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ORIGINAL ARTICLE

# Fraction of Cd in oasis soil and its bioavailability to commonly grown crops in Northwest China

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**Abstract** Heavy metals in the soil–plant system resulting from mining and wastewater irrigation have greatly threatened human health and sustainable development in Northwest China. This research used pot experiments to study the bioavailability of Cd in irrigated desert soil from the oasis regions and conducted a human health risk assessment of the Cd content in vegetables. The results show that the content of Cd associated with exchangeable and carbonate metal fractionations is not uniform in arid oasis soils cultivated with the commonly grown vegetables. These common growth vegetables are: Cole (*Brassica campestris* L.), Celery (*Apium Graveolens* L.) and carrots (*Daucus carota* L.). The results show that the content of Cd in the edible part of cole was significantly higher than celery and carrots in almost all of the treatments. However, cole can grow normally and keep increasing its biomass at a sustainable rate under the highest concentration of Cd added in the experiment. Cole is not a suitable vegetable to be planted for consumption in arid soil contaminated with Cd, celery planted under lower concentration of Cd will not threaten human health, and carrots are suitable to be planted in arid soil contaminated with Cd even in the highest concentration used in the experiment. According to this conclusion, stricter soil management systems should be implemented to protect arid land soil resources and to protect human health from the toxicity impacts.

**Keywords** Cd · Oasis soil · Fraction · Bioavailability · Crops

## Introduction

Food safety has become an important global issue in the 21st century. This could threaten regional sustainable development directly. Oasis agriculture plays an important role in the development of inland areas in Northwest China. With the rapid development of industry and the shortage of water, heavy metals such as Cd, Pb, Cu and Ni in soil, resulting from mining and wastewater irrigation, have caused large contamination in agricultural soil and could exert a great threat to human health due to their impact on the environment in Northwest China (Sang et al. 2009; Han et al. 2007; Nan and Zhao 2000). Among those trace elements of most concern, Cd has the highest bioavailability in arid and semi-arid soils, while Pb and Cr(III) have the lowest bioavailability in arid soils (Li et al. 2006). Thus, the paper focuses on the fraction of Cd in oasis soil, the bioavailability of Cd to crops, and the health risk assessment of Cd content in crops to local people.

Crops grown in contaminated soils will expose people to a high health risk. Different species of plants show different abilities to take up heavy metals from soils. Cole (*Brassica campestris* L.), celery (*Apium Graveolens* L.), and carrot (*Daucus carota* L.) were selected, which are the commonly grown crops in this area and are eaten throughout the world. The edible parts of those are: the leaf, the stem, and the root, respectively.

Bioavailability is the ratio of the accumulated content of heavy metals in a plant to the total content of heavy metals in the soil (Krishnamurti and Naidu 2003). Many studies have shown that the chemical fractions of heavy metals can

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influence the bioavailability and mobility of metals (Santos et al. 2002). The Tessier scheme is usually employed to characterize the behavior of the metals. This scheme divides the total metals into five fractions: exchangeable fraction (EXC), carbonate-bound fraction (CAB), Fe–Mn oxide bound fractions (FMO), organic bound fraction (OM) and residual fraction (RES) (Tessier et al. 1979).

In order to improve the sustainable development of oasis agriculture in Northwest China, this paper studied the total contents and the fractionation of Cd contaminated soil after cultivating the vegetables by employing the Tessier scheme. The bioavailability of Cd to cole, celery and carrots was evaluated by the fraction distribution coefficient (FDC) and mobility factor (MF). The bio-concentration factor (BCF) and the translocation factor (TF) were used to study the accumulation of Cd from irrigated desert soil to plants. The health risk for intake of Cd through the consumption of the vegetables commonly grown in control and contaminated soil was also studied. Through the scientific data presented by the health risk assessment, governmental officials and resource managers could clearly identify which species of crop is relatively safe to plant in Cd contaminated soil and could establish a specific institution for managing regional soil to protect the health of native people from the toxicity impacts.

## Materials and methods

### Physical description and soil sampling

The size of the oasis region in Northwest China is about 104,000 km$^2$. The oasis region is subject to a continental semi-arid climate (altitude = 1,380–2,278 m, annual precipitation = 118.4 mm, annual mean air temperature = 7.7 °C). Pot experiments were conducted under open air conditions in 2008 at Linze County (39°04′–39°24′N, 99°35′–100°25′E), Hexi corridor, Northwest China. The elevation ranges from 1,500 to 1,800 m. This area belongs to a semi-arid region with low precipitation (104–129 mm annually), high evapotranspiration (1,900–2,100 mm) and high temperatures in the summer (22 °C). The experimental soil type belongs to an irrigated desert soil and the textures were mainly sandy.

The physical and chemical properties of the irrigated desert soil used in the experiment are shown in Table 1. The pH of the soil (1:5 soil–water ratios) was measured by a glass electrode; organic matter (OM) content was determined using the Tyurin method; cation exchange capacity (CEC) was measured by the ammonium acetate method; and total nitrogen was measured by B-339 Kjeldahl nitrogen (Switzerland) and calcium carbonate content ($CaCO_3$) was determined using the carbon dioxide volume method.

