EFFECTS OF OXALATE AND HUMIC ACID ON ARSENATE SORPTION BY AND DESORPTION FROM A CHINESE RED SOIL

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Abstract. Studies on arsenate (As(V)) sorption and desorption have been mainly limited to soil minerals and sorption and desorption reactions in whole soils are poorly understood. In this study the sorption of As(V) by and phosphate-induced desorption from a Chinese red soil were studied in the presence of oxalate and humic acid (HA). Arsenate was strongly sorbed mainly through ligand exchange reactions on the soil. Arsenate sorption decreased in the presence of oxalate or HA. Oxalate and HA influenced As(V) sorption mainly by competing for sorption sites and reducing sorption sites, and oxalate could also decrease sorption through dissolving clay minerals. Oxalate and HA could also facilitate As(V) desorption from the soil. Both sorption and desorption kinetics were two stage processes. Sorption kinetics conducted from 0.2–840 h showed that As(V) sorption increased with increasing residence time. Sorption equilibrium was retarded and the maximum sorption decreased in the presence of oxalate or HA. Phosphate-induced desorption kinetics conducted on the soil with 24 h and 840 h of sorption equilibrium time showed a significant effect of equilibrium time on As(V) desorption. The presence of oxalate or HA during the sorption process resulted in more As(V) desorption. Due to the degradation of oxalate, soil treated with oxalate and with a sorption equilibrium time of 840 h showed no significant difference in desorption kinetics from untreated soil.

Keywords: arsenate, sorption, desorption, oxalate, humic acid, kinetics

1. Introduction

Elevated arsenic (As) concentrations in soils can originate from mining and smelting industries, wastewater irrigation, and application of As-containing pesticides, herbicides and fungicides (Smith *et al.*, 1998; Adriano, 2001). In some cases arsenic contaminated soil can present a potential to pollute surface water and groundwater or to enter the food chain through plant uptake and, therefore, has adverse effects on environmental and human health (Liu *et al.*, 2001; Nordstrom, 2002). Mobility, toxicity and bioavailability of As in soils are largely controlled by its sorption. It is therefore important to study the sorption of arsenic in soils in order to elucidate the fate of As in soils.

Arsenic occurs in soils mainly as arsenate (As(V)), which makes up 90% of the dissolved As in aerobic soils (Smith *et al.*, 1998). Arsenate has strong affinity for soil minerals and oxides, especially Fe and Al oxides and hydroxides (Livesey and

Huang, 1981; Violante and Pigna, 2002). Sorption of As(V) by soil minerals has been widely investigated and relevant mechanisms have been proposed (Anderson *et al.*, 1976; Lumsdon *et al.*, 1984; Fuller *et al.*, 1993; Goldberg and Johnston, 2001). Additionally, a great deal of research has been conducted to examine the effects of pH and electrolyte type on As(V) sorption by soil minerals (Liu *et al.*, 2001; Smith *et al.*, 2002; Cornu *et al.*, 2003). These studies mainly focused on soil minerals and the mechanisms were based on the As(V) reaction at the mineral-water interface. Soil is a heterogeneous mixture of organic matter, oxides, clay minerals and minerals and thus exerts complicated impacts on sorption of contaminants. Arsenate sorption on soil can not be explained completely by any of the mechanisms proposed for individual soil components. Therefore, the use of a whole soil to examine sorption mechanisms is necessary (Smith *et al.*, 2002; Violante and Pigna, 2002; Jiang *et al.*, 2005). The Chinese red soil, a main soil type in south China, shows a rather high sorption capacity for As(V) (Jiang *et al.*, 2005). Research on the sorption and desorption of As(V) in the soil is therefore of particular necessity.

