

Cadmium Distribution and Migration as Influenced by Polymer Modifiers in a Loam Soil

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Abstract: *This paper studies the influence of four modifiers (organic-inorganic composite modifiers, inorganic polymer compound modifiers, polyacrylate compound modifiers, organic polymer compound modifiers) on soil pH, cation exchange capacity (CEC), Cd concentration and their distribution and migration in the soil profile under high Cd concentration (40 mg/kg) during continuous remediation tub experiment. The results showed that: (1) Four modifiers significantly increased the pH and CEC in each soil layer, and inorganic polymer compound modifiers providing the best results in the 0–20 cm soil layer. (2) There is an extremely significant negative correlation between the carbonate-bound Cd and exchangeable Cd, with considerable effect in the 0–20 cm and 20–40 cm soil layers. The inorganic polymer compound modifiers had the best effect on the soil exchangeable Cd. (3) Both pH and CEC in all soil layers were negatively correlated with exchangeable Cd and positively correlated with other forms. (4) Fourier transform infrared spectrometry (FTIR) analysis showed that the modifiers immobilize soil Cd mainly through chemical precipitation, complexation and adsorption so as to reduce the bioavailability of Cd. Thus, we concluded that four modifiers are suitable for Cd mediation/Cd stabilization purposes.*

Keywords: *Cadmium, Liquid polymer modifier, Soil Cd form distribution, Profile distribution*

1. Introduction

Cadmium (Cd) is generally regarded as one of the most widespread and harmful farmland pollutants. In China, approximately 2.0×10^7 hm² of arable land has been contaminated by toxic metals and the area of farmland polluted by Cd has reached 2.8×10^5 hm² [1-11]. In the Kohistan region, northern Pakistan, the Cd concentration in soil ranged from 0.4 mg kg⁻¹ to 184 mg/kg [12]. Soils at Le Gurnigel, Swiss Jura Mountains contain Cd concentration with a maximal value recorded in the subsoil of 16.3 mg/kg [13]. It can be seen that soil in the world are heavily polluted by toxic metals. At the same time, high Cd concentration can have toxic effects on soil and can easily transport into plants and ultimately enter the food chain. Therefore, the remediation of toxic metals couldn't be limited to low-contaminated remedy. The process of adding high-contaminated Cd by hand assisted in the observation and analysis of the dynamically changing migration of soil Cd [14-25].

As a low-input and highly-effective method for controlling toxic metals pollution, chemical passivation technology can alter the form and bioavailability of toxic metals in a direct or indirect way by the addition of chemical modifiers [26]. The carboxyl and amide groups of polyacrylamides can form coordination bonds with metal ions on the surface of soil particles to form complexes [27]. Polyacrylate polymers can reduce the bioavailable Cd, it seems a promising method to enhance productivity of plants grown on Cd-contaminated soils [28]. Therefore, polymer materials have a good effect on toxic metals remedy. At the same time, it is clear that the influence of liquid polymer modifiers on soil Cd migration and transform is a new challenge faced by farmland drip irrigation system [29-35].

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Therefore, based on cotton planting under a high-contaminated Cd pollution, four independently-developed liquid polymer modifiers were added to the soil profile. The study analyzed the distribution of soil profile Cd of drip-irrigated cotton fields in Xinjiang Province northwest China, and explored the processes governing Cd migration and transformation in soil. The knowledge gained from this study is vital for the effective control of Cd pollution in cotton fields.

2. Material and methods

2.1. Test Site Condition

Test soil (Loam soil) was obtained from the Test Station of the Agricultural College, Shihezi University in Shihezi City, Xinjiang Province, China (86°03'E, 45°19'N). The soil pH and cation exchange capacity (CEC) of the soil were 7.76 and 16.25 coml/kg, respectively, total nitrogen and organic matter concentration were 0.89 and 13.25 g/kg, respectively and alkali-hydrolyzable nitrogen, available phosphorus and available potassium concentration were 60, 20, and 250 mg/kg, respectively. Cultivated layer soil had a Cd concentration of 0.25 mg kg⁻¹ and available Cd concentration of 0.15, 0.02, 0.01, and 0.01 mg/kg in the 0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm soil layers, respectively.