### Pot experiments

Six kilograms (dry weight) prepared soil samples (0–15 cm) were placed in each plastic pot for growing the plants. The pot experiments were implemented with cole, celery and carrots in different Cd spiked soils at Linze Inland River Basin Research Station in 2009. Nine overall treatments including a control soil and eight treatments were implemented and each treatment was replicated three times. According to the field pollution investigation from Bainyin oasis region in which soil type is an irrigated silt sandy soil, the concentration of Cd ranged from 0.161 to 7.75 mg kg$^{-1}$ DW (Nan and Zhao 2000). Therefore, the eight treatments were designed as follows: 0.35, 0.75, 1.25, 1.8, 2.5, 3.5, 5 and 7.5 mg kg$^{-1}$ DW, respectively, to imitate the true contamination degree in arid crop field.

The experimental soils excavated from an oasis farm were air dried, mixed in a heap, sieved at 2 mm and then ground like dust. The control soil was the common irrigated desert soil with original amounts of heavy metals.

The spiked soil samples were treated by weighting 1 g $Cd(NO_3)_2\,4H_2O$ in 1 L volumetric flask, and mixed 2, 4, 6, 8, 12, 20, 28 and 40 ml solution, respectively, in soils once for each different treatment to increase concentration. The average nitrogen content in spiked soil is 0.09 % ± 0.004, which has been measured after the treatments, as the total nitrogen content in irrigated desert soil is 0.09 %; the added concentration of nitrogen is tested to have no secondary effect on the growth of crops.

The spiked soils were mixed by hand and turned over thoroughly several times. The degree of moisture in the soils was remained at 70 % of water holding capacity after the treatment. Before planting the seeds, the soil samples were left to equilibrate in plastic boxes covered with plastic film for 2 months. The pot is 20 cm tall and the diameter of the pot is 15 cm. The pots were arranged randomly inside a netted greenhouse. Seeds were sown directly to the soil pots in late March, which is the normal growing season for these crops in Linze County and also in northwest arid areas of China. During the experimental period, each pot kept four plants, tap water was added to compensate for evaporation and transpiration, and soil moisture content was maintained at approximately 70 % of the water holding capacity. In late June, the crop samples were harvested. The number of soil samples is 81: includes 9 treatments × 3 plants × 3 replicates.

The plants were separated into two parts: the above-ground part and underground part. After removing the soil particles with tap water, the leaves, stems and roots were washed with de-ionized water three times each and dried in an oven at 70 °C for 48 h. The number of plant samples is 162 includes: 9 treatments × 3 plants × (3 replicates$_{\text{above}}$ + 3 replicates$_{\text{under}}$) which are used for accumulation of the heavy metals in plants. The number of plant samples used

Table 1 The physical and chemical properties of the irrigated desert soil used in the experiment

| Sand (%) | Silt (%) | Clay (%) | pH | CEC (cmol kg$^{-1}$) | $CaCO_3$ (%) | OM (%) | $NO_3$ (%) | Cd (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 53.6 | 39.3 | 7.1 | 8.16 | 15.01 | 8.7 | 1.14 | 0.09 | 0.16 |

for health risk assessment is 81 includes: 9 treatments × 3 plants × 3 replicates $_{\text{edible}}$.

### Determination of total metals

The total contents of Cd in the control and spiked soils were extracted by $HNO_3 + HF + HClO_4$ solution, and the Cd in the plants was extracted using $HNO_3 + HClO_4$ digestion. All digested samples were diluted to 50 ml with 0.5 % $HNO_3$ and stored at 4 °C until the concentrations of Cd were analyzed. The total metal contents were determined by an atomic absorption spectrometer (AAS) and graphite furnace (M6MKII, Thermo Fisher, USA).

### Fraction analysis

Fraction analysis of Cd in spiked soils was carried out on 1.0 g aliquots of soil according to the Tessier scheme. The five-sequential extraction procedure includes extracting the EXC fraction by 8 ml of 1 M $MgCl_2$ (pH 7.0) in a 50 ml centrifuge tube with shaking for 1 h at room temperature; the CAB fraction by 8 ml of 1 M NaOAc (pH 5.0) with shaking for 5 h at room temperature; the FMO fraction by 20 ml of 0.1 M $NH_2OH{\cdot}HCl$ in 25 % (v/v) HOAc with shaking for 6 h at 96 ± 3 °C; the OM fraction by 3 ml of 0.02 M $HNO_3$ and 5 ml 30 % $H_2O_2$ (pH 2.0) with shaking for 3 h at 85 ± 2 °C, and then adding 15 ml of 1 M $NH_4OAc$ in 20 % (v/v) $HNO_3$ with shaking for 30 min at room temperature; and the RES fraction by $HNO_3$–HF–$HCLO_4$.