The influence of inorganic ligands on As(V) sorption on soil or soils minerals has been documented by some researchers (Liu *et al.*, 2001; Violante and Pigna, 2002; Waltham and Eick, 2002). They found that As(V) sorption was significantly reduced in the presence of phosphate or silicic acid. However, research on the effects of organic ligands on As(V) sorption and desorption in soil is very limited (Liu *et al.*, 2001). Soil, especially the rhizosphere soil, has a relatively high content of low molecular weight organic anions, such as oxalate (Jones, 1998; De Cristofaro *et al.*, 2000). Humic acid accounts for a large part of soil organic carbon. Both of them are highly reactive toward metal oxides and clay minerals (Sibanda and Young, 1986; Bhatti *et al.*, 1998a, b; De Cristofaro *et al.*, 2000) and therefore may have a profound effect on As(V) sorption onto and desorption from soil. The only literature available for the effect of oxalate is a description of the phenomenon of competitive sorption of As(V) and oxalate on goethite (Liu *et al.*, 2001) and the relevant mechanism is poorly understood. Several studies have reported the influence of HA on As(V) sorption. Saada *et al.* (2003) studied As(V) sorption to kaolinite and reported that HA might provide sorption sites for As(V), thus enhancing its sorption. Grafe *et al.* (2001) demonstrated that HA and other forms of dissolved organic carbon decreased As(V) sorption on goethite and should therefore increase the bioavailability of As(V) in soil and water systems regardless of pH. Grafe *et al.* (2002) observed that the sorption processes of HA and As(V) on ferrihydrite were independent of each other and hence HA had no effect on As(V) sorption. These studies only reported the effects of HA on As(V) sorption on soil minerals and only considered arsenate sorption. Few data have been published on the effects of HA on arsenate sorption and desorption on soil.

The objective of this study was therefore to investigate (i) the As(V) sorption by and desorption from a Chinese red soil; (ii) the effects of HA and oxalate on the sorption and desorption of As(V); (iii) the effects of residence time on As(V) sorption and desorption in the presence of oxalate and HA.

2. Materials and Methods

2.1. MATERIALS

Soil was collected from the B horizon (15–30 cm depth) of a clay loam (Ultisol) in Jiangxi Province, southern China. Soil was air dried and passed through a 2-mm sieve. Total and amorphous iron and aluminum oxides were extracted by citrate-dithionite and ammonium oxalate, respectively, according to the method of Coffin (1963). Other properties for the soil, for example, pH, soil organic carbon, particle size distribution, were determined using standard methods (Sparks, 1996). Crystalline clay minerals in the soil were analyzed by X-ray diffraction (XRD) with Cu-K α radiation. Selected properties of the soil are presented in Table 1.

Sodium arsenate and sodium oxalate were of analytical reagent grade from Beijing Chemical Co (Beijing, China). The humic acid used was a commercial HA from Aldrich Chemical, Inc (St. Louis, USA). All other reagents used were of analytical reagent grade or better. The HA was used without further purification. The contents of dissolved organic C, total C and total N in the humic acid were 42.2%, 53.0% and 2.8%, respectively.

2.2. SORPTION ISOTHERMS

Sorption isotherms were constructed to determine the sorption behavior for arsenate (As(V)) to the Chinese red soil at pH 6.0 and a constant room temperature of 25 °C. Triplicate 1.00-g soil samples were equilibrated with 20 mL of background electrolyte solution of 0.01M NaNO₃ containing an As(V) concentrations ranging from 0 to 2.0 mM (from a stock solution of 10 mM sodium arsenate in 0.01M

TABLE I
Physicochemical properties of the soil

Property	
pH (1:1 in H ₂ O)	5.3
SOC (%)	0.66
Oxalate-extractable	
Fe (mg kg ⁻¹)	3469
Al (mg kg ⁻¹)	1339
Citrate-dithionite-extractable	
Fe (mg kg ⁻¹)	24995
Al (mg kg ⁻¹)	4402
Clay (%)	42.6
SSA (m ² g ⁻¹)	50.4
Minerals	quartz, kaolinite, mica, iron oxides

NaNO₃ at pH 6.0) in 50-mL polypropylene centrifuge tubes. A wide range of As(V) concentrations was selected in order to represent different contaminated conditions. Oxalate and HA were added, from stock solution and directly from the original reagent, respectively, to give initial concentrations of 1.0 or 10 mM oxalate and 0.5 or 5.0 g L⁻¹ HA. To understand the competition in sorption between As(V) and oxalate/HA, oxalate or HA was added in two ways, firstly by adding As(V) and oxalate/HA simultaneously and secondly by adding oxalate/HA in advance and shaking the soil suspension for 24 h and then adding the As(V). Two drops of toluene were added at the same time as the oxalate to inhibit soil microbial growth. The pH of the suspension was then adjusted to 6.0 and equilibrated for 24 h by shaking horizontally in darkness. The pH of the suspensions was kept constant by adjusting periodically using 0.1 M HCl when necessary. At the end of the equilibration period the suspensions were centrifuged at 7200 × g for 20 min, filtered through a 0.45-μm Millipore membrane, and analyzed for As (V), Fe, Al, Si, inorganic PO₄³⁻ (P), and dissolved organic carbon (DOC). For As sorption in the presence of oxalate or HA, the content of oxalate or DOC in the equilibrium solution was also determined. The amount of As(V) and oxalate or HA sorbed by the soils was calculated from the difference between the concentrations of the supernatant and those of the initial solutions. The amount of OH⁻ released into solution during As(V) sorption was also calculated using the method of Duquette and Hendershot (1993). In addition, specific surface areas of the soil samples treated with oxalate and HA as well as original soil were determined with a single-point BET N₂ adsorption isotherm.

