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Accumulation and Translocation of Toxic Heavy Metals in Winter Wheat (*Triticum aestivum* L.) Growing in Agricultural Soil of Zhengzhou, China

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Abstract A field experiment was conducted to study the accumulation of toxic heavy metals by winter wheat (*Triticum aestivum* L.) grown in the agricultural soil in the suburb of Zhengzhou City, China. The quantities of heavy metals (Cd, Cr, Pb, As, Hg) were determined in different parts of wheat plant. The content of five toxic metals was found significantly higher in roots than in the aerial parts of wheat (stems and leaves, and grains). Additionally, wheat roots were enriched in Cd, Pb, and Hg from the soil, while Cr and As were hardly taken up by the roots. On the other hand, the winter wheat transported five toxic heavy metals very weakly from root to grain in the various irrigation regions.

Keywords Bioconcentration factor · Heavy metal uptake · Translocation · Winter wheat (*Triticum aestivum* L.)

Toxic heavy metals enter the food chain due to uptake and accumulation by crop, posing a potential threat to human health. There are various reports on the effect of different stress conditions on the crop, paddy and natural soils (Kirkham 1983; Petruzzelli et al. 1987; Liu et al. 2005; Wong et al. 2002). Heavy metals, such as Cr, Cd, Pb, As and Hg are often cited as primary contaminants of concern, and the possibility of synergistic effects of two or more metals may be of considerable importance at some sites contaminated with heavy metals (Nan et al. 2002). These metals can be transferred and concentrated into plant tissues from the soil, and brought about significant reductions in both plant growth and grain yield of wheat (Athar and Ahmad 2002; Öncel et al. 2000). They can be toxic to photosynthetic activity, chlorophyll synthesis and antioxidant enzymes (Murzaeva 2004; Ouzounidou et al. 1997; Panda et al. 2003).

Every metal and plant interacts in a specific way, which depends on several factors such as soil type, plant, growth conditions and the presence of other ions. Metal uptake by grains was directly related to the applied heavy metal with greater concentrations of metals found in cases where metals were added separately rather than in combinations (Athar and Ahmad 2002). Different tillage systems, continuous grass and agricultural crops rotation affect the uptake and distribution of heavy metals (Al-Najar et al. 2005; Lavado et al. 2001). Liu et al. (2006, 2007) reported that rice plant and vegetables accumulated heavy metals from the agricultural soil under actual natural condition. However, few studies have been carried out on the fully grown plant of wheat raised on the agricultural soil. Therefore, a field experiment was carried out to investigate accumulation and translocation of toxic heavy metal by winter wheat grown in the agricultural soil under real field condition. This has important implication in the understanding of heavy metal contamination through the food chain.

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Materials and Methods

The crop chosen for study was winter wheat (*Triticum aestivum* L.) which was the main crop cultivated in the area, and its growing period was about 210 days (from November to May of the following year) in the suburb of Zhengzhou city, Henan Province, China (34°42′ N; 113°45′ E; altitude 110.4 m). The area has a warm spring continental weather with an annual average temperature and rainfall of 14.3°C and 640.5 mm, respectively. Wheat plants were sampled during maturity at eight sites in May 1998, which were divided into three districts: municipal sewage irrigation region (MSIR) (Chengang, Xuzhuang, and Jiagang), Yellow River irrigation region (YRIR) (Zhaolanzhuang, and Jingshuicun), and groundwater irrigation region (GWIR) (Xincun, Ershilipu and Huayuankouxiliuhuangcun). Wheat plants were selected with five points at each site, and the corresponding soils (at 0–20 cm in depth) were also collected. Sampled plants were separated into roots, aboveground material (stems and leaves), and grains, and then rinsed with deionized water, dried at 65°C for 48 h, grounded with an agate mill, and homogenized.

Metals As, Hg, Cd, Pb and Cr were determined according to previously described methods (Liu et al. 2007). A microwave assisted digestion procedure was used. About 0.5–3 g of homogenized samples was digested under pressure in Teflon vessels with 4 mL of nitric acid and 1.5 mL of hydrogen peroxide. Samples with a low aqueous content were ashed at 450°C in a furnace. On completion of the digestion and after adequate cooling, solutions were filtered and made up to 50 mL with 1% nitric acid.