### Quality control and data analysis

All experimental glassware and containers were soaked in 20 % $HNO_3$ for at least 12 h previously and rinsed with deionized water before use. To ensure the precision of experiment process, two duplicates and one standard reference sample, GSS-2 (GBW-07401) and GSV-2 (GBW-07403) were used for analysis. The percentage of analysis between the heavy metals fraction in soils and the bioavailability assessment of heavy metals in cole, celery and carrots was carried out with SPSS 13.

## Results and discussion

### The fraction distribution of Cd in spiked soil

Bioavailability of heavy metals refers to the availability of heavy metals to biological organisms such as plants, animals and human beings (Oskarsson et al. 2004). The chemical fraction of heavy metals are retained and partitioned between solution and solid phase and their redistribution to spiked soil could predict the availability of heavy metals to vegetables. Thus, it is important to determine the chemical fraction of Cd in soils when evaluating the mobility and bioavailability of Cd to different vegetables.

It could be found that, with the increasing concentration of Cd in experimental soils, every fraction of Cd in soil underwent a great change (Fig. 1), among which the EXC-F and the CAB-F of Cd exhibited great enhancement. The FDC is defined as metal fraction content accounting for the percentage by total amount of metal. The results (Fig. 2) show that in the control soil, the FMO-F of Cd was always the predominant fraction. The FMO-F of Cd accounts for 56, 52 and 63 % of the total Cd content in soil cultivated with cole, celery and carrots, respectively, and it followed the distribution order: FMO-F > CAB-F > RES-F > OM-F > EXC-F. This finding was in agreement with a study that claimed Cd mainly exists in Fe–Mn oxides fraction with $pH > 7.5$ (Qiao et al. 2003). With increasing Cd concentration, FMO-F content in different cultivated soils showed a relatively large decrease. The FDC of Cd in CAB-F, EXC-F and FMO-F underwent a significant increase in Treatment 5 (Cd 2.5 mg kg$^{-1}$ DW) in each soil cultivated with cole, celery and carrots. From Treatment 6 to Treatment 8 (Cd 3.5–7.5 mg kg$^{-1}$ DW), the FDC of Cd in the soil cultivated with cole was CAB-F (44–52 %) > EXC-F (26–31 %) > FMO-F (28–24 %) > OM-F (0.5–0.4 %) > RES-F (0.2–0.4 %); in the soil cultivated with celery was CAB (39–48 %) > EXC (27–38 %) > FMO (23–22 %) > OM (0.6–0.7 %) > RES (0.3–0.6 %) and in the soil cultivated with carrots was CAB (47–53 %) > EXC (25–33 %) > FMO (24–18 %) > RES (0.5–0.9 %) > OM (0.4–0.6 %).

The exchangeable and carbonate metal fractions are tested to discern whether they are available and readily mobile to plants. Table 2 shows the total Cd concentration in different treatment soils of the cultivated vegetables and the mobility factor (MF) of Cd in the pot experiments. The MF was calculated as the ratio of EXC-F + CAB-F to the total Cd concentration in soil, which can show the relative mobility and bioavailability of Cd in soils. It can be found that the MF value increases in each soil cultivated with cole, celery and carrots. The results show that the content of Cd associated with available fraction increased with the increase of the total content of Cd which is the same as the conclusion drawn by other researchers (Guerra et al. 2007).