2.3. DESORPTION OF ARSENATE

Since phosphate is ubiquitous in soils and could compete with As(V) for sorption sites (Violante and Pigna, 2002), it was used as a desorption reagent in the study. Therefore, desorption experiments were conducted by removing the equilibrium solution after centrifugation, replacing an equal volume of 6 mM phosphate desorbing solution and shaking the mixture for 24 h in darkness with periodical adjustment of the pH to its initial value. The solid/solution ratio, ionic strength, pH of the solution, and sampling methods were the same as for the sorption studies. The total percentage of As(V) desorbed was calculated by comparing the differences between the As(V) adsorbed previously and the amount desorbed.

2.4. SORPTION AND DESORPTION KINETICS

Sorption kinetic experiments were performed with initial As(V) concentrations of 0.2 and 2.0 mM at pH 6.0 in the presence and absence of 10 mM oxalate or 5.0 g L⁻¹ HA. Other parameters were the same as described for the sorption isotherm experiments. Samples were taken from the batch treatments over periods varying from 0.2 h to 840 h. Desorption kinetics were conducted on the soil samples with

sorption equilibrium times of 24 h and 840 h independently. Desorption time ranged from 0.5 h to 840 h.

2.5. ANALYSIS AND STATISTICS

Arsenate in solutions was determined by hydride generation atomic fluorescence spectrometry (Beijing BRAIC, China). No As(III) was detected in the equilibrium solutions. Fe, Al, P and Si in the final solutions were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES; OPTIMA2000DV, Perkin Elmer). Oxalate and phosphate were analyzed by a P/ACE MDQ capillary electrophoresis system from Beckman (Fullerton, CA, USA.) equipped with a UV detector. Dissolved organic carbon was determined by a Phoenix 8000 TOC analyzer.

All the data were obtained by analysis of triplicate subsamples. Statistical analysis was performed using SPSS (Statistical Package for Social Science) v. 10.0 and Origin 7.0.

2.6. QUALITY ASSURANCE FOR ARSENIC DETERMINATION

Quality assurance for As determination was carried out by the determination of total As in soil certified reference materials (GBW 07408 and GBW 08302) obtained from the National Research Center for Certified Reference Materials (Beijing, China). Seven replicate analyses were made of each reference material. The results obtained were $12.1 \pm 1.0 \mu\text{g g}^{-1}$ and $4.0 \pm 0.3 \mu\text{g g}^{-1}$ of As for GBW 07408 and GBW 08302 compared with the certified values of $12.7 \pm 1.7 \mu\text{g g}^{-1}$ and $3.8 \pm 0.4 \mu\text{g g}^{-1}$ of As. Our results were not statistically significantly different from the certified values ($p < 0.01$).

3. Results and discussion

3.1. ARSENATE SORPTION IN THE RED SOIL

Sorption isotherms of As(V) in the red soil with and without oxalate or HA are presented in Figure 1. The lines represent the fits of the data to the Freundlich sorption isotherm equation (shown as the solid lines in Figure 1). The results from Freundlich equation fittings are listed in Table 2. The equation showed significant correlation with R values ranging from 0.996 to 0.998 ($p < 0.01$). The As(V) sorption generally increased with increasing initial As(V) concentrations from 0 to 2.0 mM, and the soil showed a rather higher sorption capacity for As(V) compared with the reported data for As(V) sorption on soils (Livesey and Huang, 1981; Jiang *et al.*, 2005). The XRD analysis indicated only minor amounts of iron oxides in the soil. However, the ratios of oxalate to citrate-dithionate extractable Al and Fe

