Mobilization and transport of natural and water dispersible colloids in repacked Okinawa red-yellow soil columns

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Abstract
Mobilization, transport and deposition of soil colloids are the fundamental processes governing colloid-facilitated transport of contaminants. Although significant progress has been made in understanding the processes involving mobilization and transport of colloids in porous media, the leaching of natural colloids from soil parent material is not yet fully understood. This study investigates the leaching of natural red-yellow soil colloids and simultaneous transport of applied water dispersible colloids (RYS-WDC) in the saturated soil columns packed with red-yellow soil from Okinawa, Japan at two different flow rates (60mm/h and 300mm/h) at different pH conditions (natural and low pH). The effluent was measured for turbidity, pH, EC, particle size distribution and bromide tracer applied with RYS-WDC. The leaching of natural soil colloid showed similar trend but different magnitude of leached colloids concentration. The breakthrough curve showed the highest colloid leaching at initial pore volumes and gradual decrease with significant tailing effect. Transport of applied colloid was observed to follow a different kinetics without tailing effects. Thus, it suggested that the natural leaching of colloids from red-yellow soil and the transport of applied water dispersible colloid extracted from the same red-yellow soil followed different kinetics.

Key Words
Soil colloids, column experiment, leaching, breakthrough curves

Introduction
Colloid mobilization and transport in porous media is of great significance for colloid-facilitated transport of organic and inorganic contaminants that adsorb to the particles and travel to a greater distance and cause soil and groundwater contaminations. (Grolimund *et al*., 1996; Kersting *et al*., 1999). Among the different sources of mobile colloids, particles that originate from the parent materials through particle release and detachment is the most common process (Ryan and Elimelech, 1996). Such in situ release of colloidal particles is mainly due to physical perturbations or changes in chemical composition of the pore water (Ryan and Elimelech, 1996). The mobilized colloids are transported through the subsurface and result into deposition. Colloid attachment and straining (Bradford *et al*., 2002) are the two key processes for colloid deposition in the porous media. Despite the potential importance of the mobilization and transport processes, the release of colloid particles is poorly understood. Recently, a number of studies have been conducted focusing on different aspects of colloidal phenomena in porous media. However, most of the researches are focused on the transport of particles or model colloids, while release and mobilization of natural colloids from parent materials have received very little attention (Grolimund and Borkovec, 2001).

This study investigated leaching, transport and deposition of natural colloids and water dispersible colloids extracted from red-yellow soil in saturated repacked column under steady irrigation using artificial rain water. The characteristics of natural colloids leaching and breakthrough of applied soil colloids were investigated at different flow rates and pH conditions.

Methods
Kunigami mahji, a red-yellow soil (RYS), sampled at a depth of 0-5cm from hilly site of Nakijison, Okinawa, Japan was used as the porous medium in all soil columns. The physiocochemical properties of the soil are given in table 1.

Table 1. Physicochemical properties of Okinawa red-yellow soil.

Soil Name	Depth cm	Soil texture	Clay %	Silt %	Sand %	Loss on ignition %	Particle density g cm^{-3}	pH	Electrical conductivity mS/m
Red-yellow soil	0-5	Clay loam	27	46	27	11.2	2.72	8.3	17.4

Artificial rain water (ARW) with composition 0.085mM NaCl and 0.015mM $CaCl_2$ was used as the feed solution in all column experiments. Water dispersible colloidal solution (WDC) was prepared by mixing ARW and red-yellow soil in 1:100 (w/w) ratio, shaking for 24 hours and then letting it settle for another 20 hours. The RYS-WDC having Stoke's diameter less than 2 µm was siphoned from the supernatant and filtered by 1 µm filter paper to be used in the experiments.

Column experiments

The sampled red-yellow soil was wet packed in a column (4.8cm in diameter and 10cm in height) to a bulk density of 1.05g/cm^3. A 105 µm nylon filter was used at the bottom of the column to prevent any loss of fine soil particles.

Table 2. Experimental conditions in column experiments.

