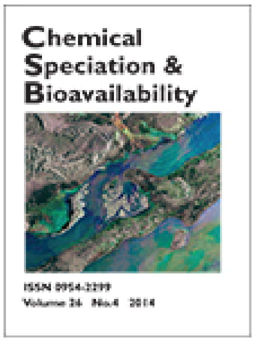

Taylor & Francis
Taylor & Francis Group

Chemical Speciation & Bioavailability

ISSN: (Print) 0954-2299 (Online) Journal homepage: http://www.tandfonline.com/loi/tcsb20

Bioaccumulation and translocation of cadmium in wheat (Triticum aestivum L.) and maize (Zea mays L.) from the polluted oasis soil of Northwestern China

Yiming Yang, Zhongren Nan & Zhuanjun Zhao

To cite this article: Yiming Yang, Zhongren Nan & Zhuanjun Zhao (2014) Bioaccumulation and translocation of cadmium in wheat (Triticum aestivum L.) and maize (Zea mays L.) from the polluted oasis soil of Northwestern China, Chemical Speciation & Bioavailability, 26:1, 43-51

To link to this article: http://dx.doi.org/10.3184/095422914X13888342841789

Published online: 12 Jan 2015.

Bioaccumulation and translocation of cadmium in wheat (*Triticum aestivum L.*) and maize (*Zea mays L.*) from the polluted oasis soil of Northwestern China

Yiming Yang[a*], Zhongren Nan[b] and Zhuanjun Zhao[b]
[a]*School of Chemical Engineering, North West University for Nationalities, Lanzhou 730030, P.R. China*
[b]*College of Resource and Environment, Lanzhou University, Lanzhou 730000, P.R. China*
**E-mail: yyiming2004@126.com*

ABSTRACT

A pot experiment was conducted to study the bioaccumulation and translocation of cadmium (Cd) in wheat (*Triticum aestivum L.*) and maize (*Zea mays L.*) grown in the Cd-polluted oasis soil in northwest China. The results showed that Cd in the unpolluted oasis soil was mainly bound to carbonate fraction (F2) and Fe–Mn oxide fraction (F3). However, a marked change of the Cd fractionation was observed with increasing soil Cd concentrations, where the concentrations of Cd in F1 (exchangeable fraction), F2 and F3 increased significantly (P<0.001 for F1, F2 and F3). The correlation analysis between the fraction distribution coefficient (FDC) of Cd in the soil and Cd concentration accumulated in the two crops showed that Cd in F1 fraction in the oasis soil made the greatest contribution on the accumulation of Cd in the two crops. Higher bio-concentration factors (BCF) of Cd were observed in the two crops' shoots compared with grains, and low translocation factors (TF) of Cd in the grains were observed for both crops. Cd had a higher accumulation in the edible parts of the wheat, but lower accumulation in those of the maize. Therefore, wheat grown in Cd-polluted oasis soil has a higher risk to human health, whereas maize has a lower risk suggesting that wheat is not suitable for cultivation as crop and consumption by humans in the Cd-polluted oasis soil, but that maize is suitable for plantation.

Keywords: bioaccumulation, translocation, cadmium, wheat and maize, oasis soil

1. INTRODUCTION

There is an increasing concern regarding food safety due to environmental pollution (Ma and Rao, 1997; Li and Thornton, 2001; Yang *et al*., 2009), in which soil pollution with anthropogenic heavy metals released from industry or agriculture such as smelting industries, residues from metalliferous mines, pesticides, fertilisers, municipal composts, has received much attention in recent years (Lu *et al*., 2005; Liu *et at*., 2007a; Guo *et al*., 2008; Wu *et al*., 2010;Chen *et al*., 2011;Wang *et al*., 2012; Guo *et al*., 2012; Osakwe *et al*., 2012; Shao *et al*., 2013; Xu *et al*., 2013). Heavy metals in soils cannot be biodegraded, but can be bio-accumulated and bio-transformed by plants, and pose toxicity to plants beyond certain limits (Nan and Zhao, 2000; Nan and Cheng, 2001; Nan *et al*., 2002; Ding *et al*., 2008; Nan *et al*., 2011; Yang *et al*., 2011a, 2011b; Wang *et al*., 2013). Intake of high doses of heavy metals through the food chain may lead to a threat to human health.

Several studies have suggested that the toxicity and mobility of heavy metals depends not only on their total amounts but also on their chemical fractionation in soil (Ma and Rao, 1997; Li and Thornton, 2001; Greenway and Song, 2002; Chojnacka *et al*., 2005; Gupta and Sinha, 2006; Silveira *et al*., 2006; Kartal *et al*., 2006; Li *et al*., 2007; Tandy *et al*., 2009; Wang *et al*., 2009; Rodríguez *et al*., 2009). There are many classification methods to assess the chemical fractions of heavy metals in soil (Tessier *et al*., 1979; Ahnstrom and Parker, 1999; Qiao *et al*., 2003; Silveira *et al*., 2006). Tessier's five-step sequential extraction method has been widely used, in which heavy metals in soils are categorised in the five fractions: exchangeable fraction (F1), carbonate fraction (F2), Fe–Mn oxide fraction (F3), organic matter fraction (F4) and residual fraction (F5) (Tessier *et al.*,

Doi: 10.3184/095422914X13888342841789

1979; Lucho-Constantino *et al*., 2005; Silveira *et al*., 2006; Rodríguez *et al*., 2009). F1 is bioavailable fractionation; F2, F3 and F4 are potential bioavailable fractionations; F5 is unbioavailable fractionation (Ma and Rao, 1997; He *et al*., 2005; Rodríguez *et al*., 2009).

The oasis soil is mainly distributed in the oasis in the arid desert region including Xinjiang Autonomous Region and the Hexi Corridor, northwest China. In recent decades, some oasis croplands have been irrigated with wastewater from the industry and agriculture activities in the arid area and therefore have been heavily polluted by heavy metals, especially by Cd in northwest China (Nan and Zhao, 2000; Nan and Cheng, 2001; Nan *et al*., 2002; Ding *et al*., 2008; Nan *et al*., 2011), which caused a threat to the oasis ecological environment and human health. Many studies have indicated that the uptake of heavy metals by plants was related not only to the physical and chemical properties of soils and soil types but also plant species (McBride, 2003; Sun *et al*., 2003; Kidd *et al*., 2007).

