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Accumulation of Cd and Pb in Spring Wheat (*Triticum aestivum L.*) Grown in Calcareous Soil Irrigated with Wastewater

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Uptake of toxic heavy metals by plants grown in polluted land has been one of the principal focuses of Environment Science research since the out-break of itai-itai disease. The contamination of agricultural environment by trace metals now become of ever-growing worldwide concern because of the transportation of trace metals in food chain. Transferring of potentially toxic elements from soils to plants has well been documented (Schuhmacher, et al., 1994; Nwosu, et al., 1995; Xu and Yang, 1995; Chen, 1996; Peles, et al., 1996; Zhang, et al., 1997; Wang and Wu, 1997; Wu, et al., 1998; Wenzel and Jockwer, 1999). Because the most researches are based on the works done in laboratory condition or in highly industrialized regions, data are poor for the situtations where heavy metals are in soils and standing crops receiving wastewater in industrializing regions (Ramachandran and D'Souza, 1998; Barmen, et al., 2000), especially in calcareous soil zone (Mench, et al., 1994). However, the greenhouse experiment measurements may not be suitable for prediction of the toxicity of heavy metals to crops under actual field conditions (Devies, 1992; Chen, 1996).

The cropland studied in this paper is located in the calcareous soil region nearby one of the major nonferrous metal mining and smelting bases in People's Republic of China. The spring wheat (*Triticum aestivum L.*) was chosen for analysis because it is a staple in the diet of the local residents in the North China. The soils and crops had, to some extent and in some areas, been polluted by heavy metals mainly through irrigating with wastewater (Nan, et al., 1999; Nan and Zhao, 2000). The research presented here is the first detailed report on the accumulation of selected trace metals in the parts of spring wheat cultivated in the region studied under field conditions. The objectives of this study is to report the accumulation levels of selected elements in different part of spring wheat, and to understand the relationships between the selected metals in crop tissues and in soils, as well as the interaction between them.

MATERIALS AND METHODS

This investigation was conducted at Baiyin city with a surface of about 501 km^2. The area is divided into two basins by the watershed, i.e., Dongdagou stream

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basin and Xidagou stream basin. All the nonferrous metal mining and smelting plants and several other factories are located along the middle-upper reaches of Dongdagou stream, and one copper processing plant and several other factories are located along the middle-upper reaches of Xidagou stream. Both of streams accept treated or untreated domestic wastewater and different industrial sewage. The wastewater and its mixture with Yellow River water have being used for irrigation to produce economically important crops for a long time.

The studied region consisted of four areas according to the types of irrigating water and the locations, i.e., two areas are irrigated with Yellow River water in Dongdagou (YDA) and Xidagou (YXA) basins, one with the mixture of wastewater and Yellow River water in Xidagou basin (MXA), and the last with wastewater in Dongdagou basin (WDA). Soil and entire spring wheat samples were randomly collected in pairs during the harvest time in august 1998 throughout the four areas described above to determine contents of cadmium (Cd) and lead (Pb). Ten pairs of soil and crop samples were collected at YDA, six at YXA, 13 at WDA, and 18 at MXA, for a total of 47 pairs. Soil samples were vertically collected with a depth of 0 to 20 cm from the region on which the test crop was growing. Entire crop was collected by way of digging and the roots were washed in place and again back to laboratory to clean further.

The crops were separated into roots, stems, and grains. The specimens were washed with tap water and distilled water followed by de-mineralized water. Special attention was given to the roots, which were scrubbed free of soil and rinsed thoroughly. All crop samples were stored in the brown paper bags, dried in oven at 70℃ for 12 hours, and then ground in a stainless steel mill for metal analysis. All soil samples were air-dried at room temperatures and purified by passing through a 1mm sieve in order to eliminate foreign matters. Fractions less than 1mm were ground further in an agate mortar. Homogenized samples were sealed in polyethylene bags for analysis.