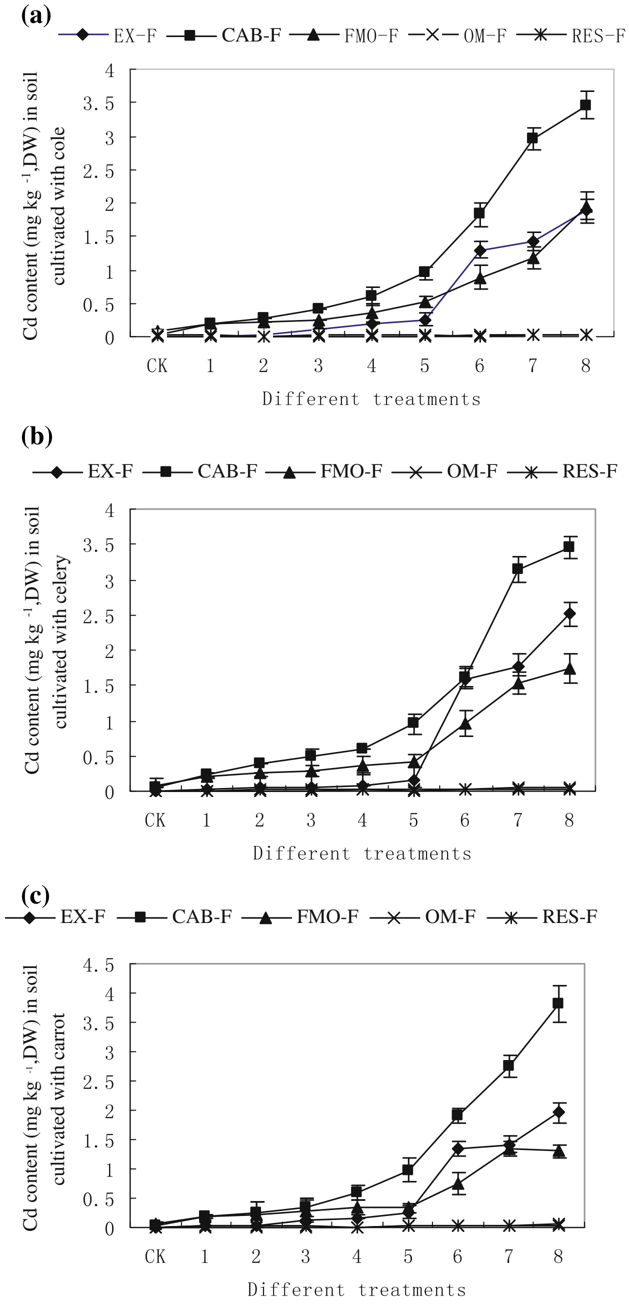

**Fig. 1** Distribution of Cd fraction content in soil cultivated with different vegetables in different treatments ($n = 81$). *EX-F* exchangeable fraction, *CAB-F* carbonates fraction, *FMO-F*, *Fe* and *Mn* oxides fraction, *OM-F* organic matter fraction, *RES-F* residual fraction

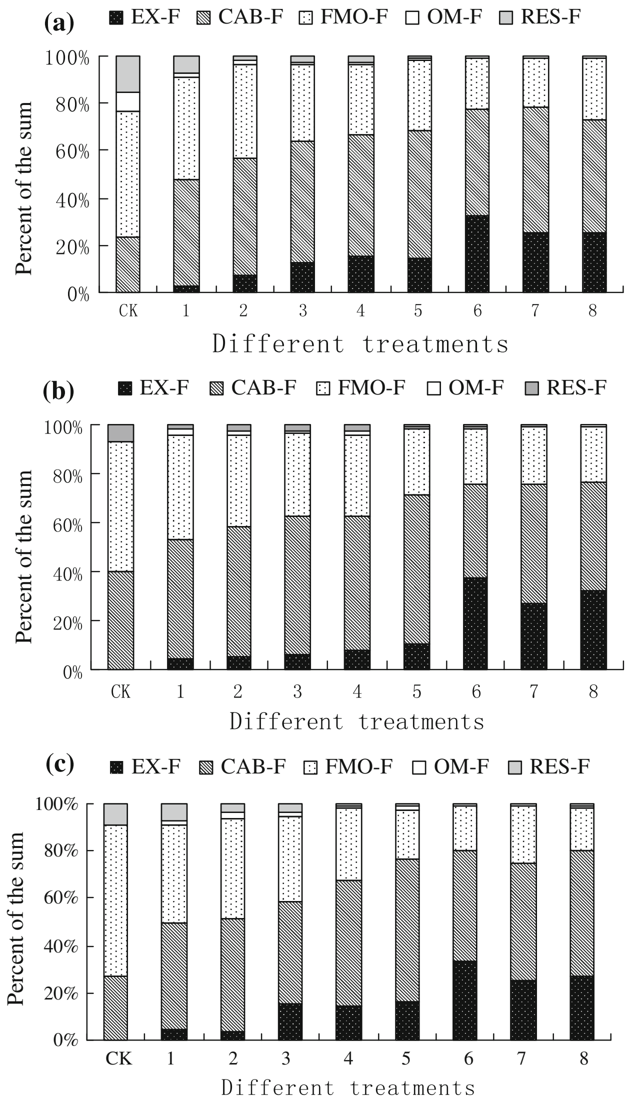

**Fig. 2** Fraction distribution coefficient (FDC) of Cd in soil cultivated with different vegetables in different treatments ($n = 81$)

In the control soil, the values of the MF were: celery (40.00) > carrot (27.27) > cole (23.07). From Treatment 5 to Treatment 8 (Cd 2.5–7.5 mg $kg^{-1}$ DW), the MF in soil cultivated with carrots showed a significant increase. These results indicate that the bioavailability and mobility is higher in celery than in other vegetables with Cd in low concentration, while it has the largest effect on carrot when the concentration of Cd is higher than that in Treatment 5 (Cd 2.5 mg $kg^{-1}$ DW). Some research has also found that Cd is the most mobile toxic heavy metal, and can be easily taken up by growing vegetables through the root system from contaminated soils (Ahumada et al. 1999).

## Growth status of the vegetables in spiked soils

The fresh weight of the vegetables is an important index for the growth status of the plant in a certain period. In order to improve agricultural production and to decrease the damage caused by heavy metals to vegetables, it is important to clarify the relationship between the concentration of Cd in spiked arid soil and the weight of vegetables. As Table 3 shows, the fresh weight of carrot (aboveground part and underground part) roughly increased and reached peak