Column No.	Flow	Water flux cm hour^{-1}	pH of influent	pH of influent ARW	pH of influent WDC	Initial concentration of influent WDC mg L^{-1}	Initial concentration of influent Br^- mg L^{-1}	Solution schedule (PVs: pore volumes)
No.1	low	5.59	Natural	6.1	none	none		ARW 60 PVs →
No.2	low	5.99	Natural	6.1	none	none		
No.3	low	5.66	Natural	6.1	7.5	141	91	ARW 20 PVs → WDC 20 PVs → ARW 20 PVs →
No.4	low	6.01	Natural	6.1	7.5	141	91	
No.5	high	30.09	Natural	6.1	none	none		ARW 60 PVs →
No.6	high	30.52	Natural	6.1	none	none		
No.7	high	31.09	Natural	6.1	7.7	199	85	ARW 20 PVs → WDC 20 PVs → ARW 20 PVs →
No.8	high	32.42	Natural	6.1	7.7	199	85	
No.9	high	30.82	low	3.8	none	none		ARW 60 PVs →
No.10	high	30.64	low	3.8	none	none		
No.11	high	31.61	low	3.8	4.0	230	77	ARW 20 PVs → WDC 20 PVs → ARW 20 PVs →
No.12	high	31.27	low	3.8	4.0	230	77	

Two sets of experiments with duplicates were conducted for each condition. The first two column experiments (No. 1 and No.2) were irrigated with ARW at an intensity of about 6cm/hr with peristaltic pump for a period of 60 pore volume. In the other two column experiments (No. 3 and No. 4), two types of solution were fed to the column consecutively. ARW was first applied for a period of 20 pore volumes and water dispersible colloids extracted from red-yellow soil (RYS-WDC) was applied for next 20 pore volumes and finally ARW was again applied for the last 20 pore volumes. Similar procedure was applied for high flux and low pH conditions. The experimental conditions and application sequences are given in table 2. The effluents were collected and monitored for turbidity, pH, EC, particle size distribution and tracer bromide concentration.

Results

Mobilization and leaching of natural soil colloids

The results of mobilized natural colloid leaching from saturated repacked red-yellow soil at low flow rate-natural pH, high flow rate-natural pH, and high flow rate-low pH conditions are illustrated in Figure 1-No.1, No.5, and No. 9, respectively. The leached natural colloids showed a similar trend but different magnitude with highest colloid leaching observed in low flow rate-natural pH conditions, which is twice as much as in high flow rate-natural pH condition. This is likely due to the more contact time. The least colloid leaching was observed at high flow rate-low pH condition. The colloid concentration increased immediately after the application of feed solution, reached maximum peak at around 4 pore volumes and gradually decreased with time. The results indicated that highly mobile colloid particles, weakly attached to the soil aggregate are released in the initial flush giving rise to the breakthrough curve (BTC). The colloids, which are strongly

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attached to the aggregate move slowly and become mobile colloids resulting in the tailing in the BTC.