Metals Cr, Cd, and Pb contents were analyzed by flame atomic absorption spectrometry (FAAS, Hitachi Z-8000, Hitachi Ltd., Tokyo, Japan), whereas concentrations of Hg and As were determined using cold–vapor atomic absorption spectrometry (CV-AAS) with a hydride generation VA-90 model (TongJi University, China) and sodium borohydride as the reductant. All reagents were supra-pure and high-purity water was employed throughout. A sample of standard reference material (NIST SRM 2709), a blank, and a determination in duplicate were included for assurance of analytical accuracy. The analytical results showed no signs of contamination and that the precision and bias of the analysis were generally <10% for metals. The recovery rates for heavy metals in SMR were around 85%–105%. Data analyses were carried out with statistical package SPSS 11.0. The statistical significance level was defined at $p < 0.05$.

Results and Discussion

The crops were wheat–rice in continuous sequence at the same location. According to the previous published data, the soils were uncontaminated with heavy metals (Liu et al. 2007). The average concentrations in agricultural soils ranged 0.11–0.14 mg kg^{-1} for Cd, 57.54–65.67 mg kg^{-1} for Cr, 14.42–19.28 mg kg^{-1} for Pb, 0.041–0.10 mg kg^{-1} for Hg, and 6.10–6.97 mg kg^{-1} for As, respectively. Concentrations of Cd, Cr, Pb and As in soils didn't vary significantly among the different irrigation regions, while content of Hg was higher in MSIR and YRIR than GWIR. Contents of Cd and Pb in the studied soil were markedly lower than that of Cd (2.82 mg kg^{-1}) and Pb (74.88 mg kg^{-1}) in the croplands near the non-ferrous metals mining and smelting base of Baiyin city, Gansu province, P.R. China (Nan et al. 2002), respectively.

Heavy metals concentrations in different parts of wheat plants are presented in Table 1. In all cases, higher concentrations of studied heavy metals were found in the roots, in comparison with the aboveground material and grains. Average Cd values in wheat roots were 3.87, 1.96, and 1.44 mg kg^{-1} for MSIR, YRIR, and GWIR, respectively. Cd concentrations of roots showed some differences in both cereals (winter wheat and rice) (Liu et al. 2007). Average Cd concentration in wheat grains was 0.018–0.023 mg kg^{-1} between various irrigation regions. No significant differences were found between MSIR and YRIR, and GWIR for Cd concentration of grain, but there were significant differences between MSIR and YRIR ($p < 0.05$), between MSIR and GWIR ($p < 0.01$) for Cd concentration of root. This indicated that different riverhead affects the uptake of Cd in the wheat root. On the other hand, Cd concentration of grain was very lower than Cd content (0.23 mg kg^{-1}) of spring wheat grain grown in contaminated soil (Nan et al. 2002). The increment of total soil content of Cd could enhance grain Cd accumulation.

The content of Cr in the wheat roots was 3.36–5.97 mg kg^{-1}, which was slightly higher than that in rice roots at the same location (Liu et al. 2007). Among the different parts of the wheat crop, the lowest value of Cr was observed for the grain (0.12–0.18 mg kg^{-1}). This was in accordance with the findings of Liu et al. (2007), who reported the lowest value of Cr in the rice grain among root, straw and grain.

The arsenic average level varied from 1.76 to 3.59 mg kg^{-1} in roots, from 0.34 to 0.91 mg kg^{-1} in stems and leaves, and from 0.11 to 0.16 mg kg^{-1} in wheat grains. A gradual increase of the contents could be observed in the wheat plant, from grain, aboveground material to root. The significant differences were found in every irrigation region between root, and stem and leaf, and grain ($p < 0.01$), whereas no significant differences were found between various irrigation regions for As content of root. The concentration in the winter wheat grain was very much lower than in wheat grain (0.7 mg kg^{-1}) cultivated agricultural area of West Bengal Delta Plain, irrigated with As rich groundwater (Norra et al. 2005). The arsenic concentrations in stems and leaves, and grains were similar in both

Table 1 Heavy metal concentrations in wheat plants (mg kg^{-1}dw)