**Table 2** Total Cd content in soils and the mobility factor (MF) of Cd with different crops ($n = 81$)

| Treatment no. | Soil cultivated with cole | | Soil cultivated with celery | | Soil cultivated with carrot | |
|---|---|---|---|---|---|---|
| | Soil Cd concentration | MF$^\#$ | Soil Cd concentration | MF | Soil Cd concentration | MF |
| CK$^*$ | 0.13 | 23.07 | 0.15 | 40.00 | 0.17 | 27.27 |
| 1 | 0.44 | 47.72 | 0.47 | 53.19 | 0.44 | 50.00 |
| 2 | 0.55 | 56.36 | 0.72 | 58.33 | 0.51 | 47.05 |
| 3 | 0.81 | 64.19 | 0.86 | 62.79 | 0.78 | 58.97 |
| 4 | 1.17 | 66.66 | 1.12 | 62.50 | 1.13 | 67.25 |
| 5 | 1.76 | 68.75 | 1.56 | 71.15 | 1.61 | 77.01 |
| 6 | 4.05 | 77.28 | 4.21 | 76.01 | 4.04 | 80.44 |
| 7 | 5.59 | 78.17 | 6.52 | 75.31 | 5.59 | 79.96 |
| 8 | 7.35 | 72.65 | 7.79 | 76.63 | 7.17 | 80.33 |

CK$^*$ control

MF$^\#$ MF was calculated as (EXC-F + CAB-F)/total Cd in soil × 100

value at Treatment 7 (5 mg kg$^{-1}$ DW) with the increasing concentration of Cd in soil. It indicates that this value was the critical concentrations to carrot, and if the concentration exceed this value, the growth of the plant could be restrained and the plant would be poisoned by Cd in soils. The fresh weight of both the aboveground and underground parts of celery decreased with the increasing concentration of Cd in arid soils. The Cd concentration made no significant effect on fresh weight of the cole plant.

These results indicate that low concentrations of Cd in arid soil could promote the growth of carrots, while high concentration of it could restrain them which have the same results with other studies (Li et al. 2006). With the increasing concentration of Cd, the growth of celery could be restrained by disabling the roots from absorbing nutritional elements from the soil. Cole can grow normally and keep the biomass at a sustainable increase, even under the highest concentration of Cd (7.5 mg kg$^{-1}$ DW) added in the experiment. Another study found that the fresh weight of cabbage (*Brassica oleracea* L.) and wild-rice stem (*Zizania latifolia* L.) showed a significant increase compared with the control when Cd concentrations were added at 20–25 mg kg$^{-1}$ DW, respectively (Greger et al. 2007). These vegetables have a certain tolerance to maintain growth when Cd concentration has not exceeded the peak value. This is probably because the nitrate reductase and the isocitric enzyme in the plants have been stimulated (Patra et al. 1994).

## Accumulation and bio-concentration of Cd in different parts of crops

Table 4 shows the Cd concentration in the aboveground part and underground parts of vegetables cultivated in spiked arid soils under eight treatments of Cd. The mean values of Cd in different parts of cole, celery and carrots show significant differences ($P < 0.05$) with the increasing concentration of Cd. The content of Cd accumulated in different parts of the vegetables. The sequences of Cd concentration in the underground part of celery and carrot

**Table 3** Changes of fresh weight of aboveground part and underground part of crops cultivated with Cd spiked soils ($n = 162$)

| Cd mg kg$^{-1}$ | Fresh weight of the aboveground part (g/pot) | | | Fresh weight of the underground part (g/pot) | | |
|---|---|---|---|---|---|---|
| | Cole | Celery | Carrot | Cole | Celery | Carrot |
| CK | 0.86 ± 0.12 | 2.58 ± 1.05 | 13.30 ± 4.25 | 21.43 ± 3.24 | 7.32 ± 2.35 | 9.19 ± 1.99 |
| 1 | 0.59 ± 0.13 | 1.35 ± 0.65 | 11.80 ± 2.11 | 14.38 ± 1.95 | 6.50 ± 2.17 | 9.69 ± 1.03 |
| 2 | 0.49 ± 0.07 | 1.88 ± 0.15 | 10.02 ± 6.32 | 13.77 ± 3.16 | 5.82 ± 0.74 | 7.91 ± 2.94 |
| 3 | 0.55 ± 0.03 | 1.96 ± 0.18 | 13.75 ± 2.82 | 15.68 ± 2.08 | 6.73 ± 2.74 | 9.39 ± 1.55 |
| 4 | 0.40 ± 0.31 | 1.00 ± 0.20 | 10.05 ± 1.53 | 17.09 ± 1.5 | 4.94 ± 0.42 | 9.08 ± 1.05 |
| 5 | 1.08 ± 0.53 | 0.86 ± 0.56 | 12.31 ± 3.15 | 27.56 ± 6.04 | 3.85 ± 1.97 | 7.89 ± 1.08 |
| 6 | 1.07 ± 0.48 | 0.84 ± 0.53 | 13.49 ± 4.49 | 21.11 ± 3.22 | 2.96 ± 1.52 | 8.99 ± 3.22 |
| 7 | 0.73 ± 0.19 | 1.05 ± 0.21 | 15.52 ± 1.86 | 17.68 ± 5.75 | 2.37 ± 0.62 | 12.02 ± 0.90 |
| 8 | 0.87 ± 0.40 | 0.62 ± 0.42 | 6.48 ± 1.55 | 24.36 ± 4.4 7 | 3.10 ± 2.61 | 5.20 ± 1.74 |

Values are presented as mean ± standard deviation of three replicates were significantly higher than those in aboveground part but the concentration of Cd in the underground part of cole was lower than that in aboveground part.