Cadmium is a toxic trace element to plants and animals, and can cause damage even at very low concentrations (Wagner, 1993; Liu *et al.,* 2007a; Wang *et al.,* 2007; Xu *et al.,* 2007; Huang *et al.,* 2009; Su *et al.,* 2009; Sun *et al.,* 2009; Yang *et al.,* 2009) and can be taken up by crops easily (Wagner, 1993; Liu *et al*., 2007a; Huang *et al*., 2009). In China, much soil has been polluted with Cd which is one of the most important and typical heavy metal pollutant (Chen, 1996; Su *et al*., 2009; Liu *et al*., 2010). According to the literature, about 14000 hm^2 of agricultural soils have been polluted with Cd in China (Chen, 1996; Su *et al*., 2009). Moreover, Cd may pose risk to human and animal health through consumption of crops although the plant tissue concentrations may not be generally phytotoxic (Liu *et al*., 2007b). In order to avoid the pollution of the food chain by Cd, it is essential to assess its bioavailability in soil (Cornu *et al*., 2009).

Some studies (Yang *et al*., 2011a, 2011b; Wang *et al*., 2013) have reported chemical speciation and bioavailability of Cd in oasis soil, bioaccumulation and translocation of Cd in vegetables grown in the Cd-polluted oasis soil in northwest China. Their findings showed that Cd in F1 in the oasis soil made the greatest contribution on the accumulation of Cd in both cole and celery, and Cd had higher accumulation in the edible parts of the two vegetables.

As crops consumed for their edible parts, wheat (*Triticum aestivum L.*) and maize (*Zea mays L.*) have been widely cultivated in northwestern China where individual consumption figures for the grains of wheat and maize by the local population is approximately 0.35 kg and 0.05 kg average per person per day, respectively (Chinese Nutrition Society, 2008). People who consume crops grown in Cd-polluted soils in the area are at risk of an elevated Cd exposure. The present work aimed to study the bioaccumulation and translocation of Cd in wheat and maize grown in the Cd-polluted oasis soil in northwestern China using pot experiments. Human health risks from these crops were also evaluated.

2 MATERIALS AND METHODS

2.1 Experimental design

Experimental reagents were selected with superior grade (Tianjin Kermel Chemical Reagents Corporation, China) and certified reference material samples, GSS-1 (GBW07401) and GSB-6 (GBW10015) were used. The two parameters bio-concentration factor (BCF) and the translocation factor (TF) were calculated. BCF was the ratio of the metal concentration in plant tissues to that in their rooted soils (Yang *et al*., 2009; Sun *et al*., 2009; Wang *et al*., 2009), and TF was the ratio of metal concentration in other plant parts to that in roots (Sun *et al*., 2009; Wang *et al*., 2009).

Pot experiments were conducted under open air conditions at Linze county, Hexi corridor, northwest China. This area belongs to an arid region with low precipitation (104–129mm annually), high evapotranspiration (1900–2100mm), and high temperatures in the summer (22ºC).The irrigation-silting soils are derived from oasis/desert soils, and textures are mainly sandy. Other soil properties are as follows: pH (in H_2O) 8.47, organic mater (OM) content 1.54%, $CaCO_3$ content 7.39%, and cation exchange capacity (CEC) 8.11 cmol kg^{-1}. The background concentration level of Cd in oasis soil is 0.118 mg kg^{-1} dry weight (dw) in northwestern China (Chen, 1996).

The soil used was an irrigation-silt sandy soil, excavated from an oasis farm at 0-20cm depth with spade, and sub-samples collected were mixed to obtain a composite sample in accordance with the standard method (Keith, 1996; Ministry of Environmental Protection of P.R. China, 2004). The soil sample was air dried and ground, then passed through a 10 mm sieve to remove large stones and grass debris. Nine treatments (one control and eight amendments) were replicated three times in a randomised block design. The control was not amended with inorganic Cd. The others, one by one, were spiked with different solutions of cadmium nitrate to elevate soil Cd concentrations as follows: 0.35, 0.7, 1.05, 1.4, 2.1, 3.5, 4.9 and 7.0 mg kg^{-1} dw for Cd, which was designed based on our field pollution investigation in the Cd-polluted oasis soil (Nan *et al*., 2011). The heavy metal was added by spraying a solution of metal salt over relatively dry soil spread out on a large tray. The soil was turned over and sprayed several times, then watered and left for equilibration outdoors for four weeks and transferred to pots before planting crops. The wheat and maize plants were seeded directly into the soil in the pots, and two weeks after sowing, the number of seedlings was thinned to four per pot for wheat, one for maize. During the experimental period, tap water was added to compensate for evaporation and transpiration and soil moisture content was maintained at approximately 60% of water holding capacity.

Whole plants were harvested after 120 days of growth and cut with scissors into separate parts grown under and above the soil. Shoots (leaves + stems) and grains were washed three times using de-ionised water. Roots were washed thoroughly with tap water to eliminate soil particles, and rinsed three times with de-ionised water. Roots and shoots were dried in an oven at 70℃ to constant weight, and the grains were air-dried to constant weight. The grain chaff was removed with machine (OHYA-25, Japan), and the grain was oven-dried at 60℃ to constant weight. The oven-dried samples were ground with a stainless steel grinder (FW-100, China), passed through 2 mm nylon sieve for further experiment, and the dry weight (dw) of roots, shoots and grains were recorded.

Composite soil samples were collected from the pots after harvesting the crops, air-dried at room temperature, ground with pestle and mortar, passed through 100 mesh (ϕ= 0.149 mm) nylon sieve.

Plant samples and soil samples were stored in plastic bottles, respectively, before analyses.

2.2 Determination of Cd in soils and crops

Total Cd concentrations in soils were determined according to national standards of China (State Environmental Protection Administration of China, 1997). Total Cd in the crops was extracted using the acid digestion mixture (HNO_3–$HClO_4$–HF) (EPA3010A, 1996). The clear solution obtained from the digestion was filtered and reconstituted to the desired volume for analysis using an atomic absorption spectrometer (AAS, M6MK2, Thermo Electron Corporation, USA).