2.2. Test Program

The continuous remediation test was conducted at the Test Station of the Agricultural College, Shihezi University in Shihezi City, Xinjiang Province northwest China from April 5th to September 5th, 2017, and April 5th to September 5th, 2018. The test involved one Cd contamination treat, four modifier treatments, namely V1 (organic-inorganic composite modifiers), V2 (inorganic polymer compound modifiers), V3 (polyacrylate compound modifiers) and V4 (organic polymer compound modifiers), a treatment with no modifier addition as control group, a total of five treatments, three repetitions per treatment and a random group arrangement. The four modifiers were independently developed, basic properties of modifiers as shown in (**Table 1**). Cotton (Xinluzao 60) was chosen as the barrel-planted test crop. The original soil was packed into a plastic bucket (length × width × height = 30 cm × 30 cm × 80 cm), which were then buried back into the field to maintain the stress effect. Based on previous studies and pre-test results, cadmium chloride (CdCl₂•2.5H₂O) solution was added into the barrels and mixed fully in the plough layer. The Cd concentration in a plough layer reaches approximately 40 mg/kg in the dry soil after three weeks. On April 26th, 2017, an addition of urea (345 kg/hm²) and compound fertilizer (17-17-17) (555 kg/hm²) was conducted. On April 30th, 2017, four modifiers (8.48 kg/hm²) were added diluted with water. After emergence, six seedlings were planted in each barrel. The seedlings were irrigated for the first time on June 11th. The irrigation cycle was 5 days during the growth period. The irrigation volume was 4500 m³/hm². No fertilizers and modifiers were added at later stages. After the first harvest, the soil in each barrel was mixed and removed soil samples were collected from the 0–20, 20–40, 40–60, and 60–80 cm layers for analysis. Modifiers, urea and compound fertilizers at the rate used above were added and no cadmium is added before the second crop was planted. The same growing and harvesting methods used for the first crop were used for the second crop.

2.3. Measurement methods

The soil available Cd was extracted using diethylenetriaminepentaacetic acid (DTPA) reagent [36]. We adopted five-step continuous extraction [37] for grading soil Cd forms. The extracting agent and order were as follows: 1 mol/L MgCl₂ solution for the extraction of exchangeable Cd (EXE), 1 mol/L NaAc solution for extraction of carbonate-bound Cd (CARB), 0.04 mol/L NH₂OH•HCl solution for extraction of FeMnO, 0.02 mol/L HNO₃ and 6 mL 30% H₂O₂ for extraction of organic Cd (Org),

10 mL aqua regia and 10 mL perchloric acid for extraction of residual Cd (Res). The Cd concentration in the decoction liquid and extract was measured using a Hitachi Z2000 graphite atomic absorption spectrophotometer (PinAAcle900T, PerkinElmer, USA).

The soil pH was measured using a PHS-P acidity meter and the water-soil ratio was 2.5:1. The soil cation exchange capacity (CEC) was measured using the soil sodium acetate exchange method [38-45].

Infrared spectroscopy analysis was adopted using the KBr pressed-disk method with a scanning range of 4 000 – 400 cm^{-1} and a resolution 2 cm^{-1} .

2.4. Data Analyses

The data were processed using Excel 2016 (Microsoft, USA), and the one-way analysis of variance (ANOVA) was performed using SPSS 23.0 (SPSS Inc., Chicago, IL, USA). Multiple comparisons between different treatments were conducted using Duncan's new multiple range method (significance level: $\alpha = 0.05$). The charts were drawn using Origin 8.0 (Origin Lab, Massachusetts, USA).

Table 1. Basic properties of modifiers used

Treatment	Material	Notes
CK	\	\
V1	Modifier I	An organic-inorganic composite modifiers based on potassium dihydrogen phosphate, a colorless liquid, which can enhance soil pH, increase the negative charge on the soil surface and strengthen metal adsorption.
V2	Modifier II	An inorganic polymer compound modifiers mainly composed of polyaluminum chloride. This is a light yellow liquid that features in surface adsorption, surface complexation etc., and can be electrically neutralized and co-precipitated with metal.
V3	Modifier III	A compound modifiers composed of polypropylene and iron sulfate. A colorless liquid that features in surface adsorption and co-precipitation for metals
V4	Modifier IV	An organic polymer compound modifiers mainly based on polyacrylamide and manganese sulfate. A colorless liquid that features in surface adsorption, surface complexation etc.

3. Result and discussions

3.1. Total and Available Cd Concentration in Topsoil

This is Cd concentration in topsoil after two growing seasons of continuous remediation (Figure 1). In the first harvest and second harvest, there was no significant difference in total Cd concentration between the treatments. Addition of modifiers in the V2 and V4 treatments significantly reduced available Cd concentration compared to the CK treatment for both harvests ($P < 0.05$). In the first harvest, compared with the CK treatment, available Cd concentration was decreased by 16.23 and 9.99% in the V2 and V4 treatments, respectively. In the second harvest, compared with the CK treatment, available Cd concentration was decreased by 17.38, 20.25, 15.98, and 19.66% in the V1, V2, V3, and V4 treatments, respectively.