TABLE II
Parameters of the Freundlich equation for As(V) sorption by the soil in the presence and absence of oxalate or HA

	K (mmol ¹⁻ⁿ L ⁿ kg ⁻¹)	n	r^2
Original soil	11.03 ± 0.20	0.298 ± 0.013	0.995
Soil + 0.001 M Oxalate	7.07 ± 0.10	0.415 ± 0.017	0.995
Soil + 0.01 M Oxalate	6.26 ± 0.12	0.401 ± 0.022	0.992
Soil + Pre-0.01 M Oxalate	8.31 ± 0.10	0.358 ± 0.012	0.997
Soil + 0.5 g L ⁻¹ HA	6.78 ± 0.09	0.413 ± 0.016	0.996
Soil + 5 g L ⁻¹ HA	6.96 ± 0.12	0.399 ± 0.020	0.993
Soil + Pre-5 g L ⁻¹ HA	8.81 ± 0.10	0.367 ± 0.012	0.997

K is the Freundlich sorption coefficient and n (dimensionless) describes isotherm curvature.

(0.30 for Al and 0.14 for Fe) suggested that significant proportions of Al and Fe were in forms of low crystallinity (Johnson *et al.*, 1986). This accounted for the high sorption capacity of the soil (Livesey and Huang, 1981; Jiang *et al.*, 2005).

With the increasing As(V) sorption, significant enhancements in the release of dissolved organic carbon (DOC) and the major inorganic anions, such as OH⁻ and PO₄³⁻, were observed (Table 3). Arsenate sorption could account for the release of the anions from the soil through the ligand exchange with soil organic carbon and other anions (Arai *et al.*, 2005). Weakly complexed anions and some of the soil organic carbon (mainly aliphatic carboxyl) on the soil surface could be substituted by As(V) via competition for the sorption sites because both As(V) and the anions could occupy common sorption sites (Anderson *et al.*, 1976; Livesey and Huang, 1981; Arai *et al.*, 2005). Surface precipitates might also occur in the soil since the bulk solution was far beyond saturation with respect to the solubility of iron or aluminium arsenate (Livesey and Huang, 1981; Fuller *et al.*, 1993). However, if precipitation predominated in the soil, we would not expect the obvious enhancement in the release of dissolved Al and Fe since these cations would otherwise precipitate with As(V) in the system. Table 3 shows an increase in the dissolved Fe and Al with increasing As(V) sorption together with a parallel increase in DOC. Some of the organic ligands released from the soil along with As(V) sorption could chelate metal ions in solution, such as Fe and Al, resulting in the release of Fe and Al ions from the soil surface in turn.

3.2. EFFECTS OF OXALATE AND HA ON THE SORPTION OF ARSENATE IN THE SOIL

Arsenate sorption significantly decreased in the presence of oxalate or HA (Figure 1), and the maximum reductions of 36.7% and 40.1% were obtained in the presence of 10 mM oxalate and 5.0 g L⁻¹ HA, respectively, indicating that both oxalate and HA could suppress As(V) sorption.

Figure 1. Arsenate sorption isotherms of the red soil in the presence and absence of (a) oxalate, (b) HA at pH 6.0. Background electrolyte: 0.01 M NaNO₃; solid/solution: 50 g L⁻¹. Pre-indicates oxalate or humic acid addition 24 h before As(V) addition.

Because of the complex nature of soil components, the effect of oxalate or HA on As(V) sorption could result from different factors. First, in a similar way to As(V), oxalate could be retained on soil surfaces through ligand exchange (Bhatti *et al.*, 1998b). Humic acid is rich in phenolic/catecholic OH⁻ and may also compete with As(V) for surface sorption sites (Grafe *et al.*, 2001). So oxalate and HA could inhibit As(V) sorption in soil through competition for sorption sites. Figure 2 shows the relationship between the sorption of As(V) and oxalate/HA. There was a significant negative correlation between oxalate/HA and As(V) sorbed with correlation coefficients (R) of 0.986 for oxalate and 0.990 for HA ($p < 0.01$). Competition

TABLE III
Release of Fe, Al, OH⁻, Si, PO₄³⁻, and dissolved organic C (DOC) from the soil during the As(V) sorption isotherm in the absence of oxalate or HA at pH 6.0.

