Polish J. of Environ. Stud. Vol. 16, No. 2 (2007), 199-207

Original Research

Pb, Cu, Zn and Ni Concentrations in Vegetables in Relation to Their Extractable Fractions in Soils in Suburban Areas of Nanjing, China

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Received: July 4, 2006
Accepted: October 27, 2006

Abstract

To investigate the bioavailability and bio-enrichment of metals from soils to vegetables, the concentrations of Ni, Pb, Zn, and Cu in vegetables and their grown soils sampled from eight suburban areas of Nanjing, China, were determined, and the fractions of these metals in soils was characterized by using the BCR sequential extraction procedure. The results showed that the residual fraction was the dominant proportion for Pb (46%-64% in total), Cu (49%-73% in total) and Ni (40%-61% in total) in soils, whereas Zn was found mainly in the oxidizable fraction (31%-69% in total). The translocation coefficients of metals in leaf/root systems revealed that Cu, Zn and Ni were mainly accumulated in roots, whereas Pb mainly in the leaves of these vegetables. The enrichment coefficients of metals in leaf/root systems indicated that Zn had the strongest capacity of accumulation from soils to vegetables among all four elements. No significant correlations were found among metal concentrations in the vegetables, the metal fractions in corresponding soils, and the enrichment coefficients from soils to plants.

Keywords: heavy metal, fraction, edible vegetable, soil, mobility

Introduction

Soil contamination with anthropogenic heavy metals, mainly from industrial activities, agricultural practices and atmospheric deposition, has received increasing attention in recent years [1-2]. These metals can be easily accumulated in the topsoil, resulting in bio-toxicity to plants and animals. As cities are densely clustered with pollution sources resulting from human activities, urban soils are prone to be polluted by heavy metals and other pollutants. Extremely high levels of contamination with heavy metals in urban soils had been found in many countries [3-5]. Continuous urbanization and industrialization of Nanjing, P.R. China, leads to an increasing heavy metal pollution in urban soils. Wu *et al.* [6] investigated heavy metals in urban soils in Nanjing City, and found that the total concentrations of Pb, Cu, Zn and Cd were 177.1 ± 103.7, 39.86 ± 39.9, 273.3 ± 131.6 and 1.1 ± 0.7 mg kg^{-1}, respectively.

Soil is not only the key nutrient-bearing environment for plant life [7], but also a supplier of many pollutants to plants because plants can uptake toxic substances through their roots from soils [8-9]. The accumulation of heavy metals from soils to vegetables has been studied extensively due to the close relation of vegetables to human health. Alam *et al.* [10] investigated the contents of arsenic and heavy metals in vegetables, and suggested that Pb concentrations in all the vegetables grown at Samta, in Bangladesh,

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would be a health hazard for human consumption. Yusuf *et al.* [11] studied the concentrations of Cd, Cu and Ni in five different edible vegetables from three industrial and three residential areas of Lagos City, Nigeria, and concluded that these heavy metals in industrial areas were much higher than those of the residential areas.

It is widely recognized that bioavailability of heavy metals in soils depends strongly on their chemical forms and their binding ways [12]. Therefore, both single and sequential extraction schemes have been developed to evaluate the mobility or bioavailability of metals in soils, sediments and sewage sludges during recent decades [13-14]. Those techniques were thoroughly reviewed by Kot *et al.* [15]. Among these extraction schemes, the BCR (now the Measuring and Testing Program), developed by the Community Bureau of Reference, has been applied widely to fractionate metals in soils and sediments [16].

Many investigations on heavy metals in vegetables and their corresponding soils had been conducted in recent years [17-19]. Wenzel and Jokwer [20] found that the concentrations of Cd, Pb and Zn in Thlaspi shoots were less or similar to the amount of these metals in the exchangeable fraction of the soils. Poschenriede *et al.* [21] reported that the Cu and Zn concentrations in plants growing on and off a malachite site were correlated well to the metal concentrations in the soil. Sinha *et al.* [22] found highly positive correlations between metals accumulated in some plants (leafy vegetables and bearing plants) and the available metals in soils. However, Fytianos *et al.* [23] concluded that the correlations between metal concentrations in soils and vegetables were generally poor for the majority of cases. Moćko and Wacławek [12] used the linear multiple regression to describe the dependence of the metals uptake on the concentrations of their speciation mobile forms in soils, and their results indicated no such relation.

The aim of the present study is to investigate concentrations of Pb, Cu, Ni, and Zn in selected vegetables and corresponding soils collected from the suburban areas of Nanjing City, to investigate the enrichment and translocation of these metals from soils to vegetables, and to identify the relationships among metal concentrations in vegetables, chemical forms of metals in corresponding soils, and the enrichment coefficients of the plant/soil system.

Materials and Methods

Description of the Sampling Sites

The city of Nanjing, with more than 6 million inhabitants, is located in the eastern part of China (E118°22'~119°14', N31°14'~32°37'). It is one of the biggest industrial cities in Jiangsu province, P.R. China. A number of pollution sources in the city, including oil refineries, steel industries, electric manufactures and hundreds of other smaller industrial units, emit heavy metals and other toxic elements into the local environment.

Eight sampling sites in the near suburb of Nanjing, which named as Banqiao (BQ), Baguazhou (BZ), Fangshan (FS), Getang (GT), Huaqi (HQ), Pukou(PK), Shangfang (SF), and Tangshan (TS), were selected for the present study, and these sites were scattered in different directions with similar distances away from the center of the city (Fig. 1). Most vegetables cultivated in these areas are sold at the local markets. Four kinds of vegetables, including *Celery*, *spinach*, *cole* and *garlic*, were selected as vegetable samples. These vegetables are considered as food sources for local residents, and thus they are of great importance to human health in this area.