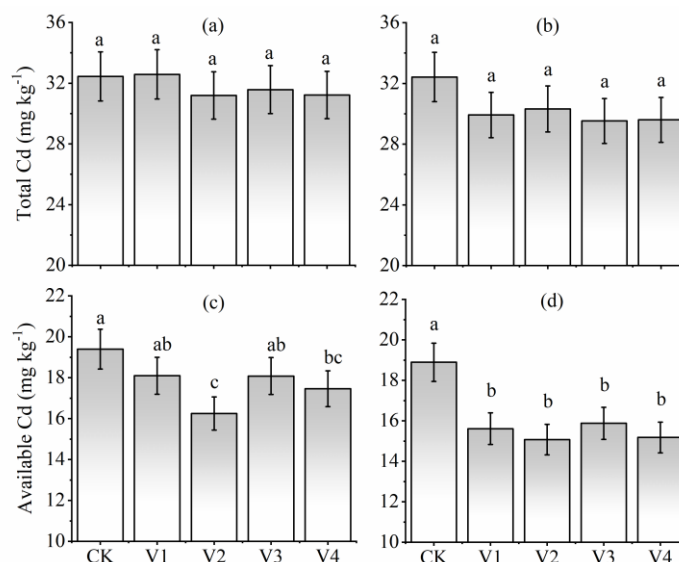


Figure 1. Soil total Cd and available Cd concentration in topsoil. Cd concentration in the (a), (c) first harvest and second harvest (b), (d). Different lowercase letters indicate a significant difference ($P < 0.05$)

3.2. The Influence of Modifiers on Soil Cd form in Topsoil

As shown in Figure 2, the order of all forms of topsoil Cd was EXE > Org > Res > FeMnO > CARB for both harvests. Addition of modifiers reduced exchangeable Cd concentration, and increased carbonate-bound Cd, Fe-Mn oxides-bound Cd, Organic Cd and residuals Cd concentration compared to the CK treatment for both harvests. In the first harvest, compared with the CK treatment, exchangeable Cd concentration was decreased by 8.11-19.39% ($P < 0.05$). In the second harvest, compared with the CK treatment, exchangeable Cd concentration was decreased by 31.98-56.03% ($P < 0.05$).

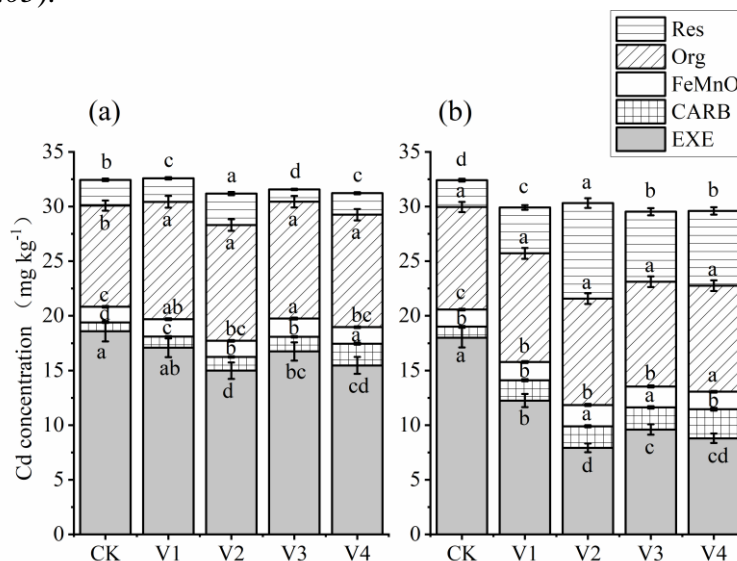


Figure 2. Soil Cd form in topsoil. Cd concentration in the first harvest (a) and second harvest (b). EXC, CARB, FeMnO, Org and Res indicate exchangeable Cd, carbonate-bound Cd, Fe-Mn oxides-bound Cd, Organic Cd and residuals Cd, respectively. Different lowercase letters indicate a significant difference ($P < 0.05$)

3.3. Total and Available Cd Concentration in the Soil Profiles

The influence of the addition of the four modifiers on total Cd and available Cd in the soil profiles is shown in Figure 3, the soil total Cd concentration was 31.22 – 32.58 mg/kg at the 0 – 20 cm layer, 3.93 – 4.10 mg/kg at the 20 – 40 cm layer, 1.96 – 2.09 mg/kg at 40 – 60 cm layer, and 1.33– 1.41 mg/kg at the 60 – 80 cm layer. It was evident that soil profile total Cd concentration decreased significantly with an increase in soil depth ($P < 0.05$). The total Cd in soil was mainly concentrated in the 0– 20 cm surface layer; however, the differences between total Cd soil concentration for various treatments were minor.