Humans consume the aboveground part of cole and celery and the underground part of carrots. It is more meaningful to investigate the accumulation of Cd in the edible part of vegetables rather than to accumulate total amounts in plants when assessing the health risk for people who live in the arid region. The plant's ability to absorb heavy metals primarily depends on the plant species and several other soil characteristics, such as soil pH, organic matter content, CEC and $CaCO_3$, which can strongly immobilize heavy metals in soil and make them unavailable to plants. In order to compare the accumulation and translation capacity of commonly grown vegetables in the arid land plant-soil system, the BCF and translocation factor (TF) were conducted (Greger et al. 2007). The BCF is equal to the metal concentration in plant tissues divided by that in the rooted soils. The BCF of Cd in the aboveground part and the underground part of vegetables is shown in Table 5. In the study, BCF $< 1$ indicates that there is lower Cd accumulation in the parts of the plants than there is in the soil. The average BCF of Cd in the edible parts of the vegetables can be ordered thus: cole $(1.096) >$ carrot $(0.781) >$ celery $(0.733)$. The average BCF of Cd in the inedible part of the vegetables can be ordered as: celery $(2.134) >$ cole $(0.777) >$ carrot $(0.354)$. The variation trends of the BCF of the edible part of vegetables with Cd in soil are shown in Fig. 3. When increasing Cd concentration in soil, similar tendencies in edible part of cole and celery could be observed from the BCF curve. This indicates that the edible part of cole and celery are readily absorbing Cd from soils due to its increasing bioavailability at lower concentration from CK to Treatment 5 (Cd 0.1–2.5 mg $kg^{-1}$ DW) and the bioavailability of Cd showed a downward trend at higher concentration in arid soil (Cd 2.5–7.5 mg $kg^{-1}$ DW). However, the BCF values of cole were more than that of celery (except the control soil). It indicates that Cd could accumulate in the edible part of cole in higher amount than celery. On the contrary, the accumulation of Cd in edible part of carrots in control soil is high and the BCF values of carrots showed a clearly descending trend. It represents that the bioavailability of Cd in carrots decreased gradually with increasing Cd concentration in arid soil. Because the edible part of carrots is the root, the results illustrated that the concentration of Cd in leafy vegetables is higher than in root vegetables. Many studies also found the similar phenomenon (Li et al. 2006; Lakhdar et al. 2010).

The TF was equal to the metal concentration in other parts of plant divided by that in plant root. TF values in Table 5 show the ability of vegetables to transfer Cd from the underground part to the aboveground part of the plant. The average TF of Cd in the aboveground part of vegetables were cole $(1.901) >$ carrot $(0.421) >$ celery $(0.371)$. The TF of Cd in the aboveground part of cole was more than one, which suggested that more trace metals had been readily transferred from root to leaves. Another research has reported that accumulating heavy metals in the underground part is a common strategy to protect the photosynthesizing tissues of the plants (Lakhdar et al. 2010). These finding are consistent with the present study's finding regarding the accumulation of Cd in some vegetables in arid soil. In root vegetables and legumes, such as tomato (*Solanum lycopersicum* L.), chili pepper (*Capsicum frutescens* L.) and bean (*Phaseolus vulgaris* L.), Cd usually accumulates in the underground part more than in the aboveground part. The concentration of Cd in the aboveground part is higher than in the underground part of leafy vegetables such as cabbage (*Brassica oleracea* L.), cole (*Brassica campestris* L.) and spinach (*Spinacia oleracea* L.) (Li et al. 2006; Lakhdar et al. 2010; Zheljazkov and Nielsen 1996).

**Table 4** Concentration of Cd in different parts of vegetables (mg $kg^{-1}$ DW) ($n = 162$)

| Treatment no. | Cd content in the aboveground part | | | Cd content in the underground part | | |
|---|---|---|---|---|---|---|
| | Cole | Celery | Carrot | Cole | Celery | Carrot |
| CK | 0.01 ± 0.18 | 0.002 ± 0.01 | 0.004 ± 0.03 | 0.01 ± 0.02 | 0.009 ± 0.16 | 0.009 ± 0.01 |
| 1 | 0.02 ± 0.06 | 0.04 ± 0.13 | 0.010 ± 0.17 | 0.01 ± 0.03 | 0.09 ± 0.31 | 0.035 ± 0.04 |
| 2 | 0.06 ± 0.11 | 0.05 ± 0.09 | 0.015 ± 0.08 | 0.03 ± 0.12 | 0.16 ± 0.12 | 0.040 ± 0.01 |
| 3 | 0.18 ± 0.19 | 0.12 ± 0.14 | 0.015 ± 0.02 | 0.19 ± 0.21 | 0.24 ± 0.22 | 0.037 ± 0.03 |
| 4 | 0.31 ± 0.20 | 0.12 ± 0.23 | 0.018 ± 0.13 | 0.17 ± 0.12 | 0.39 ± 0.02 | 0.055 ± 0.12 |
| 5 | 0.36 ± 0.03 | 0.15 ± 0.31 | 0.027 ± 0.32 | 0.15 ± 0.01 | 0.36 ± 0.09 | 0.079 ± 0.08 |
| 6 | 0.31 ± 0.15 | 0.19 ± 0.14 | 0.035 ± 0.02 | 0.08 ± 0.22 | 0.42 ± 0.14 | 0.089 ± 0.03 |
| 7 | 0.64 ± 0.24 | 0.29 ± 0.21 | 0.054 ± 0.05 | 0.40 ± 0.23 | 0.61 ± 0.09 | 0.093 ± 0.16 |
| 8 | 0.70 ± 0.04 | 0.29 ± 0.07 | 0.063 ± 0.14 | 0.48 ± 0.15 | 0.84 ± 0.17 | 0.100 ± 0.03 |