Components	MSIR (n = 15)		YRIR (n = 10)		GWIR (n = 15)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Cd						
Roots	2.63–4.83	3.87 ± 1.13	1.43–2.49	1.96 ± 0.54	1.40–1.47	1.44 ± 0.038
Leaves and stems	1.27–1.90	1.46 ± 0.38	0.70–1.19	0.89 ± 0.26	0.78–1.25	0.94 ± 0.27
Grains	0.015–0.025	0.023 ± 0.011	0.015–0.024	0.019 ± 0.016	0.016–0.019	0.018 ± 0.002
Cr						
Roots	2.55–8.07	5.50 ± 2.78	4.16–6.77	5.97 ± 1.57	2.92–3.73	3.36 ± 0.41
Leaves and stems	1.41–1.95	1.79 ± 0.33	1.45–1.81	1.66 ± 0.19	1.21–1.77	1.51 ± 0.28
Grains	0.16–0.23	0.18 ± 0.042	0.12–0.21	0.16 ± 0.12	0.087–0.18	0.12 ± 0.052
Pb						
Roots	18.49–30.83	24.25 ± 6.21	21.55–22.76	22.16 ± 0.61	16.31–21.43	18.87 ± 2.56
Leaves and stems	11.45–25.39	18.90 ± 7.02	14.42–18.49	17.13 ± 2.35	11.77–17.28	14.91 ± 2.83
Grains	0.12–1.43	0.99 ± 0.61	0.14–1.88	1.01 ± 0.36	0.12–1.66	0.99 ± 0.40
Hg						
Roots	0.084–0.19	0.12 ± 0.061	0.092–0.095	0.093 ± 0.016	0.075–0.090	0.085 ± 0.0087
Leaves and stems	0.042–0.061	0.054 ± 0.010	0.034–0.052	0.043 ± 0.0093	0.040–0.048	0.045 ± 0.0044
Grains	0.0024–0.0037	0.0029 ± 0.0008	0.0026–0.0028	0.0027 ± 0.0001	0.0021–0.0028	0.0024 ± 0.0004
As						
Roots	2.65–5.95	3.59 ± 2.06	1.58–1.95	1.76 ± 0.19	1.67–4.31	2.99 ± 1.32
Leaves and stems	0.48–1.24	0.83 ± 0.38	0.17–0.52	0.34 ± 0.18	0.51–1.30	0.91 ± 0.39
Grains	0.10–0.12	0.11 ± 0.02	0.070–0.20	0.14 ± 0.14	0.12–0.21	0.16 ± 0.046

cereals (winter wheat and rice). Conversely, the As content was considerably lower in wheat root than rice root (20.87–23.89 mg kg^{-1}) ($p < 0.01$) (Liu et al. 2007). The higher As contents measured in the roots are due to an Fe-rich mineral plaque which coat the rice roots (Norra et al. 2005).

Ranges of Hg concentration were 0.085–0.12 mg kg^{-1} for root, 0.043–0.054 mg kg^{-1} for stem and leaf, and 0.0024–0.0029 mg kg^{-1} for grain among the various irrigation regions. No significant differences were found between MSIR and YRIR, and GWIR for Hg concentration of root. Compared with rice, Hg concentration of grain was significantly lower in wheat ($p < 0.01$). In addition, the concentrations of Cd, Cr, As and Hg in the edible grain were well below the Chinese national food guideline limit. Therefore, the wheat grain was uncontaminated with Cd, Cr, As and Hg.

Average values of Pb in wheat roots were 18.81–24.25 mg kg^{-1} in different irrigation regions, which no significant differences were found between MSIR and YRIR, and GWIR. Among root, stem and leaf, and grain, the lowest value of Pb was also observed for the grain (0.99–1.01 mg kg^{-1}). Winter wheat showed higher concentrations of Pb in each part than the rice rotation with winter wheat, respectively (Liu et al. 2007). This indicated that its uptake and accumulation in winter wheat were higher than in rice. Moreover, concentrations of Pb in the wheat grain approach the Chinese national food guideline limit (1.0 mg kg^{-1}). Therefore, it is worth noticing Pb contamination in the wheat grain. In general terms, the contents of five toxic metals were higher in roots than in the aerial parts for both crops (wheat and rice) cultivated in the agricultural soil, indicating that the roots act as barrier for metal translocation and protect the edible parts from toxic heavy metal contamination.

The bioconcentration factor (BCF) was calculated as the ratio of the content of heavy metal in the wheat plant to that in the soil. Figures 1, 2 show the BCF values for Cr, As, Pb, Cd, and Hg in wheat plant. When a BCF ≤ 1, it indicates that the plant can only absorb but not accumulate heavy metals; when a BCF > 1, it shows that plant can accumulate metals. Chromium BCF value range for wheat in different irrigation regions was 0.058–0.094 (root), 0.026–0.030 (stem and leaf), and 0.0021–0.0030 (grain). There are nearly the same trend of Cr uptake between winter wheat and rice (Liu et al. 2007). Additionally, Cr uptake by wheat and rice plants was not significantly different among the various irrigation regions. Therefore, it can be concluded that Cr bioavailability was very low in the agriculture soil for the both crops.