Figure 3 show that the soil available Cd concentration was 16.25 – 19.40 mg/kg at 0 – 20 cm, 1.49 – 1.98 mg/kg at 20 – 40 cm, 0.96 – 0.99 mg/kg at 40 – 60 cm, and 0.15 – 0.54 mg/k at 60 – 80 cm. The change in soil available Cd concentration was similar to that of soil total Cd. The soil profile available Cd concentration also decreased significantly with an increase in soil depth ($P < 0.05$). The available Cd was mainly concentrated in the 0 – 20 cm layer, and differences in the soil available Cd concentration with different treatments were evident.

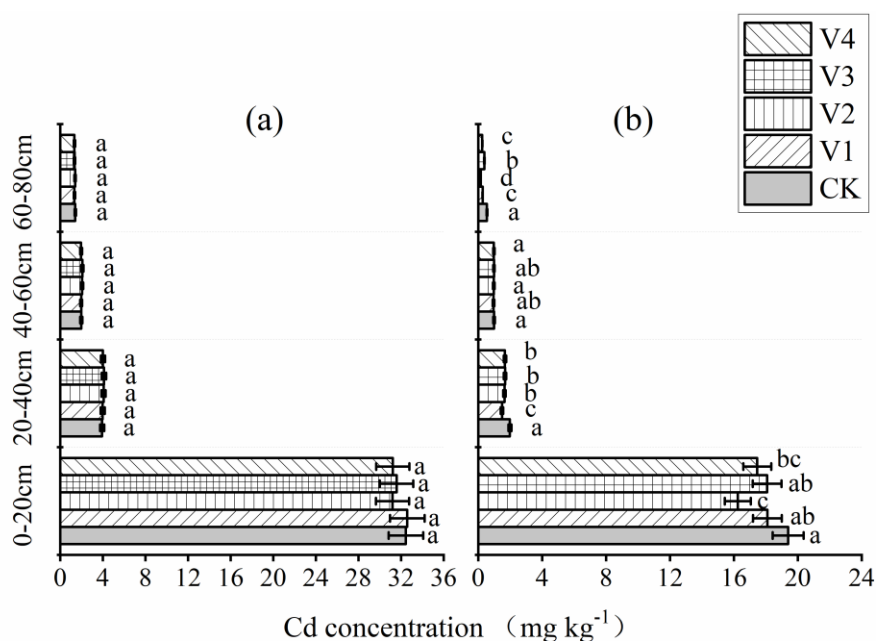


Figure 3. Effect of different treatments on cadmium concentration in the soil profiles. Soil total Cd (a) and available Cd (b) concentration. Different lowercase letters indicate a significant difference ($P < 0.05$).

3.4. The Influence of Modifiers on Soil Cd form in the Soil Profiles

Figure 4 shows the influence of adding the four modifiers on the Cd form in different soil layers. As shown in this Figure, compared with the CK treatment, the soil exchangeable Cd concentration in the 0 cm – 20 cm soil layer in the V2, V3, and V4 treatments significantly decreased by 3.61, 1.85, and 3.13 mg/k, respectively ($P < 0.05$), carbonate bounded Cd in the V1, V2, V3, and V4 treatments significantly increased by 0.21, 0.46, 0.54, and 1.19 mg/kg, respectively ($P < 0.05$), Fe-Mn bounded Cd in the V1 and V3 treatments significantly increased by 0.17 and 0.24 mg/kg, respectively ($P < 0.05$), organic bounded Cd in the V1, V2, V3, and V4 treatments significantly increased by 1.48, 1.33, 1.43, and 1.03 mg/kg, respectively ($P < 0.05$), residual Cd in