As(V) added (mmol kg ⁻¹ soil)	Amount released (mmol kg ⁻¹ soil)					
	Fe	Al	Si	PO ₄ ³⁻	DOC	OH ⁻
0	0.01	0.16	0.67	0.001	17.3	0
1	0.02	0.21	0.84	0.003	18.1	1.34
2	0.03	0.25	0.93	0.004	18.6	2.27
4	0.05	0.29	0.97	0.005	19.1	4.23
8	0.12	0.60	0.99	0.008	20.0	5.16
16	0.23	0.75	1.34	0.014	21.1	9.70
24	0.25	0.82	1.54	0.018	22.6	11.6
32	0.27	0.91	1.71	0.029	24.8	13.7
40	0.31	1.04	1.85	0.030	26.3	14.4

The measurements were in triplicate, with the uncertainty being generally less than $\pm 5\%$.

between As(V) and oxalate/HA became more evident with increasing As(V) added to the solution, and more sorption sites occupied by oxalate/HA were replaced by As(V) since the amounts of oxalate/HA amendments were constant. Oxalate or HA released could form soluble complexes with Fe and Al, thus with the increase in oxalate and HA in solution caused by sorption, the release of Fe and Al significantly increased ($p < 0.01$).

Arsenate sorption declined more when oxalate was added 24 h before As(V) addition compared with the results for simultaneous addition of oxalate and As(V). But the difference was not significant for HA. It has been confirmed that both oxalate/HA and As(V) sorption are time-dependent (Fox *et al.*, 1990; O'Reilly *et al.*, 2001). If competition for sorption sites was the only way that oxalate/HA affected As(V) sorption, such effects should also be affected by residence time and we would not get the conflicting data on the comparative effects of oxalate and HA sorption. The results suggested that oxalate and HA could exert influence on As(V) sorption in some other ways apart from competition for sorption sites. Dissolution of clay minerals including poorly crystalline (amorphous) Fe and Al oxides and thus decrease in sorption sites could also occur when oxalate or HA is added. Organic acids, especially the simple aliphatic acids such as oxalate have been observed to accelerate the dissolution of mineral surfaces (Jones, 1998; Eick *et al.*, 1999). Comparing Table 3 and Figure 2, we can see a great differences in Fe and Al concentrations between the systems with and without oxalate or HA. If the soluble Fe and Al were only caused by complexation, we would not expect such big differences. Specific surface area determination shows the specific surface area of the soil was reduced by 33.8% with oxalate and by 59.6% with

Figure 2. Relationships among oxalate (a)/ HA (b) sorption and amount of Fe, and Al released during the As(V) sorption isotherms at pH 6.0 shown in Figure 1. Concentrations of oxalate and HA added were 1.0 mM and 0.5 g L⁻¹, respectively.

HA after equilibration for 24 h, thus indicating that oxalate and HA amendments significantly affected the soil surface characteristics and consequently the number of sorption sites (Kaiser and Guggenberger, 2003). Humic acid could also enhance soil aggregation possibly by bridging or flocculation, which could improve soil structure and thus reduce sorption sites (Piccolo and Mbagwu, 1999; Bronick and Lal, 2005). However, such an effect might be minor compared with the mineral dissolution by oxalate.

3.3. EFFECTS OF OXALATE AND HA ON ARSENATE DESORPTION

Figure 3 shows As(V) desorption by 6 mM phosphate at pH 6. After 24 h only about 35 to 55% of the adsorbed As(V) was desorbed because of its high affinity for soil components (Violante and Pigna, 2002). The amounts of As(V) desorbed from the

sorption subsamples tended to increase with increasing As(V) loadings. However, the changes in the desorption ratio, defined as the ratio of the desorbed fraction to the total amount of As(V) adsorbed, were not obvious at the various As(V) concentrations studied, indicating that as the amount of As(V) absorbed increased, the desorbed fraction also increased correspondingly. The desorption ratio of As(V) in the presence of oxalate or HA was about 10% higher than that without oxalate or HA. The phenomenon that adsorbed As(V) were more easily desorbed in the presence of oxalate or HA could be attributed to the reduction in sorption sites because of the effects of oxalate or HA on the soil surface characteristics (Kaiser and Guggenberger, 2003). In addition, the oxalate or HA sorbed on the subsamples could be released into the solution in the desorption process (Sibanda and Young, 1986; Bhatti *et al.*, 1998a; Violante and Pigna, 2002) and thus would also facilitate As(V) desorption.