2.3 Determination of Cd fractionation in soil using Tessier's sequential extractions

Tessier's sequential extraction procedure was used in this experiment. Cd was extracted by $MgCl_2$ solution in F1; by HAc–NaAc solution in F2; by NH_2OH•HCl solution in F3; by HNO_3–H_2O_2–NH_4Ac solution in F4; and by HNO_3–$HClO_4$–HF solution in F5 (Tessier *et al.*, 1979). Cd in soil solutions obtained from Tessier's sequential extraction procedure was also determined by an atomic absorption spectrometer (AAS, M6MK2, Thermo Electron Corporation, USA).

2.4 Quality assurance of data generation

Replicates, blanks and certified reference materials, GSS-1 (GBW07401) and GSB-6 (GBW10015), were included for quality assurance. The total and various speciation Cd concentrations in soils and plants (wheat and maize) were determined in triplicate, and the coefficient of variation ranged between 3% and 10% in triplicate analysis. The percentage recovery from certified reference materials was from 90% to 110% throughout the analysis procedures.

2.5 Statistical analysis

The means and standard deviations (SD) were calculated by Excel2003 for windows. One-way analysis of variance was carried out with SPSS16.0. The significant (P<0.05) difference observed between treatments and multiple comparisons were made by the LSD test.

3 RESULTS AND DISCUSSION

3.1 Chemical fractions of Cd in the oasis soil

The experiment results in Figure 1 showed that planting two different crops (wheat and maize) had no effect on the Cd chemical fractions distribution in the oasis soil (Figure 1) (P<0.001). With increasing Cd concentrations in soils, the concentrations of Cd in exchangeable fraction (F1), carbonate fraction (F2) and Fe–Mn oxide fraction (F3) increased significantly (P<0.001 for F1, F2 and F3) probably because of the addition of Cd in the form of solution, which was highly bioavailable. The parameter fraction distribution coefficient (FDC) usually was defined as the percentage of the each heavy metal fraction, and the FDCs of Cd increased significantly in F1 and F2 (P<0.001) with increasing soil Cd

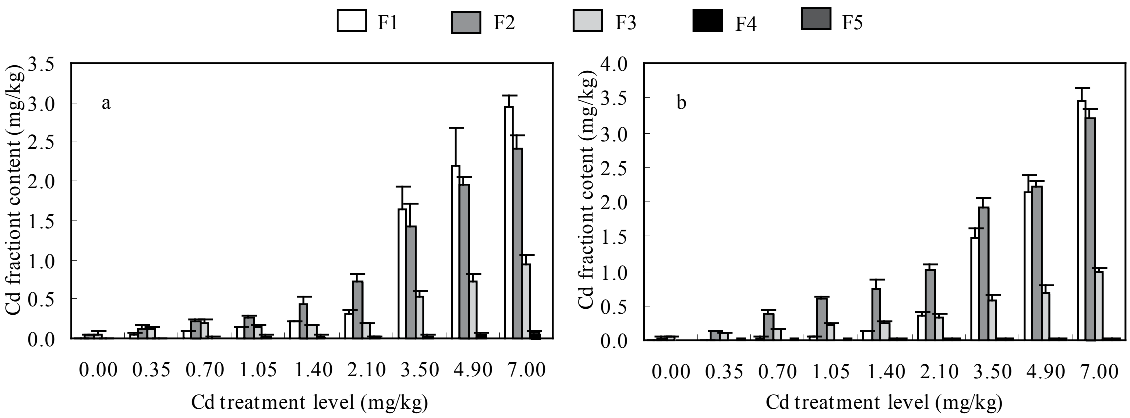

Figure 1 Distribution of the concentration of Cd fractions in the soil in which wheat (a) and maize (b) was grown, respectively. F1, exchangeable fraction; F2, carbonate fraction; F3, Fe–Mn oxide fraction; F4, organic matter fraction; F5, residual fraction. Values are means±SD of three replicates.

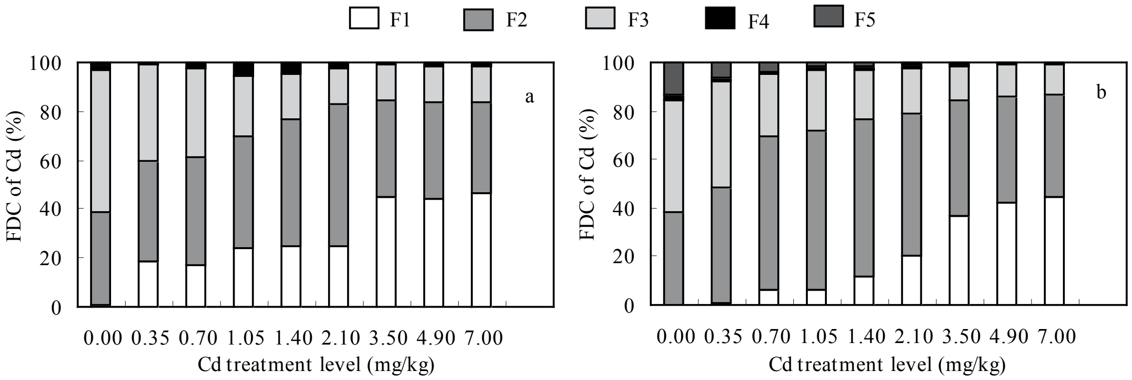

Figure 2 Distribution of the fraction distribution coefficient (FDC) of Cd in the soil in which wheat (a) and maize (b) was grown, respectively. Values are means of three replicates.

concentration probably because of greater mobility of Cd and higher $CaCO_3$ concentration in the soil (Nan *et al*., 2011), however, reduced significantly in F3 (P<0.001) (Figure 2).

F5 comprises primary and secondary minerals within the crystal structure that is unlikely to be released in the mid- and long-term under the conditions normally found in nature. Previous studies have shown that in unpolluted soils, F5 was the main heavy metals fraction which was not bio-available for the plants (Gao *et al*., 2001; Wang and Zhou, 2003; Guo and Zhou, 2005), but the percentage of heavy metals associated with available fraction increased with the increase of total heavy metals in the growth medium (Gao *et al*., 2001; Wang and Zhou, 2003; Zhou *et al*., 2003; Guo and Zhou, 2005; Lucho-Constantino *et al*., 2005). Bose *et al* (2008) reported that Cd was bound with F3 in unpolluted garden soil in India. Similar results were observed in present study. The results suggested that the fraction of Cd in unpolluted soil was mainly in F3, however, the bioavailable fraction concentration increased significantly (P<0.001), and the percentage of Cd associated with F5 decreased significantly (P<0.001) with increased soil Cd concentrations.