the V2 treatment significantly increased by 0.52 mg/kg ($P < 0.05$). In 20 – 40 cm soil layer, exchangeable Cd concentration in the V1, V2, V3, and V4 treatments significantly decreased by 0.50, 0.42, 0.33, and 0.42 mg/kg, respectively ($P < 0.05$), whereas the V4 treatment increased carbonate bounded Cd by 0.12 mg kg⁻¹, the V3 treatment increased Fe-Mn bounded Cd by 0.07 mg/kg, the V1 treatment increased organic bounded Cd by 0.37 mg/kg, and the V2 treatment increased residual Cd by 0.11 mg/kg. The soil exchangeable Cd concentration did not decrease significantly in the 40 cm – 60 cm soil layer, whereas the V1, V2, V3 and V4 treatments significantly decreased soil exchangeable Cd concentration in the 60 – 80 cm soil layer at rates of 0.27, 0.38, 0.21, and 0.36 mg/kg, respectively ($P < 0.05$). Exchangeable Cd concentration decreases, whereas that the carbonate bounded Cd, Fe-Mn bounded Cd, organic bounded Cd and residual Cd increased, which indicates that the addition of four modifiers can stabilize the Cd, and reduce Cd bioavailability and mobility. The abilities of the four modifiers treatments to stabilize Cd were rated as V2 > V4 > V3 > V1. The responses to the stabilizing effect of the modifiers on Cd were different for the different soil layers. The stability effect was as follows: 0 – 20 cm > 20 – 40 cm > 60 – 80 cm > 40 – 60 cm.

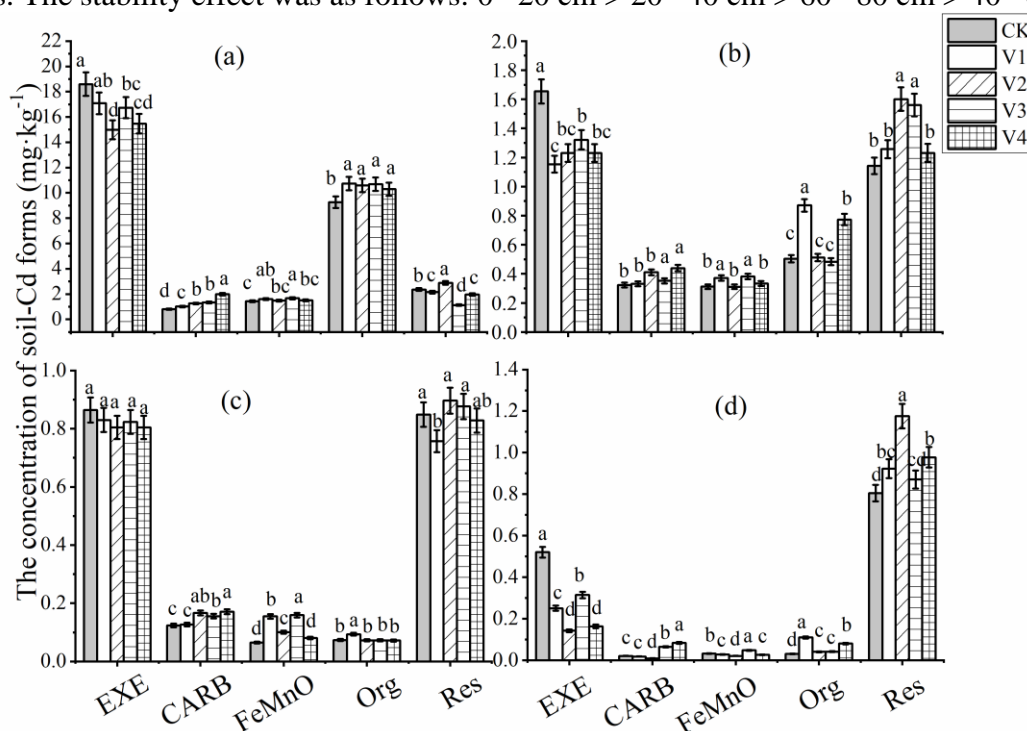


Figure 4. The influence of different treatments on the Cd form in different soil layers. (a) 0 -20 cm soil layer, (b) 20 -40 cm soil layer, (c) 40 -60 cm soil layer, (d) 60 -80 cm soil layer. Different lowercase letters indicate a significant difference ($P < 0.05$)

3.5. Influence of Modifiers on Soil pH and CEC

The addition of the four modifiers significantly ($P < 0.05$) increased soil pH (Figure 5), with the highest effect in the 0 cm – 20 cm soil layer. Compared with the CK treatment, the V1, V2, V3, and V4 treatments increased soil pH by 2.57, 5.52, 2.62, and 3.76%, respectively. The V4 treatment had the greatest effect on increasing pH in the 20 – 40 cm soil layer. No significant difference in soil pH from the five treatments in the 40 – 80 cm soil layer.