BCF value of As ranged from 0.29 to 0.53 (root), from 0.057 to 0.13 (stem and leaf), from 0.017 to 0.024 (grain), and all values were below 1.0. The winter wheat uptake of As was not significantly different among the various

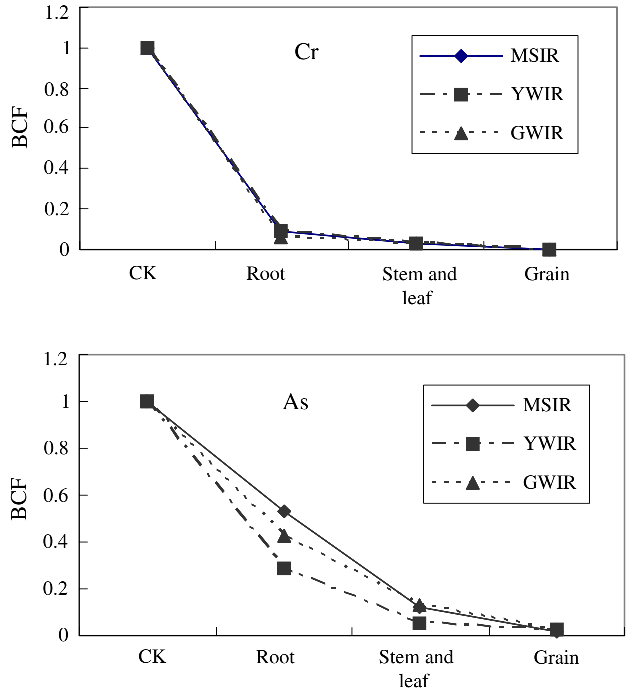

Fig. 1 BCF values of Cr and As of winter wheat from the suburb of Zhengzhou, China

irrigation regions. Noteworthy wheat root has lower capacity to uptake As compared with rice root (Liu et al. 2007). These differences between winter wheat and rice depend on the individual plant species and genotype.

BCF range of Pb in the winter wheat was 1.15–1.32, 0.89–1.03, and 0.053–0.069 for root, stem and leaf, and grain, respectively. BCF value of Pb in each part was higher in wheat than rice plant (0.27–0.43 for root, 0.10–0.14 for straw, and 0.011–0.029 for grain). The rhizosphere changes of various crops affect Pb bioavailability. BCF value of Pb in the winter wheat grain is higher than in the grain of spring wheat grown in contaminated soils, where Pb content of soil is 3.32 times higher than in the studied agricultural soil (Nan et al. 2002). This indicates that the uptake of Pb is not only related to the plant species, but to the total concentration in the soil.

BCF range of Cd in winter wheat was 13.05–27.6 for root, 7.6–10.42 for stem and leaf, and 0.16–0.17 for grain. BCF value of Cd for the grain of winter wheat is higher than the spring wheat grown in contaminated soils (Nan et al. 2002), where Cd content of soil is up to 22.5 times higher than the agricultural soil. Additionally, the Cd uptake by wheat roots has the relation: MSIR > YRIR > GWIR. It is possible that the organic contaminant in municipal sewage enhanced Cd uptake. Zarcinas et al. (2004) also reported that Cd uptake was strongly correlated with organic matter. Winter wheat and rice root accumulated high quantities of Cd^{2+} when grown in non-pollution areas as in a medium