Values are presented as mean ± standard deviation of three replicates

**Table 5** Bio-concentration factor (BCF) of Cd in different part of vegetables and translocation factor (TF) of Cd from underground part to aboveground part of vegetables ($n = 162$)

| Treatment | Cole in spiked soil | | | Celery in spiked soil | | | Carrot in spiked soil | | |
|---|---|---|---|---|---|---|---|---|---|
| | BCF | | TF | BCF | | TF | BCF | | TF |
| | Above[a] | Under[b] | | Above | Under | | Above | Under | |
| CK | 0.832 | 0.833 | 1 | 0.223 | 1 | 0.222 | 0.571 | 1.285 | 0.444 |
| 1 | 0.43 | 0.211 | 2 | 1.113 | 2.541 | 0.444 | 0.769 | 1.692 | 0.285 |
| 2 | 0.881 | 0.443 | 2 | 0.876 | 2.856 | 0.312 | 0.555 | 1.481 | 0.375 |
| 3 | 1.134 | 1.95 | 0.947 | 1.444 | 2.474 | 0.5 | 0.217 | 0.536 | 0.405 |
| 4 | 1.982 | 1.081 | 1.823 | 0.882 | 2.876 | 0.307 | 0.185 | 0.567 | 0.327 |
| 5 | 1.55 | 0.808 | 2.4 | 0.721 | 1.731 | 0.277 | 0.385 | 0.464 | 0.341 |
| 6 | 0.782 | 0.203 | 3.875 | 0.476 | 1.053 | 0.452 | 0.156 | 0.419 | 0.393 |
| 7 | 1.333 | 0.823 | 1.6 | 0.492 | 3.582 | 0.475 | 0.202 | 0.348 | 0.581 |
| 8 | 0.956 | 0.654 | 1.458 | 0.378 | 1.096 | 0.345 | 0.148 | 0.236 | 0.63 |
| Average | 1.096 | 0.777 | 1.901 | 0.733 | 2.134 | 0.371 | 0.354 | 0.781 | 0.421 |