2.0 g of crop (root, stem, and grain) sample was dissolved in the mixture of H_2O_2-$HClO_4$-HNO_3, and 0.5 g of air-dried soil sample in the mixture of HCl-HNO_3-$HClO_4$-HF. These samples were digested in a Teflon-PFA using MDS-9000 (ORIENT). The concentrations of selected heavy metals were determined by ICP (Ilia, et al., 1999). For all analyses control standard solutions were run at the start, during and at the end of sample runs to ensure continued accuracy. Analytical precision of the method was improved by including several duplicate samples (10% of total). Reproducibility was within ±5%.

Data were analyzed using one-way ANOVA (LSD) and Pearson correlation. All statistical analyses were done through using the statistical package SPSS8.0 and Excel97 for Windows.

RESULTS AND DISCUSSION

The concentrations of Cd and Pb in spring wheat tissues and soil samples from four areas of Baiyin region and the result of one-way ANOVA are shown in Table 1. The ratios of heavy metal concentration between crop parts and soils, and the Pearson correlation coefficients of selected metal concentrations in the soil and crop parts are listed in Table 2 and 3.

Table 1. Arithmetic concentrations (mg kg^{-1}, DW), standard deviations, and ranges of selected heavy metals in spring wheat parts and in soils from four areas of Baiyin region

		Cadmium				Lead			
Area		N	AM	SD	Range	N	AM	SD	Range
YXA	Grain	4	0.02	0.00	0.01-0.02	6	0.21	0.11	0.06-0.36
	Stem	3	0.07	0.01	0.06-0.09	6	0.38	0.24	0.10-0.71
	Root	5	0.15	0.10	0.03-0.30	6	2.46	1.03	0.33-3.32
	Soil	6	0.16	0.02	0.14-0.19	6	20.71	2.89	16.16-25.45
MXA	Grain	14	0.05	0.04	0.01-0.13	18	0.16	0.09	0.04-0.34
	Stem	17	0.11	0.07	0.04-0.30	15	0.50	0.22	0.19-0.98
	Root	18	0.50	0.27	0.24-1.53	18	2.39	1.36	0.35-5.55
	Soil	18	0.58	0.28	0.18-1.18	18	17.48	5.74	17.21-38.30
YDA	Grain	6	0.07	0.01	0.06-0.08	8	0.17	0.07	0.04-0.29
	Stem	7	0.06	0.02	0.05-0.11	9	0.38	0.18	0.16-0.74
	Root	10	0.38	0.18	0.06-0.66	10	3.30	1.39	0.45-5.48
	Soil	10	0.25	0.04	0.18-0.33	10	21.80	5.19	14.96-30.83
WDA*	Grain	13	0.61	0.41	0.09-1.33	13	1.29	1.05	0.12-4.03
	Stem	13	1.91	1.32	0.22-4.83	13	1.93	1.17	0.58-4.17
	Root	13	6.92	4.32	0.53-15.56	13	28.41	10.80	12.14-44.10
	Soil	13	10.36	4.42	2.76-19.32	13	239.71	69.71	145.11-413.36

N=Sample Size. AM=Arithmetic Mean. SD=Standard Deviation. Detection limits: 0.01ppm for Cd, 0.04ppm for Pb. An asterisk indicates that this area has significant difference with others by LSD at $p<0.05$.

Mean concentrations in soils for Cd were 0.16±0.02, 0.58±0.28, 0.25±0.04, and 10.36±4.42 mg kg^{-1} for YXA, MXA, YDA, and WDA, respectively. These contents were 2, 8, 3, and 148 times higher than the soil Cd background value (BV) (0.072mg kg^{-1}) reported by Wang and Wei (1995). Mean concentrations in soils for Pb were 20.71±2.89, 17.48±5.74, 21.8±5.19, and 239.71±69.71 mg kg^{-1} for YXA, MXA, YDA, and WDA, respectively. The soil Pb contents at YXA, MXA, and YDA had the same order of magnitude with the BV (18mg kg^{-1}) reported by Wang and Wei (1995), but the soil Pb content at YDA was 13 times higher than the BV.