The addition of the four modifiers increased soil cation exchange capacity (CEC) (Figure 5). In 0 cm – 20 cm layer, compared with CK, the V1, V2, V3, and V4 treatments increased soil CEC by 1.35, 4.43, 1.56, and 2.61 cmol/kg, respectively, in the 20 – 40 cm soil layer, CEC increased by

4.95, 3.43, 4.69, and 8.08 cmol/kg, respectively, in the 40 – 60 cm soil layer, CEC increased by 3.01, 2.33, 2.97, and 0.99 cmol/kg, respectively, and in the 60 – 80 cm soil layer, CEC increased by 3.01, 0.99, 2.97, and 2.33 cmol/kg, respectively. It is evident that the modifiers have the best effect on CEC in the 20 –40 cm soil layer.

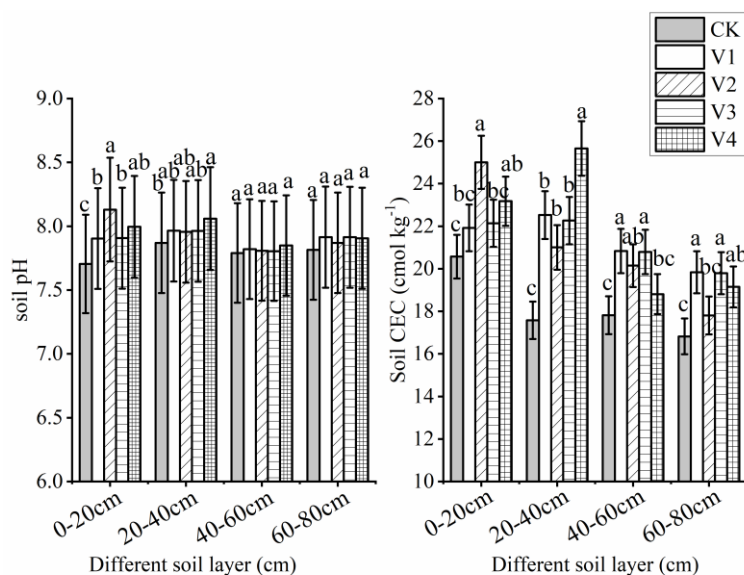


Figure 5. Effect of applying modifiers on soil pH and cation exchange capacity (CEC). Different lowercase letters indicate a significant difference ($P < 0.05$).

3.6. Analysis of Correlation Between Chemical form of Soil Cd and pH and CEC After Adding Modifiers

The correlation coefficients (r) between soil pH, CEC and Cd forms in different soil layers and results of significance tests are shown in Table 2. In the 0 – 20 cm soil layer, soil pH was negatively correlated with the exchangeable Cd ($P < 0.01$), but positively correlated with the carbonate bounded Cd, Fe-Mn bounded Cd, organic bounded Cd, and residual Cd ($P < 0.01$). CEC was negatively correlated with exchangeable Cd ($P < 0.01$), but positively correlated with organic bounded Cd ($P < 0.01$). Exchangeable Cd was negatively correlated with carbonate bounded Cd and organic bounded Cd ($P < 0.01$). In the 20 – 40 cm soil layer, soil pH was negatively correlated with exchangeable Cd ($P < 0.01$), but positively correlated with the carbonate bounded Cd and Fe-Mn bounded Cd ($P < 0.01$). CEC was positively correlated with organic bounded Cd ($P < 0.01$). Exchangeable Cd was negatively correlated with carbonate bounded Cd and Fe-Mn bounded Cd ($P < 0.01$). In the 60 cm – 80 cm soil layer, soil exchangeable Cd and residual Cd were negatively correlated ($P < 0.01$). No significant correlations were evident between soil pH, CEC and Cd forms in the 40 – 60 cm and 60 – 80 cm soil layers.