3.2 Effects of Cd stress on crop growth

The dry weight of roots, shoots and grains of crops grown with different Cd treatments is listed in Table 1.

Values are presented as mean±SD of three replicates. One-way ANOVA (1 factor: different Cd treatments) was performed for each parameter on Cd concentration. Data in the same column followed by different letters are significantly different from each other (P<0.05) according to the LSD test.

The dried biomass of crop roots, shoots and grains generally increased at first, and reached peak values, then decreased with increased soil Cd concentrations (Table 1). When the treatment level of Cd was 3.50 mg kg^{-1}, the dried biomass of wheat grains reached the maximum value (12.47±1.91 g/pot), increased by 82.6%, compared with the control, indicating that this value was hazardous threshold of wheat, and beyond it, the growth of wheat grain would be inhibited. Similarly, when the treatment level of Cd was 3.50 mg kg^{-1}, the dry biomass of maize grains reached the maximum value (23.38±2.63 g/pot), increased by 17.4%, compared with the control, suggesting that this value was hazardous threshold of maize, and beyond it, the growth of maize grain would be inhibited.

Some studies (Dong and Chen, 1982; Zhang and Huang, 2000; Li, 2006) have reported that dried weight of crops (wheat and maize) increased at first, then decreased under soil Cd stress. This conclusion was in agreement with the present studies. These results indicated that the toxic effect of Cd on crops had threshold values. Crop growth could be enhanced by lower concentrations of Cd (≤3.50 mg kg^{-1} for both wheat and maize), but inhibited by higher concentrations. This may

Table 1 Effects of a range of Cd treatments on the biomass of crops

Cd Treatment level (mg kg^{-1})	Dry weight (g/pot)					
	Wheat root	Wheat shoot	Wheat grain	Maize root	Maize shoot	Maize grain
0.00	1.20±0.14a	8.36±0.85a	6.83±1.18a	6.27±2.79a	19.47±6.06a	19.92±0.00b
0.35	1.33±0.36a	8.09±0.42a	9.31±1.65ab	13.36±6.63b	38.75±16.93bc	15.83±8.35ab
0.70	1.59±0.34a	9.94±0.67a	9.20±2.46ab	12.61±1.20b	33.84±6.46bc	15.87±7.65ab
1.05	1.35±0.17a	9.33±1.01a	8.09±2.68a	11.06±3.43b	37.46±6.48bc	10.04±0.06a
1.40	1.33±0.24a	9.00±1.83a	9.88±3.55ab	12.16±2.85b	41.59±3.60c	20.01±10.58b
2.10	1.11±0.23a	9.43±1.67a	10.87±1.91b	11.63±4.18b	29.55±2.96abc	22.76±2.34b
3.50	1.33±0.09a	9.62±0.61a	12.47±1.91b	10.04±4.09b	25.90±3.32ab	23.38±2.63b
4.90	1.43±0.15a	7.39±1.52a	10.16±2.42ab	9.35±3.71b	35.56±7.98bc	20.81±6.37b
7.00	1.43±0.37a	8.44±1.32a	9.73±0.36ab	12.11±2.64b	30.98±8.44abc	15.99±5.94ab

be attributed to the high concentrations of Cd that damaged the crop roots (Zhang and Huang, 2000; Jiang, 2004; Fan *et al.*, 2010), and inhibited uptake of the nutrient elements in the roots, then inhibited the growth of the crops.

3.3 Bioaccumulation of Cd in crops

3.3.1 Bioaccumulation of Cd in wheat and maize

The amounts and distribution of Cd accumulated in crops under various treatments are shown in Table 2. Cd concentrations in crops increased significantly (P<0.001) with increased soil Cd concentrations. Compared with the control, wheat and maize grains Cd concentrations increased by 31.6 fold and 7.0 fold, respectively at the Cd level of 7.00 mg kg^{-1} in the soil.

One-way ANOVA (1 factor: different Cd treatments) was performed for each parameter on Cd concentration. Data in the same column followed by different letters are significantly different from each other (P<0.05) according to the LSD test.

According to the China Environmental Quality Standard for Soils (State Environmental Protection Administration of China, 1995), Cd limit for the soils used for crop production is 1.0 mg kg^{-1} where soil pH >7.5. At a Cd level of 1.0 mg kg^{-1} in soil, Cd concentration in crops was 0.6 mg kg^{-1} for wheat grain (calculated by statistical regression equation y=0.4093x+0.2092, R^2=0.973, P<0.001, where y is Cd concentration in grains, x is the concentration of Cd in soils) and 0.01mg kg^{-1} for maize grain (calculated by y=0.0109x+0.0007, R^2=0.945, P<0.001), respectively. At this level of Cd addition, the national allowable limit of Cd in crops was exceeded in wheat, but not exceeded in maize, compared with maximum levels of contaminants in foods, 0.1 mg kg for both wheat and maize (Ministry of Health of the People's Republic of China and Standardization Administration of China, 2005).

Wang *et al*. (2008) found that at a Cd level of 0.5 mg k^{-1} in the soil, Cd concentration in the corresponding maize grain was 0.109 mg kg^{-1}, which exceeded the allowable limit of Cd in maize. This conclusion was not in agreement with present study probably because of different soil properties or crop cultivates.

In general, wheat accumulated higher Cd concentrations in its edible parts than maize, which was in agreement with Wang *et al*. (2002) who found growing wheat in Cd-contaminated soil would pose a higher risk to human health rather than growing maize.

The present study found the order of Cd accumulation in both wheat and maize was root > shoot > grain (Table 2). Similar results were observed in the previous studies (Nan and Cheng.2001; Nan *et al*., 2002; Wang *et al*., 2007; Wang *et al*., 2008; Tian *et al*., 2009).

