA, and the Zn, Cu and Pb content was determined by AAS.

3. Results and discussion

3.1. General properties and clay mineral composition of the soils

The soil types, soil pH, organic matter content, particle distribution and other soil properties were listed in Table 1. The surface soil of Udic Luvisols (Brown soil) from Qixia showed a strong acid reaction at pH 4.94. The soil pH of Usdic Luvisols (Cinnamon soil) from Taian was pH 7.05. However, the soil pH of Aquic Vertisols (Shajiang Black soil) was 8.13, due to the presence of the free $CaCO_3$ in the soil. The soil cation exchange capacity

Table 2
Clay mineral composition and relative content of the soil samples

Soil type	Location (County in Shandong)	Sm-Vr[a] (%)	14 Å mineral (%)	Illite (%)	Kaolinite (%)	Quartz (%)
Udic Luvisols	Qixia	0	15	30	55	0
Usdic Luvisols	Taian	4	28	42	24	2
Aquic Vertisols	Dongping	15	29	36	20	0

[a] Sm-Vr: weakly hydroxyinterlayered smectite with minor amounts of vermiculite.