3.4. KINETICS OF ARSENATE SORPTION AND DESORPTION IN THE PRESENCE OF OXALATE AND HA

Figure 4 shows the kinetics of As(V) sorption in soil in the presence and absence of oxalate and HA at pH 6.0 with As(V) concentrations of 0.2 and 2.0 mM over a period of 0.2 h to 840 h. Arsenate sorption was characterized by an initial fast and then a very slow rate of sorption. The two-stage sorption kinetics observed in this experiment was similar to the results for As(V) sorption on goethite reported by O'Reilly *et al.* (2001).

In the presence of oxalate or HA, As(V) sorption within 24 h was decreased by 34.6% and 36.2%, respectively, for the samples with the initial As(V) loading of

Figure 3. Desorption of As(V) by phosphate (6.0 mM) at pH 6.0. Background electrolyte: 0.01 M NaNO₃; solid/solution: 50 g L⁻¹. The desorption samples had been incubated with 24 h in the presence and absence of oxalate or HA.

Figure 4. Arsenate [(a) 0.2 mM, (b) 2.0 mM] sorption kinetics in the red soil in the presence of oxalate and HA at pH 6.0. Background electrolyte: 0.01 M NaNO_3 ; solid/solution: 50 g L^{-1} .

0.2 mM. Similar results were obtained for the samples with 2.0 mM As(V) loading. At the same time, sorption equilibrium was retarded and the maximum As(V) sorption decreased by 8.1% and 16.1% in the presence of HA at As(V) loadings of 0.2 and 2.0 mM. This phenomenon could be attributed to the surface complexes and competition for sorption sites as well as the unfavorable electrostatic field generated from HA sorption (Sibanda and Young, 1986). No effect of oxalate was observed on As(V) sorption after a long equilibrium period, which could be the result of biodegradation of oxalate by soil microbes (Fox *et al.*, 1990). Although toluene was added to retard microbial growth in the samples in our study, microbial activity was inhibited for only a short time (O'Keefe *et al.*, 1987).

Arsenate desorption kinetics (Figure 5) was also characterized by an initial fast and then a slower reaction. More than 41% and 35% of As(V) were desorbed within 24 h for the samples without oxalate or HA for 24 h and 840 h equilibrium time, respectively, followed by a small amount of additional desorption during the subsequent period of the experiments. There were apparent effects of both sorption

Figure 5. Arsenate desorption kinetics by phosphate (6.0 mM) at pH 6.0. Background electrolyte: 0.01 M NaNO_3 ; solid/solution: 50 g L^{-1} . The samples had been incubated with sorption residence times of (a) 24 h and (b) 840 h in the presence and absence of oxalate or HA.

equilibrium time and the presence of oxalate or HA on As(V) desorption. The slow desorption reactions were more noticeable for the samples with longer equilibrium times. After 840 h the total desorption ratio reached about 50% and 41% for the samples with the sorption equilibrium time of 24 h and 840 h, respectively. The results indicate that a significant amount of As(V) was still retained in the soil even after 840 h of desorption since the phosphate added was three times higher than the initial As(V) concentration for the sorption experiments, which is in agreement with the observations of O'Reilly *et al.* (2001).

The previously sorbed oxalate and HA facilitated the desorption of As(V) from soil. Due to the degradation, oxalate had no significant influence on desorption kinetics for the samples with a residence time of 840 h. While HA always promoted

As(V) desorption from soil mainly through affecting soil surface characteristics as stated above. Similar desorption kinetics were obtained from the sorption samples at the lower As(V) loading (0.2 mM) (data not shown).

4. Conclusions

Our results illustrate several important aspects of the sorption and desorption of As(V) in this Chinese red soil. Arsenate was strongly sorbed mainly through ligand exchange on the soil. The presence of oxalate/HA retarded the sorption equilibrium, decreased the maximum sorption and increased the desorption of As(V) from soil. Oxalate and HA affected As(V) sorption on the soil through competition for sorption sites and reduction of sorption sites, and the effect of these mechanisms were not completely the same. Oxalate and HA could also facilitate As(V) desorption from the soil. Kinetic studies revealed that As(V) sorption involved an initial fast and then a subsequent slow sorption reaction. Oxalate and HA exerted similar effects on sorption and desorption kinetics of As(V) in the soil.

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