The BCF of Cd in crop roots, shoots and grains under various treatments are shown in Table 3. The BCF value for Cd ranged from 3.93–7.66 for roots, 0.72–2.41 for shoots, 0.46–0.91 for grains in wheat, respectively; 0.80–3.61 for roots, 0.12–1.04 for shoots, 0.00–0.02 for grains in maize, respectively. In general, the BCFs for Cd in wheat were

Table 2 Concentration of Cd in crops with different Cd treatments

Cd Treatment level (mg kg^{-1})	Cd concentration (mg kg^{-1} dw)					
	Wheat root	Wheat shoot	Wheat grain	Maize root	Maize shoot	Maize grain
0.00	0.59±0.08a	0.09±0.00a	0.08±0.01a	0.07±0.03a	0.03±0.01a	0.01±0.00a
0.35	1.69±0.30ab	0.24±0.03a	0.23±0.08ab	0.37±0.16ab	0.07±0.02a	0.01±0.00a
0.70	3.07±0.36ab	0.38±0.13a	0.33±0.06ab	2.23±0.30ab	0.19±0.12a	0.04±0.06ab
1.05	4.09±0.35b	1.34±0.22b	0.51±0.11b	3.08±0.72bc	0.17±0.06a	0.01±0.00a
1.40	6.39±0.60bc	1.59±0.56b	0.58±0.16b	3.29±0.28bc	0.14±0.10a	0.01±0.00a
2.10	9.60±2.30c	2.17±0.42b	0.90±0.01bc	5.56±2.22c	1.81±0.37b	0.04±0.00ab
3.50	14.27±0.88d	3.39±0.58c	1.94±0.38d	9.57±2.40d	2.54±0.82c	0.05±0.03ab
4.90	21.45±3.57e	4.55±0.70d	2.30±0.42de	15.48±2.07e	3.73±0.21d	0.05±0.02ab
7.00	22.90±2.55e	4.50±0.98d	2.61±0.43e	15.71±3.34e	5.92±0.64e	0.08±0.03b

Values are presented as mean±SD of three replicates.

Table 3 Bioconcentration factors (BCF) and translocation factors (TF) of Cd in crops with Cd treatments

Cd Treatment level (mg kg^{-1})	Wheat					Maize				
	BCF_{root}	BCF_{shoot}	BCF_{grain}	TF_{shoot}	TF_{grain}	BCF_{root}	BCF_{shoot}	BCF_{grain}	TF_{shoot}	TF_{grain}
0.00	6.19	0.89	0.84	0.14	0.14	0.80	0.36	0.00	0.45	0.00
0.35	5.20	0.74	0.70	0.14	0.14	1.38	0.27	0.01	0.20	0.01
0.70	5.92	0.72	0.64	0.12	0.11	3.61	0.30	0.01	0.08	0.00
1.05	7.34	2.41	0.91	0.33	0.12	3.41	0.19	0.00	0.05	0.00
1.40	7.66	1.90	0.70	0.25	0.09	2.84	0.12	0.01	0.04	0.00
2.10	7.63	1.73	0.71	0.23	0.09	3.19	1.04	0.02	0.33	0.01
3.50	3.93	0.93	0.54	0.24	0.14	2.38	0.63	0.01	0.26	0.01
7.00	4.34	0.92	0.46	0.21	0.11	3.04	0.73	0.01	0.24	0.00

higher than in maize (P<0.001). Many studies have indicated that maize shoot had high accumulation for Cd, and could be considered as a Cd hyperaccumulator for remediation of the Cd-contaminated soil (Jiang, 2004; Weng and Yu, 2006; Wang *et al*., 2007; Li *et al*., 2008; Tian *et al*., 2009). This conclusion was not in agreement with present study probably because of different soil properties or crop cultivars.

Sun *et al*. (2003) found that the cumulative coefficients of heavy metals were higher in plants under low heavy metal doses, in contrast, the cumulative coefficients of heavy metals were low under high doses, but the absolute amount of heavy metals accumulated increased with the increased heavy metal doses. Similar results were observed in the present study, the BCFs in the two crops increased, reached a maximum value, then decreased with increasing soil Cd concentrations (Table 3).

In general, the TFs of Cd in wheat grain were higher than those in maize (Table 3), suggesting that Cd had greater mobility towards uptake by the grain in wheat than that in maize. This conclusion was in agreement with Wang *et al*. (2002).

The above-mentioned results showed that the BCF of Cd in wheat and maize had threshold values, beyond which, the roots of wheat and maize may be damaged by Cd, although the uptake and accumulation of Cd in wheat and maize was continuing, but their uptake rates gradually reduced, hence the BCF of Cd in wheat and maize increased at first, then decreased. The above results also suggested that wheat accumulated higher Cd concentrations in its edible parts than maize grown in the polluted oasis soil. Therefore, the wheat grown in the Cd-polluted oasis soil, if consumed by humans, has higher risk to human health than the maize.

3.3.2 Relationship between the accumulation in crops and chemical fractions of Cd in the soil

Significantly positive correlation was found between the FDCs of Cd in F1 in the soil and Cd concentrations in crop roots, shoots and grains, respectively (Table 4), the corresponding correlation coefficients (CC) were 0.909 for roots, 0.933 for shoots and 0.929 for grains of wheat, respectively; and 0.978 for roots, 0.938 for shoots and 0.962 for grains of maize, respectively.

Zhu *et al.* (2002) reported that exchangeable Cd was the highest available fraction and made the most contribution to the lettuce plant in purple soil; Cui *et al.* (2005) found that exchangeable Cd were extractable by reed plant; and Wang *et al.* (2008) observed that there was an obvious relativity between Cd content in corn to available Cd in soil. Similar results were observed in the present study where exchangeable Cd (F1) was the most available fraction for both wheat and maize, which indicated that Cd in F1 made the greatest contributions on the accumulation of Cd in the roots, shoots and grains of both wheat and maize (Table 4).

Yang *et al.* (2011b) reported that there was significantly negative correlation between the percentage of Cd in F5 in the soil and the accumulation of Cd in the roots and shoots of both cole and celery. In present study, significantly negative correlation was also observed between the FDCs of Cd in F5 in the soil and Cd concentrations in crops roots, shoots and grains, respectively, except for maize shoots (Table 4), which indicated that Cd in F5 was unavailable fraction for both wheat and maize.