Mean concentrations in grains for Cd were 0.02±0.004, 0.05±0.04, 0.07±0.01, and 0.61±0.41 mg kg^{-1} for YXA, MXA, YDA, and WDA, respectively. Mean concentrations in grains for Pb were 0.21±0.11, 0.16±0.09, 0.17±0.07, and 1.29±1.05 mg kg^{-1} for YXA, MXA, YDA, and WDA, respectively. Only at WDA, the contents of Cd and Pb exceeded the hygienic standards for grain of National Standard Bureau of P. R. China (0.1mg kg^{-1} for Cd and 1.0mg kg^{-1} for Pb, DW).

They were 6 and 1.3 fold greater than the hygienic standards, respectively.

It is clear from the results (Table 1) that the accumulation levels of Cd and Pb by spring wheat parts increased as the total contents of the trace elements increased in the cultivated land. These findings have important implications because high contents in crop parts, especially in grain, increase the potential risk to the health of local peoples and the physical condition of animals feed with straw in the long run.

The results of one-way ANOVA indicated that there had not any statistically significant differences between samples of crop parts and soils from YXA, MXA, and YDA. The trace metal concentrations of samples collected from WDA were significantly higher than that from others. This result confirmed that the land irrigated with Yellow River water and domestic wastewater rather than with nonferrous operator effluent did not elevate the grain contents of selected metals, and the soil irrigated with nonferrous industrial wastewater was the main source of heavy metals absorbed by crops. The WDA is the only one area located close to the nonferrous smelters and can be irrigated with the mixture of mining and smelting industrial effluent and domestic wastewater (Nan and Zhao, 2000).

There were significant differences between the two metal concentrations of crop parts and soils. The contents of Cd and Pb in crop parts were several or even several hundreds times lower than the element concentrations in corresponding soils except for Cd in roots (Table 2). The reason may be that the alkaline pH of gray calcareous soil does not favor higher Cd and Pb absorbed by spring wheat roots due to precipitation of carbonates and hydroxides, in which the two elements were less soluble and hence less plant-available (Xu and Yang, 1995). The absorption ratio (crop part to soil) of Cd was 0.06 to 0.13 for grain, 0.18 to 0.43 for stem, and 0.67 to 1.52 for root. Root Cd concentration in some areas exceeded that in soil. The absorption ratio of Pb was 0.005 to 0.01 for grain, 0.01 to 0.03 for stem, and 0.12 to 0.15 for root.

Table 2. Accumulation ratios of heavy metal concentration between spring wheat crop parts and soils and their proportions

	Cd				Pb			
	G/S	St/S	R/S	G:St:R	G/S	St/S	R/S	G:St:R
YXA	0. 13	0. 43	0. 94	1:3:7	0. 01	0. 02	0. 12	1:2:12
YDA	0. 28	0. 24	1. 52	1:1:5	0. 01	0. 02	0. 15	1:2;15
MXA	0. 09	0. 19	0. 86	1:2:10	0. 01	0. 03	0. 14	1:3:14
WDA	0. 06	0. 18	0. 67	1:3:11	0. 01	0. 01	0. 12	1:1:12

G:St:R denotes grain:stem:root. G=grain. St=stem. R=root. S=soil.

The translocation process of heavy metals in crop parts is influenced by many mechanisms including anatomical, biochemical, and physiological (Salt, et al., 1995). Naturally, cadmium and lead occur in all plants but have not been shown to be essential in plant nutrition or metabolism, and probably taken up passively by