[a] Aboveground part of the vegetables

[b] Underground part of the vegetables

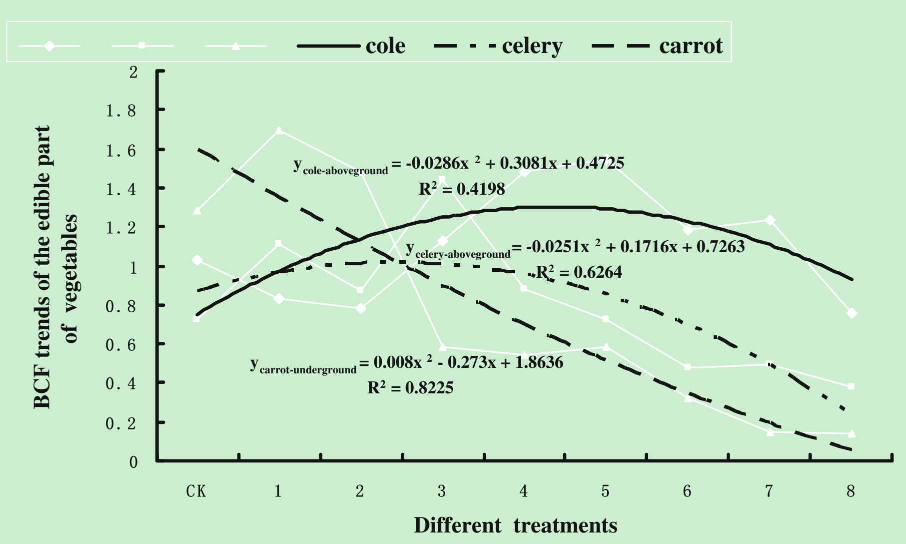

**Fig. 3** The variation trends of the BCF of the edible part of vegetables ($P < 0.05$)

## Health risk assessment of Cd in crops to people

As shown in Table 4, it also found that with the increasing concentration of Cd and the content of Cd in the aboveground part of the vegetables was: cole > celery > carrot. The conclusion was consistent with the finding of other research that heavy metals appeared to accumulate more easily in the edible part of the vegetable than in other crops such as grains of fruit. However, this shows a slight difference with the report that leafy vegetables are high accumulators of metal Cd, followed by root vegetables, and then legumes, when comparing one vegetable to another (Alexander et al. 2006). Figure 4 shows the correlation of Cd concentration added in soil and the edible part of plants. In the experiment, Cd content in each edible part of the plants increased linearly with increasing Cd concentration in arid soil. The tolerance limits of Cd in food set by Ministry of Health of PRC (GB/2762—2005) were 0.2 mg kg$^{-1}$ for leafy vegetables and 0.1 mg kg$^{-1}$ for root vegetables. In this experiment, cole and celery belong to the category of leafy vegetables, and carrot is classified as a root vegetable. It was determined that Cd content in the edible part (underground part) of carrot has not exceeded the criterion until the highest concentration (Cd 7.5 mg kg$^{-1}$ DW). However, Cd content in the edible part (aboveground part) of cole (0.18 mg kg$^{-1}$ DW) and celery (0.19 mg kg$^{-1}$ DW) almost reached the criterion at Treatment 3 (1.25 mg kg$^{-1}$ DW) and Treatment 6 (3.5 mg kg$^{-1}$ DW). The previous study also found that cole is not a suitable vegetable to be planted in oasis soil

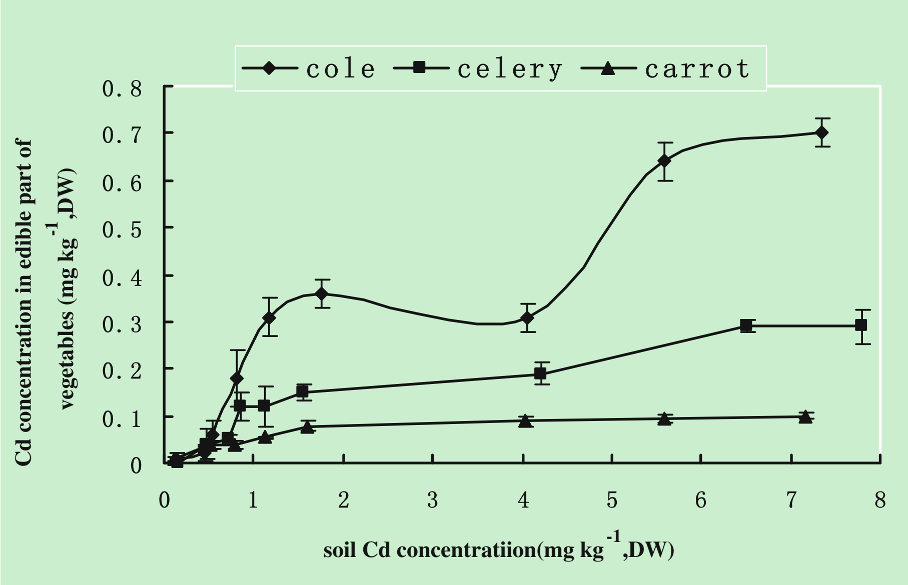

**Fig. 4** The correlation of Cd concentration (mg kg$^{-1}$, DW) in soil and the edible part of vegetables, the edible part of cole: the aboveground part of the plant; the edible part of celery: the aboveground part of the plant; and the edible part of carrot: the underground part of the plant

contaminated by Cd and Pb (Lakhdar et al. 2010). Especially, when Cd concentration is added to the highest treatment in experiment, Cd content in the edible part of cole could reach 0.7 mg kg$^{-1}$ DW, which is 2.4 times higher than the level in celery and 7 times more than that in carrots. This indicates that when Cd concentration exceeds the peak value in arid soils, people who consume cole and celery produced in Cd contaminated soil will be vulnerable to a great health risk.

## Conclusion

The results show that in the control soil, the FMO-F of Cd was always the predominant fraction with pH > 7.5, and with increasing the total content of Cd in arid soil, the content of Cd associated with exchangeable and carbonate metal fractions increased significantly. However, the MF was not uniform in the arid oasis soils cultivated with different vegetables.

The fresh weight of the celery decreased with the increasing concentration of Cd in arid soils. The Cd concentration made no significant effect on fresh weight of the cole plant. However, the results indicate that low concentrations of Cd in arid soil could promote the growth of carrots, while higher concentration (exceed the peak value 5 mg kg$^{-1}$ DW) could restrain them. The content of Cd in the edible part of cole was significantly higher than that in the celery and in the carrots under most of the treatments; however, cole can grow normally and sustainably increase its biomass under the highest concentration of Cd (7.5 mg kg$^{-1}$ DW) added in the experiment. Cole (*Brassica campestris* L.) is not a suitable vegetable to be planted for consumption in arid soil contaminated with Cd; Celery (*Apium Graveolens* L.) planted under lower concentration of Cd will not threaten people's health; and carrots (*Daucus carota* L.) are suitable to be planted in arid soil contaminated with the highest concentration of Cd (7.5 mg kg$^{-1}$ DW) in the experiment. In conclusion, stricter soil management systems should be implemented to protect arid land soil resources and prevent the damaging impacts on human health.

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