4. CONCLUSIONS

Cadmium in the unpolluted oasis soil was mainly bound to the Fe–Mn oxide fractionation (F3) and carbonate fractionation (F2). However, the fractional distribution of Cd changed significantly with increasing Cd concentrations in the soil, where concentrations of Cd in exchangeable fractionation (F1), those bound to carbonate fractionation (F2) and Fe–Mn oxide fractionation (F3) increased significantly.

Relatively lower concentrations of Cd could facilitate the growth of wheat and maize, but their growth was inhibited at higher concentrations. The Cd in F1 made the greatest contribution in the accumulation of Cd in the two crops. The translocation factor of Cd in wheat grain was higher than in maize grain, and Cd had higher accumulation in the edible part of wheat.

Therefore, wheat grown in the Cd-polluted oasis soil has a higher potential of risk to human health, but maize has a lower risk according to individual consumption figures for these grains which are approximately 0.35 kg and 0.05 kg average per person per day, respectively. Therefore it is suggested that wheat grown in the Cd-polluted oasis soil is not suitable for cultivation and consumption of humans, but maize is suitable for plantation.

Table 4 Correlation coefficients (R) between the F1 fraction distribution coefficients (FDC) of Cd in the soil and concentrations of Cd in crop roots, shoots and grains

Chemical fractions	R (wheat)			R (maize)		
	Root	Shoot	Grain	Root	Shoot	Grain
F1	0.909**	0.933**	0.929**	0.978**	0.938**	0.962**
F2	–0.247	–0.194	–0.342	–0.401	–0.506	–0.450
F3	–0.745**	–0.801**	–0.717*	–0.808**	–0.702*	–0.760**
F4	–0.379	–0.292	–0.421	–0.656*	–0.614*	–0.638*
F5	–0.747**	–0.788**	–0.751*	–0.661*	–0.546	–0.614*

Significant at level *P<0.05; **P<0.01.

ACKNOWLEDGMENTS

This work was supported by the Fundamental Research Funds for the Central Universities in Northwest University for Nationalities (No.31920130023), the National Natural Science Foundation of China (No.51178209) and the Innovative Research Team Program of Northwest University for Nationalities.

REFERENCES

Ahnstrom, Z. S. and Parker, D. R. (1999) Development and assessment of a sequential extraction procedure for the fractionation of soil cadmium. *Soil Sci. Soc. Am. J.*, **63**, 1650-1658.

Bose, S., Jain, A., Rai, V. and Ramanathan, A. L. (2008) Chemical fractionation and translocation of heavy metals in Canna *indica L.* grown on industrial waste amended soil. *J. Hazard. Mater.*, **160**, 187-193.

Chen, H. M. (1996) *Heavy metals in plant-soil systems*. Science Press, Beijing.

Chen, J. Q., Wang, Z. X., Wu, X., Zhu, J. J. and Zhou, W. B. (2011) Source and hazard identification of heavy metals in soils of Changsha based on TIN model and direct exposure method. *Transf .Nonferrous Metals Soc. China*, **21**, 642-651.

Chinese Nutrition Society (2007) *Chinese dietary guidelines* Tibet People Press, Lasa.

Chojnacka, K., Chojnacki, A., Górecka, H. and Górecki, H. (2005) Bioavailability of heavy metals from polluted soils to plants. *Sci. Total Environ.,* **3**3, 175-182.

Cornu, J. Y., Parat, C., Schneider, A., Authier, L., Dauthieu, M., Sappin-Didier, V *et al*. (2009) Cadmium speciation assessed by voltammetry, ion exchange and geochemical calculation in soil solutions collected after soil rewetting. *Chemosphere*, **76**, 502-508.

Cui, Y., Ding, Y. S., Gong, W. M. and Ding, D. W. (2005) Study on the correlation between the chemical forms of the heavy metals in soil and the metal uptake by plant. *J. Dalian Maritime Univ.*, **31**, 59-63.

Ding, H. X., Nan, Z. R., Liu, X. W., Li, Y., Wang, S. L. and Qin, S. (2008) Characteristics of selected heavy metal pollution in suburb cropland, Jinchang city, Gansu, China. *J. Agro-Environ. Sci.*, 2**7**, 2183-2188.

Dong, K. Y. and Chen, J. M. (1982) Effect of Cd on crops growth and accumulation . *Environ. Sci.*, **3**, 31-34.

EPA 3010A, 1996. See, http//www.epa.gov/epaoswer/hazwaste/testmain.htm, *Revision2, 3010A*, 1-51.

Fan, M. Q., Li, Y. Y., Miao, J., Yu, H. Y. (2010) Influences of Cd^{2+} stress on seed germination and seedling growth of wheat. *J. Anhui Agr. Sci.*, **38**, 14239-14241.

Gao, Y. Z., He, J. Z. and Ling, W. T. (2001) Fractionation of heavy metal cadmium and copper in some soils in Hubei province. *J. Huazhong Agric. Univ.*, **20**, 143-147.

Greenway, G. M. and Song, Q. J. (2002) Heavy metal speciation in the composting process. *J. Environ. Monit.*, **4**, 300-305.

Guo, G. H., Wu, F. C., Xie, F. Z. and Zhang, R. Q. (2012) Spatial distribution and pollution assessment of heavy metals in urban soils from southwest China. *J. Environ. Sci.,* **24**, 410-418.

Guo, G. L. and Zhou, Q. X. (2005) Speciation distribution and bioactivity of heavy metals in contaminated phaiozem. *Environ. Chem.*, **24**, 383-388.

Gupta, A. K. and Sinha, S. (2006) Chemical fractionation and heavy metal accumulation in the plant of *Sesamum indicum* (L.) var. T55 grown on soil amended with tannery sludge, Selection of single extractants. *Chemosphere*, **64**, 161-173.

He, Z. L., Yanga, X. E. and Stoffellab, P. J. (2005) Trace elements in agroecosystems and impacts on the environment. *J. Trace Elements Med. Biol.,* **19**, 125-140.

Huang, Y. Z., Hu, Y. and Liu, Y. X. (2009) Combined toxicity of copper and cadmium to six rice genotypes (*Oryza sativa* L.). *J. Environ. Sci.,* **21**, 647-653.