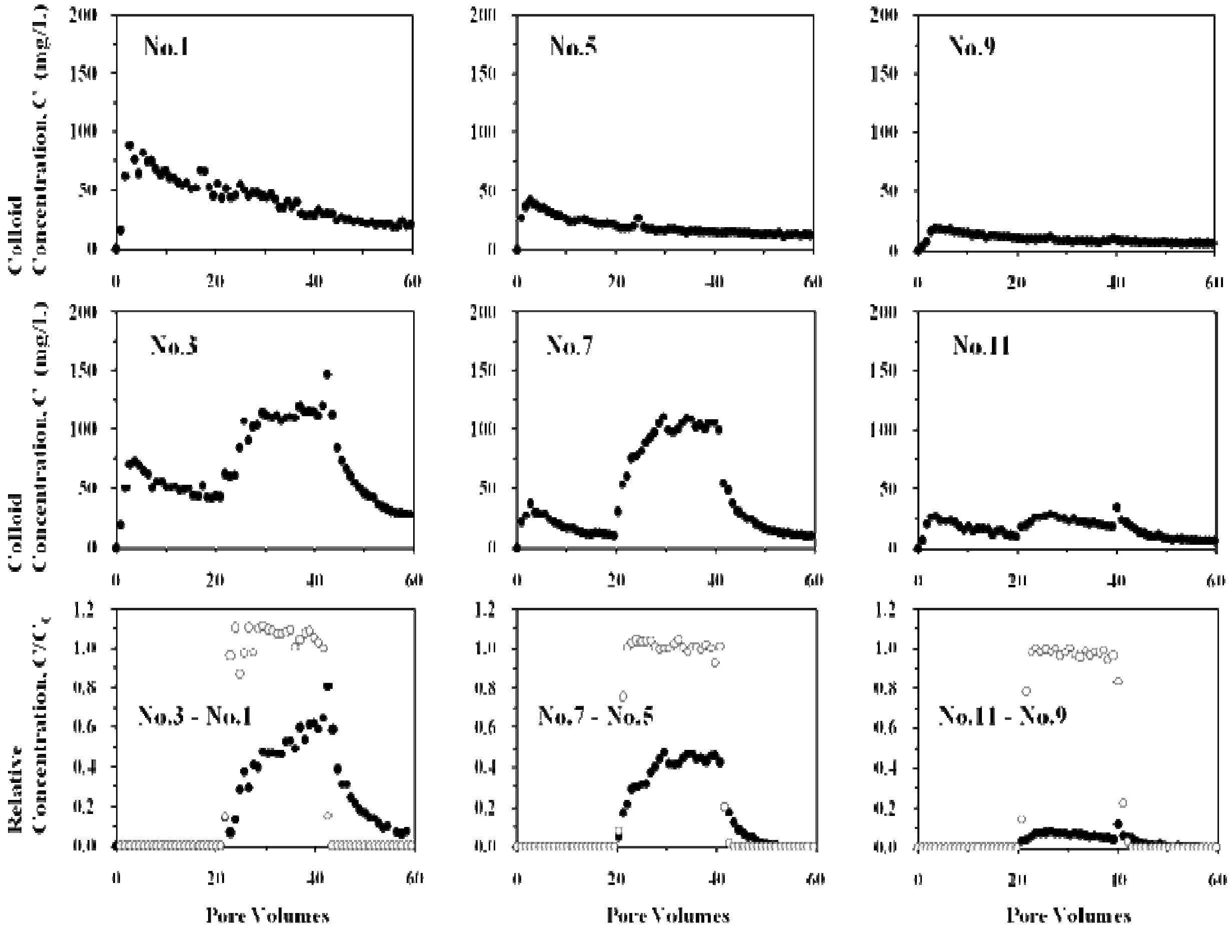

Figure 1. Results of colloid leaching from saturated repacked red-yellow soil columns at low flow rate-natural pH of influent, high flow rate-natural pH, and high flow rate-low pH conditions. No. 1, 5, and 9 represents mobilized natural colloid leaching breakthrough curves (BTC); No. 3, 7, and 11 represent natural and applied colloids BTC. The lowest figures show the breakthrough curves for the applied colloids obtained by the deduction of No. 1, 5, and 9 from No. 3, 7, and 11, respectively. Open circles represents BTC for tracer bromide ion.

Transport of applied water dispersible colloids

Breakthrough and breakdown curves of applied water dispersible colloids with natural colloid leaching curves are shown in Figure 1 No. 3, No. 7 and No. 11 for the three different conditions. Assuming that the leaching of natural colloids and transport of applied water dispersible colloids occur independently, the breakthrough and breakdown curves for applied water dispersible colloids (total colloids minus natural colloids) were obtained in Figure 1 (bottom three Figures).

The applied colloid breakthrough seemed to have reached plateau before breakdown, especially for high flow rate-natural pH. The curves also illustrate that both irreversible and reversible attachments of colloids are dominant in low flow rate condition but the irreversible attachment of colloids is more dominant in high flow rate conditions. Less tailing effect was observed for the transport of applied water dispersible colloids than for natural colloid leaching and thus, indicates that natural colloid leaching and transport of WDC follow a different kinetics. About 90% of the total applied colloids deposited at high flow rate and low pH conditions, while about 50% were leached for natural pH conditions indicating the significant effect of pH in colloid mobilization and transport.

The particles size distribution (PSD) of influent applied colloid is similar to the PSD of natural colloids (Figure 2).

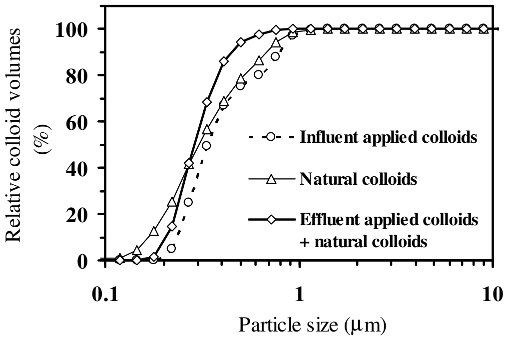

Figure 2. Particle size distribution for influent applied water dispersible colloids, effluent natural colloids, and total of effluent applied colloids and natural colloids.

Conclusion

A series of column experiment were conducted to investigate the leaching and transport of soil colloids from red-yellow soil. Continuous natural colloid leaching was observed when artificial rain water was applied at the top of the column. When water dispersible colloid solution was applied, about 50% of the colloids were recovered from the effluent without tailing for high and low flux at natural pH condition. However, almost all of applied colloids were retained (only 10% recovered) at high flux and low pH condition. Natural colloid leaching and applied colloid transport follow different transport mechanisms, although the parent material for the both condition is from the same red-yellow soil. The knowledge regarding the colloid fate and transport in natural soils, obtained from laboratory experiments and numerical analysis is required for better prediction of colloid facilitated transport of contaminants.

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