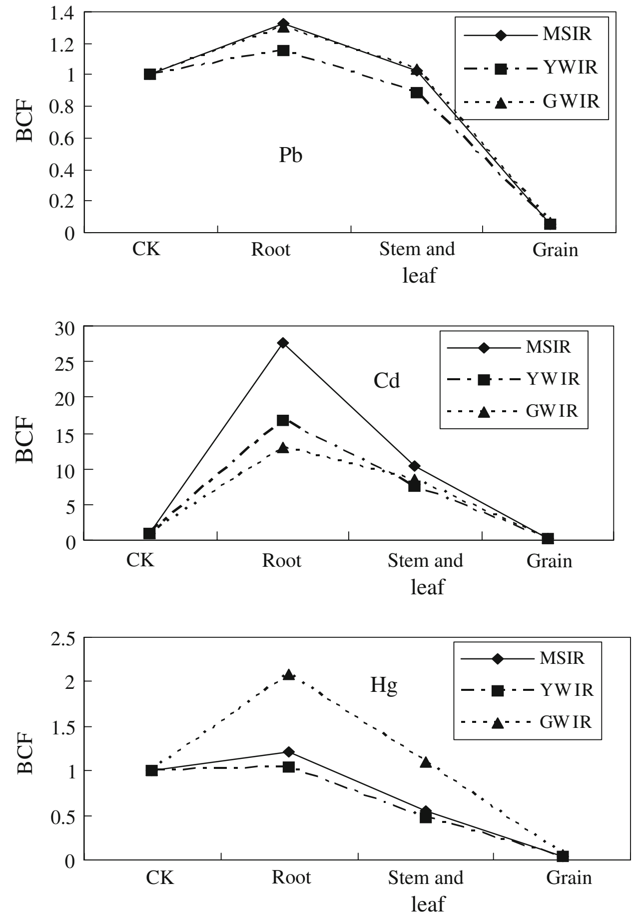

Fig. 2 BCF values of Pb, Cd and Hg of wheat plants from the suburb of Zhengzhou, China

containing this metal (Rubio et al. 1994; Liu et al. 2007). In response to Cd, higher plants synthesize sulphur-rich peptides, phytochelatins (PCs). PC–heavy metal complexes have been reported to accumulate in the vacuole. Retention of Cd in the root cell vacuoles might influence the symplastic radial Cd transport to the xylem and further transport to the shoot (Stolt et al. 2003).

BCF range of Hg was 1.03–2.09, 0.48–1.10, and 0.029–0.059 for root, stem and leaf, and grain in winter wheat, respectively. Some difference for Hg uptake was observed in various irrigation regions. The mechanism has not been elucidated yet.

In conclusion, wheat plants showed the greatest accumulation of Cd, Hg, and Pb in the roots, though there are different in various irrigation regions. Nevertheless, As and Cr were hardly taken up by the wheat root. The heavy metal uptake by winter wheat roots was in the following order: Cd > Hg > Pb > As > Cr, in contrast to rice root, where it was Cd > As > Hg > Pb > Cr (Liu et al. 2007). Thus, passage from ex planta to in planta regions of the soil–plant system is dependent not only on properties of the plant, but also on those of the heavy metal pollutant.

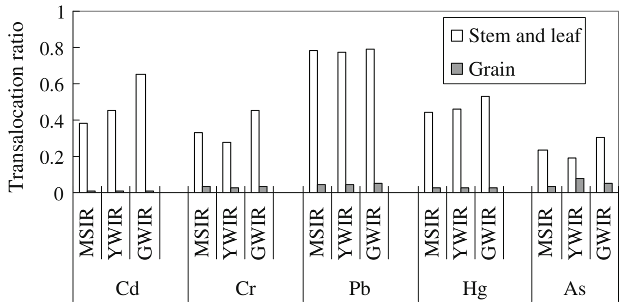

Fig. 3 Translocation ratios of heavy metals in the stem and leaf, and grains of wheat plant

Further, translocation ratios ($HM_{stem\ and\ leaf\ or\ grain}/HM_{root}$), from root to stem and leaf or grain, were calculated for each heavy metal. Figure 3 showed translocation ratios of Cd, Hg, As, Cr, and Pb in winter wheat in various irrigation regions, and all values were below 1. Translocation ratio of stem and leaf was more than that of grain for each heavy metal in the different irrigation. Moreover, the translocation factor from stem and leaf to grain ($HM_{grain}/HM_{stem\ and\ leaf}$) was found smaller than that of root to stem and leaf ($HM_{stem\ and\ leaf}/HM_{root}$) of wheat plant except for arsenic in the YWIR. This finding is in good agreement with the results obtained in wheat grown in soil amended with industrial sludge by Bose and Bhattacharyya (2008). For five toxic heavy metals, absorption of wheat plant had the relation: Root $>$ Straw $\gg$ Grain. It is important to note that five toxic heavy metals were transported very weakly into the grain of winter wheat. Additionally, the results revealed that winter wheat transported As very weakly into the stem and leaf, whereas Pb was transported most easily into the stem and leaf among studied heavy metals. Compared with rice plant, winter wheat transported Hg very weakly from root into grain, but arsenic was transported more easily into stem and leaf, and grain of the winter wheat than rice (Liu et al. 2007). The five heavy metals examined in the research have different chemical properties and consequently each metal has peculiar accumulation and translocation capacity.

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