Table 2. Correlation analysis of chemical forms of cadmium, pH, and CE

Cd Forms	0-20cm			20-40cm			40-60cm			60-80cm		
	pH	CEC	EXE	pH	CEC	EXE	pH	CEC	EXE	pH	CEC	EXE
EXE	-0.669**	-0.964**	/	-0.986**	-0.617*	/	-0.173	-0.302	/	-0.086	-0.396	/
CARB	0.925**	0.628*	-0.752**	0.899**	0.568*	-0.902**	0.322	0.284	-0.539	0.112	0.437	-0.189
FeMnO	0.982**	0.474	-0.542*	0.944**	0.417	-0.950**	-0.334	0.232	-0.179	0.164	0.368	0.451
Org	0.884**	0.681**	-0.751**	0.487	0.656**	-0.554*	0.222	0.476	0.165	0.027	0.512	-0.430
Res	0.834**	0.596*	-0.534*	0.408	0.210	-0.470	0.559*	0.248	-0.196	0.311	0.123	-0.788**

EXC, CARB, FeMnO, Org and Res indicate exchangeable Cd, carbonate-bound Cd, Fe-Mn oxides-bound Cd, Organic Cd and residuals Cd, respectively. * and ** indicate levels of $P < 0.05$ and $P < 0.01$, respectively

3.7. Soil Fourier Transform Infrared Spectroscopy (FTIR) Test Analysis

We adopted fourier transform infrared spectroscopy (FTIR) deduction and semi-quantitative analysis to measure the functional group characteristics of the molecule so as to verify the effect of modifiers on the structure of organic soil compounds. Figure 6 shows the FTIR test results of a mixture of modifiers and Cd contaminated soil. Figure 6 shows that OH stretching vibration and the broadened OH absorption band appear near 3 624 and 3 414 cm^{-1} , respectively, and a sharp OH absorption peak and alcohol hydroxyl R-OH are introduced. At 1 430 cm^{-1} , anti-symmetrical stretching appears, indicating the existence of CO_3^{2-} in each treatment. Silicon asymmetric stretching vibration and silicone Si-C stretching occurs near 1 000 and 695 cm^{-1} , respectively. C-O-S symmetry stretching occurs near 800 cm^{-1} , indicating that sulfate esters exist in each treatment. A symmetrical angle of PO_4 appears near 468 cm^{-1} , indicating that inorganic phosphates exists in each treatment. These bands showed higher intensities under the V1 and V2 treatments, indicating large amounts of adsorbed and crystallized water, CO_3^{2-} , SiO_2 , sulfate esters, and inorganic phosphates. Under the Cd, V3 and V4 treatments, aromatic ethers and enol ethers appeared near 1037 cm^{-1} , indicating that more aromatic ethers and enol ethers are produced under the V3 and V4 treatments.

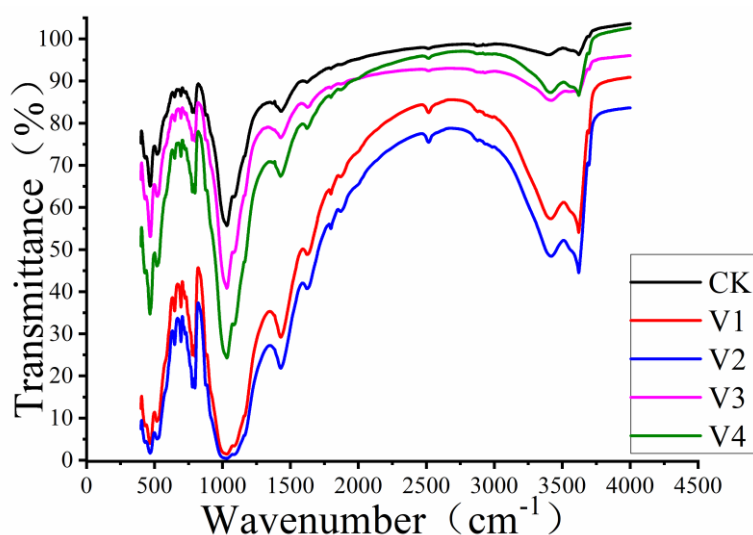


Figure 6. FTIR spectra of a mixture of modifiers and Cd contaminated soil

Cd has aggregation characteristics in surface soil. Two growing seasons of continuous remediation shows that the effect of modifiers on the remediation of total Cd and available Cd in topsoil is similar for both harvests. On the other hand, soil Cd tends to migrate vertically from the topsoil to bottom layers in moderate and heavy loam soils [46]. Egiarte et al. [47] founded Cd mainly accumulated at 48 to 53 cm, which was the depth of the water table. The study revealed differences in the soil profile Cd in lime loam. After entering the soil, Cd will migrate downwards due to the effects of drip irrigation, becoming less concentrated and more stable below the 40 cm soil layer. In general, Cd concentration is highest in the 0 –20 cm soil layer. Studies have also shown that modifiers can passivate toxic metals in soil [48]. In this study, the addition of modifiers had no significant effect on total Cd concentration, but significantly decreased the available Cd concentration, decreased the mobility of Cd, weakened the ability of Cd to migrate downward, and decreased the leaching of Cd into groundwater. The degree of effect of the four modifiers treatments on stabilizing Cd could be rated as $\text{V2} > \text{V4} > \text{V3} > \text{V1}$.