Jiang, H. S. (2004) Effect of Cd intimidation on physiological characteristics of maize. *J. Liaoning Univ. Petrol. Chem. Technol.*, **24**, 35-41.

Kartal, S., Aydın, Z., Tokaliog, L. S. (2006) Fractionation of metals in street sediment samples by using the BCR sequential extraction procedure and multivariate statistical elucidation of the data. *J. Hazard. Mater.*, **132**, 80-89.

Keith, L.H. (1996) *Principles of environmental sampling*. 2nd edn. American Chemical Society, Washington, DC,.

Kidd, P. S., Domínguez-Rodríguez, M. J., Díez, J. and Monterroso, C. (2007) Bioavailability and plant accumulation of heavy metals and phosphorus in agricultural soils amended by long-term application of sewage sludge. *Chemosphere*, **66**, 1458-1467.

Li, G. L. (2006) Effect of cadmium on maize seeds germination and seedling growth. *Territory Natural Resources Study*, **2**, 91-92.

Li, M. S., Luo, Y. P. and Su, Z. Y. (2007) Heavy metal concentrations in soils and plant accumulation in a restored manganese mineland in Guangxi, South China. *Environ. Pollut.*, **147**, 168-175.

Li, N. Y., Li, Z. A., Zou, B. and Zhuang, P. (2008) Effects of intercropping different crops with maize on the Cd uptake by maize. *Chin. J. Appl. Ecol.*, **19**, 1369-1373.

Li, X. and Thornton, I, (2001) Chemical partitioning of trace and major elements in soils contaminated by mining and smelting activities. *Appl. Geochem.,* **16**, 1693-1706.

Liao, G. L., Liao, D. X. and Li, Q. M. (2008) Heavy metals contamination characteristics in soil of different mining activity zones. *Trans. Nonferrous Metals Soc. China*, **18**, 207-211.

Liu, J. G., Qian, M., Cai, G. L., Yang, J. C. and Zhu, Q. S. (2007a) Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain. *J. Hazard. Mater.,* **143**, 443-447.

Liu, W. T., Zhou, Q. X., An, J., Sun, Y. B. and Liu, R. (2009) Variations in cadmium accumulation among Chinese cabbage cultivars and screening for Cd-safe cultivars. *J. Hazard. Mater.*, **173**, 737-743.

Liu, Y. G., Ye, F., Zeng, G. M., Fan, T., Meng, L. and Yuan, H. S. (2007b) Effects of added Cd on Cd uptake by oilseed rape and pai-tsai co-cropping. *Trans. Nonferrous Metals Soc. China*, **17**, 846-852.

Lu, A. X., Zhang, S. Z. and Shan, X. Q. (2005) Time effect on the fractionation of heavy metals in soils. *Geoderma*, **125**, 225-234.

Lucho-Constantino, C. A., Prieto-García, F., Del Razo, L. M., Rodríguez-Vázquez, R. and Poggi-Varaldo, H. M. (2005) Chemical fractionation of boron and heavy metals in soils irrigated with wastewater in central Mexico. *Agric., Ecosystems Environ.*, **108**, 57-71.

Ma, L. Q. and Rao, G. N. (1997) Chemical fractionation of cadmium, copper, nickel, and zinc in contaminated soils. *J. Environ. Qual.*, **13**, 372-376.

McBride, M. B. (2003) Toxic metals in sewage sludge-amended soils, has promotion of beneficial use discounted the risks? *Adv. Environ. Res.,* **8**, 5-19.

Ministry of Environmental Protection of the People's Republic of China (1997) *Soil quality determination of lead, cadmium-graphite furnace atomic absorption spectrophotometry* (GB/T17141-1997).

Ministry of Environmental Protection of the People' s Republic of China (2004) *The Technical Specification for Soil Environmental Monitoring* (HJ/T 166-2004).

Ministry of Health of the People's Republic of China and Standardization Administration of China (2005) *Maximum levels of contaminants in foods* (GB2762-2005).

Nan, Z. R. and Zhao, C. Y. (2000) Heavy metal concentrations in gray calcareous soils. *Water, Air, Soil Pollut.*, **118**, 131-141.

Nan, Z. R. and Cheng, G. D. (2001) Behaviors of heavy metals (Cd and Pb) in crops grown in land of arid regions irrigated by wastewater. *Agro-environ. Protect.*, **20**,210-213.

Nan, Z. R., Li, J. J., Zhang, J. M. and Cheng, G. D. (2002) Cadmium and zinc interactions and their transfer in soil-crop system under actual field conditions. *Sci. Total Environ.*, **285**,187-195.

Nan, Z. R., Liu, X. W., Zhao, Z. J., Wang, S. L., Yang, Y. M. and Wang, Z. W. (2011) *Chemical bevavior and ecological risk assessment in soil-crop system in arid oasis region.* Chinese Environmental Science Press, Beijing.

Osakwe, S. A., Akpoveta, O. V.，Okoh, B. E. and Ize-Iyamu, O. K. (2012) Chemical forms of heavy metals in soils around municipal waste dumpsites in Asaba Metropolis, Delta State, Nigeria. *Chem. Spec. Bioavail.*, **24**, 23-38.

Qiao, X. L., Luo, Y. M., Christie, P. and Wong, M. H. (2003) Chemical speciation and extractability of Zn, Cu and Cd in two contrasting biosolids-amended clay soils. *Chemosphere*, **50**, 823-929.

Rodríguez, L., Ruiz, E., Alonso-Azcárate, J. and Rincón, J. (2009) Heavy metal distribution and chemical speciation in tailings and soils around a Pb-Zn mine in Spain. *J. Environ. Manage.*, **90**, 1106-1116.

Shao, X., Cheng, H. G., Duan, X. L. and Lin, C. Y. (2013) Concentrations and chemical forms of heavy metals in agricultural soil near the world's largest and oldest tungsten mine located in China . *Chem. Spec. Bioavail.*, **25**, 125-132.

Silveira, M. L., Alleoni, L. R. F., O'Connor, G .A. and Chang, A. C. (2006) Heavy metal sequential extraction methods – A modification for tropical soils. *Chemosphere*, **64**, 1929–1938.

State Environmental Protection Administration of China (1995) *Environmental quality standard for soils* (GB 15618-1995).