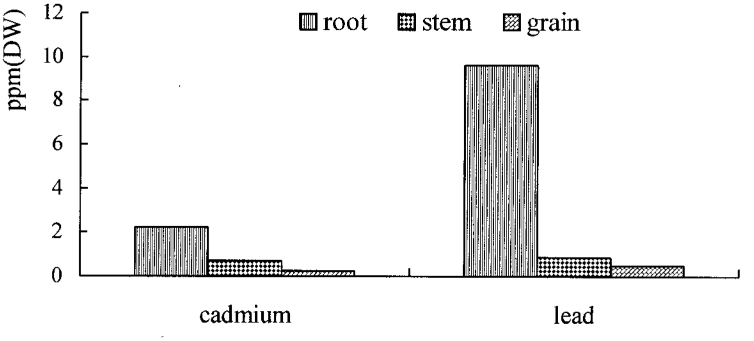

Figure 1. Boxplots of Cd and Pb contents in roots, stems and grains of spring wheat for whole region

roots, and usually confined to roots (Adriano, 1986; Streit and Stumm, 1993). In this work, the elements studied at four areas were highest in roots, followed by stems, and then low in grains(Fig.1). Roots contained at least 12 times the concentration found in grain for Pb, and 5 times for Cd. This finding is in accordance with the result that roots contain at least twice the Cd concentration found in tops (Koeppe, 1977), and give an implication that the contaminated soil be phyto-remedied through digging out the crop roots.

Table 3. Pearson correlation coefficients of the Cd and Pb concentrations in the soil (s) and spring wheat parts: root (r), stem (st), and grain (g).

	Cds	Cdr	Cdst	Cdg	Pbs	Pbr	Pbst
Cdr	0.96**						
Cdst	0.89**	0.94**					
Cdg	0.73**	0.78**	0.84**				
Pbs	0.90**	0.84**	0.85**	0.76**			
Pbr	0.89**	0.83**	0.86**	0.78**	0.96**		
Pbst	0.75**	0.66**	0.63**	0.42**	0.82**	0.84**	
Pbg	0.59**	0.55**	0.65**	0.62**	0.69**	0.75**	0.49**

**. Correlation is significant at the 0.01 level (2-tailed).

The absorption fraction of soil Cd (0.06 to 1.52) was bigger than that of soil Pb (0.01 to 0.15). The accumulation ratios of Cd and Pb indicated that the translocation amount of Cd from soil to above ground portions of spring wheat was more than that of Pb. The fraction of Pb in our investigation was also lower than the values (0.03 to 0.50) suggested by Karamanos et al.(1976). This result confirms that lead is bound more tightly than cadmium in gray calcareous soil and spring wheat roots restrict the movement of Pb more than that of Cd into grains. These findings are in agreement with the results of previous researches. Cd is readily taken up by roots and distributed throughout the plant although the amount of up-taken is tempered by soil factors and plant factors. Lead belongs to the category that trace elements distribute mostly in roots with very little in shoots although the distribution may change with some plant species and with very high soil contents (Adriano, 1986). Although the availability of Cd in soil to crops was more than that of Pb, our result showed that only a small fraction of Cd deposit was recovered by spring wheat.

Positive significant Pearson's correlations were found among the selected metals in the crop parts and soils (Table 3). The coefficients between the cadmium and lead contents were 0.62, 0.63, 0.83, and 0.90 for grain, stem, root, and soil ($p<0.01$), respectively. Cadmium content in soil was also significantly correlated with lead content in grain ($r=0.59$, $p<0.01$), stem ($r=0.75$, $p<0.01$), and root ($r=0.89$, $p<0.01$). Lead content in soil was, in turn, remarkably affected the cadmium accumulation in grain ($r=0.76$, $p<0.01$), stem ($r=0.85$, $p<0.01$), and root ($r=0.84$, $p<0.01$). These results confirm that the two elements act synergistically on crop metal accumulation under actual condition, which agrees with the findings of previous experiment studies (Wu et al., 1998). When the two trace metals (Cd and Pb) are present in soil as co-exist materials, it is difficult to predict their behavior. The interaction between Cd and Pb in this research in gray calcareous soil indicate that the present of Cd and Pb in the soil together could enhance the uptake of each element by spring wheat. So, it is necessary to study the levels of pollutant elements in human tissues and commercial animals from the Baiyin region in order to understand the risks of contaminated food products (cereal, egg, and meat) for human healthy in the following study.

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