It is generally known that the direct effect of toxic metals on the environment depends on the metal redistribution in the soil through absorption, complexation, reduction and precipitation [49]. Therefore, research on toxic metal forms is extremely relevant. Bioavailable Cd increases with an increase in the proportion of exchangeable Cd [50]. In contrast, higher proportions of carbonate bounded, Fe-Mn bounded, organic bounded and residual Cd reduces Cd bioavailability [51]. During two growing seasons of continuous remediation, addition of modifiers reduced exchangeable Cd concentration, and increased carbonate-bound Cd, Fe-Mn oxides-bound Cd, Organic Cd and residuals Cd concentration for both harvests. It shows that the passivation effect of modifiers is continuous. At the same time, the study showed that exchangeable Cd mainly exists in the soil surface, whereas residual Cd mainly exists in the lower soil layers. The addition of modifiers decreased exchangeable Cd in the different soil layers, and increased the carbonate bounded, Fe-Mn bounded, organic bounded and residual Cd forms. This is because the addition of modifiers can significantly increase pH and CEC in the different soil layers. The increase of pH increases the variable negative charge on the soil surface and then increases the adsorption of Cd^{2+} . The increase of CEC will improve the ability of soil to stabilize Cd, thus it is more beneficial to reduce the exchangeable Cd [52]. FTIR analysis showed that the increase of the carbonate bounded Cd is due to the fact that the modifiers increase soil CO_3^{2-} and react to form a CdCO_3 precipitate. The Fe-Mn bounded Cd concentration is increased because the modifiers bring a large amount of OH^- into the soil, and reacts with soil Fe^{2+} and Mn^{2+} to form $\text{Fe}(\text{OH})_2$ and $\text{Mn}(\text{OH})_2$, thereby facilitating its combination with Fe and Mn oxides, resulting in larger amounts of Fe-Mn bounded Cd [53]. The increase of the residual Cd is due to the modifiers increasing soil functional groups such as Si-O, Si-C, and their combination with Cd to form silicate compounds.

Correlation analysis showed that exchangeable Cd in the 0–20 cm and 20–40 cm soil layers was extremely negatively correlated with carbonate bounded Cd, organic bounded Cd, carbonate bounded Cd, and Fe-Mn bounded Cd, respectively, which reveals that exchangeable Cd in the 0 cm–20 cm soil layer is mainly transformed into the carbonate bounded and organic bounded Cd. The exchangeable Cd in the 20–40 cm soil layer is mainly transformed into the carbonate bounded Cd and Fe-Mn bounded Cd. At the same time, in the 0 cm–20 cm soil layer, soil pH and CEC are extremely negatively correlated with exchangeable Cd. In the 20–40 cm soil layer, exchangeable Cd is extremely negatively correlated with soil pH and significantly negatively correlated with CEC, it similar to the results of Xu et al. [54] and Azhar et al. [55]. The study showed that the modifiers changed the soil Cd forms by increasing the soil pH and CEC, and finally decreased the availability of soil Cd.

4. Conclusions

Under two growing seasons farming practices, the modifiers had the continuous effect of passivation. Lime soil Cd will migrate downwards due to drip irrigation, and tend to stabilize below the 40 cm soil layer. Generally, the Cd concentration in the 0-20 cm soil layer is higher than that in other soil layers. Among them, the soil surface mainly contains exchangeable Cd, whereas the lower soil layers mainly contain residual Cd. The modifiers can effectively remove a large amount of Cd in the soil. In addition to direct adsorption, the modifiers can increase soil pH and CEC, and can also combine with other ions to promote the transportation of unstable Cd to stable Cd in the soil, thereby effectively reduce the migration and toxicity of Cd. And the effect of the modifiers on stabilizing Cd is as follows: inorganic polymer compound modifiers > organic polymer compound modifiers > polyacrylate compound modifiers > organic-inorganic composite modifiers.



Acknowledgements: This research was supported by the International Science & Technology Cooperation Program of China (2015DFA11660), and the International Science & Technology Cooperation Program of Shihezi University (GJHZ201802).

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Manuscript received: 13.03.2020