State Environmental Protection Administration of China (1997) *Soil quality–Determination of lead, cadmium-Graphite furnace atomic absorption spectrophotometry* (GB/T 17141-1997).

Su, D. C., Xing, J. P., Jiao, W. P. and Wong, W. C. (2009) Cadmium uptake and speciation changes in the rhizosphere of cadmium accumulator and non-accumulator oilseed rape varieties. *J. Environ. Sci.*, **21**, 1125-1128.

Sun, J. L., Wu, W. J., Zhao, R. X. and Zhang, X. X. (2003) Studies on pollution of heavy metals in soils and technology of plant remediation. *J. Changchun Univ. Sci. Technol.*, **26**, 46-48.

Sun, Y. B., Zhou, Q. X., Wang, L. and Liu, W. T. (2009) Cadmium tolerance and accumulation characteristics of *Bidens Pilosa* L. as a potential Cd-hyperaccumulator. *J. Hazard. Mater.*, **161**, 808-814.

Tandy, S., Healey, J. R., Nason, M. A., Williamson, J. C. and Ones, D. L. (2009) Heavy metal fractionation during the co-composting of biosolids, deinking paper fibre and green waste. *Bioresource Technol.*, **100**, 4220-4226.

Tessier, A., Campbell, P. G. C. and Bisson, M. (1979) Sequential extraction procedure for the speciation of particulate tracemetals. *Anal. Chem.*, **51**, 844-851.

Tian, S., Ding, Y. Z. and Ju, X. H. (2009) Study on the response of maize to heavy metal stress and its applications in phytoremediation. *J. Anhui Agric. Sci.*, **37**, 2208-2222.

Wagner, G. J. (1993) Accumulation of Cadmium in crop plants and its consequences to human health. *Adv. Agron.*, **51**, 173-212.

Wang, M., Zou, J. and Duan, X. (2007) Cadmium accumulation and its effects on metal uptake in maize (*Zea Mays L.*). *Bioresource Technol.*, **98**, 82-88.

Wang, Q. R., Liu, X. M., Dong, Y. T. and Cui, Y. S. (2002) Contamination and characters of vegetation polluted by heavy metals in typical industrial regions subjected to sewage as irrigation. *Agri-environ. Protect.,* **21**, 115-118.

Wang, Q. Y., Zhou, D. M., Cang, L., Li, L. Z. and Wang, P. (2009) Solid/solution Cu fractionation of a Cu contaminated soil after pilot-scale electrokinetic remediation and their relationships with soil microbial and enzyme activities. *Environ. Pollut.*, **157**, 2203-2208.

Wang, X., Ding, W.G., Nan, Z. R., Liao, Q. and Wu, W. F. (2013) Fraction of Cd in oasis soil and its bioavailability to commonly grown crops in northwest China. *Environ. Earth Sci.*, **70**, 471-479.

Wang, X. and Zhou, Q. X. (2003) Distribution of forms for cadmium, lead, copper and zinc in soil and its influences by modifier. *J. Agro-Environ. Sci.,* **22**, 541-545.

Wang, Y. C., Qiao, M., Liu, Y. X. and Zhu, Y. G. (2012) Health risk assessment of heavy metals in soils and vegetables from wastewater irrigated area, Beijing-Tianjin city cluster, China. *J. Environ. Sci.*, **24**, 690-698.

Wang, Y. H., Wang, J. W., Ji, S. J., Li, B., Cui, J. H. and Wang, S. C. (2008) Study on the influence of contamination of soil on the safe quality of maize and forecasting to soil condition. *Food Process.*, **33**, 59-86.

Weng, Q. H. and Yu, L. H. (2006) The ability of accumulation cadmium and the best harvest time of six series maize inbred lines in Cd-contaminated soil. *Acta Ecol. Sinica*, **26**, 4066-4670.

Xu, L., Wang, T. Y., Luo, W., Ni, K., Liu, S. J., Wang, L. *et al*. (2013). Factors influencing the contents of metals and As in soils around the watershed of Guanting Reservoir, China. *J. Environ. Sci.*, **25**, 561-568.

Xu, Z. Q., Zhou, Q. X. and Liu, W. T. (2009) Joint effects of cadmium and lead on seedlings of four Chinese cabbage cultivars in northeastern China. *J. Environ. Sci.,* **21**, 1598–1606.

Wu, Y. G., Xu, Y. N., Zhang, J. H. and Hu, S. H. (2010). Evaluation of ecological risk and primary empirical research on heavy metals in polluted soil over Xiaoqinling gold mining region, Shaanxi, China. *Trans. Nonferrous Metals Soc. China*, **20**, 688-694.

Yang, Y. M., Nan, Z. R., Zhao, Z. J., Wang, S. L., Wang, Z. W. and Wang, X. (2011a) Chemical fractionations and bioavailability of cadmium and zinc to cole (Brassica campestris L.) grown in the multi-metals contaminated oasis soil, northwest China. *J. Environ. Sci.* (in Chinese), **23**, 275-281.

Yang, Y. M., Nan, Z. R., Zhao, Z. J., Wang, S. L., Wang, Z. W. and Wang, X. (2011b) Bioaccumulation and Translocation of Cadmium in Cole (*Brassica campestris L.*) and Celery (*Apium graveolens*) Grown in the Polluted Oasis Soil, Northwest of China. *J. Environ. Sci.* (in Chinese), **23**, 1368-1374.

Yang, Y., Zhang, F. S., Li, H. F. and Jiang, R. F. (2009) Accumulation of cadmium in the edible parts of six vegetable species grown in Cd-contaminated soils. *J. Environ. Manage.*, **90**, 1117-1122.

Zhang, J. B. and Huang, W. N. (2000) Advances on physiological and ecological effects of cadmium on plants. *Acta Ecol. Sinica*, **20**, 514-523.

Zhou, G. H., Huang, H. C. and He, H. L. (2003) Behavior and fate of cadmium in natural and $CdCl_2$-spiked soils in southeastern suburb of Beijing. *J. Agro-Environ. Sci.*, **22**, 25-27.

Zhu, B., Qing, C. L. and Mu, S. S. (2002) Bioavailability of exotic zinc and cadmium in purple soil. *Chinese J. Appl. Ecol.*, **13**, 555-558.