Sampling and Pre-Treatment

A total of 32 vegetable samples and 32 corresponding soil samples were collected from the eight sites. At least three vegetable samples of each vegetable species including *celery*, *spinach*, *cole,* and *garlic*, were randomly collected, and then mixed to form a compound sample for each sampling site. Soil samples were composite mixtures of soils from the rhizosphere of each vegetable sample. The maximum soil depth was about 20 cm, according to the ploughed horizon of local area (about 20 ± 2.5 cm deep). They were sampled manually in a corresponding area within a 30 cm diameter around each vegetable sample. The soil samples were packed carefully into polyethylene bags and transported to the laboratory.

In laboratory, the vegetable samples were washed with tap water, and then rinsed with deionized water. Each vegetable sample was divided into root and leaf, cut into small pieces with a plastic cutter, and then dried at 90°C in a furnace to constant weights. The dried vegetable samples were ground, and then kept in clean polyethylene bags for measurement. The soil samples were air dried at room temperature. They were ground in an agate mortar, sieved through 0.25 mm nylon sieve, and then kept in clean polyethylene bags for analysis [24].

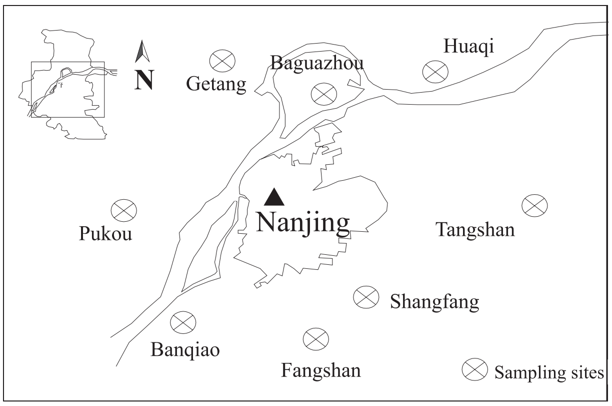

Fig. 1. Scheme of sampling sites in the suburban areas of Nanjing City, P.R. China.

Digestion and Extraction Procedures

Determination of Physicochemical Properties of Soils

Soil pH and electric conductivity (EC) were measured with soil extract at a soil/deionized water ratio of 1:5 (w/v) using a digital pH meter and electric conductivity meter. Soil organic matter content and cation exchange capacity (CEC) were determined by the method described by Lu [25]. Total nitrogen (TN) was extracted by Kjeldhal digestion, and TN in the digest was determined in the form of NH_4-N by indophenol blue method. Total phosphorus (TP) and total potassium (TK) were measured by digesting soil samples, and then determined by inductively coupled plasma atomic emission spectrometry (ICP-AES, Leeman Labs Prodigy, USA). The physicochemical properties of soil samples were summarized in Table 1.

Digestion of Vegetable Samples

To determined metal concentrations in the vegetable samples, 0.1g of each powdered vegetable sample was wet digested with 15 ml concentrated HNO_3-$HClO_4$ (3:1) acid mixture in a 25 ml Teflon PFA (perfluoroalkoxy) vial. After 3 drops of HF acid was added, the mixtures were heated to a clear solution, and then to near dry. The cooled residue was dissolved in 5 ml 10% HNO_3 and the solution was diluted to 25 ml with deionized water for measurements [23].

Extraction Procedures for Soil Samples

Sequential extraction was conducted by using the BCR sequential extraction procedure described as Ure *et al.*[16]. For practical reasons, the weight of sample and volume of extractant were reduced by half to keep the same weight/volume ratio as the original BCR extraction scheme. The following extraction procedure was conducted in lab.

- Exchangeable Fraction (F1). Twenty ml 0.11 mol l^{-1} acetic acid was added in a 50 ml polypropylene centrifuge tube containing 0.5000 ± 0.0001 g of soil sample. The tubes were shaken for 16 h at ambient temperature (20 ± 1 ^oC) on an end-over mechanical shaker operating at 40 rpm. The extract was separated from the solid residue by centrifugation (4000 rpm), decanted into a polyethylene container, and stored at -4 ^oC until analyzed. At this step, metals in ionic form, bound to carbonates and the exchangeable fraction were extracted.
- Reducible Fraction (F2). The residue from the step above was shaken with 20 ml 0.1 mol l^{-1} hydroxylamine hydrochloride (acidified to pH=2 with nitric acid). The extraction procedure was the same as that of in the *F1*. At this step, metals bound to amorphous iron and manganese oxides and hydroxides were released.
- Oxidizable Fraction (F3). To residue from *F2*, 20 ml hydrogen peroxide (30%, acidified to pH=2 with nitric acid) was carefully added, and, after digestion, the extraction was continued in 25 ml ammonium acetate (1 mol l^{-1}, acidified to pH=2 with nitric acid). The extraction procedure was the same as described for F1. At this step, metals bound to organic matter and sulfides were extracted.
- Residual Fraction(F4). The residue from *F3* was dried at room temperature, and then digested using the method described for total metal concentrations of vegetables. At this step, metals bound to silicate lat-

Table 1. Physicochemical properties of soils collected from suburban areas of Nanjing, China.

[a)] Sampling Sites	pH 1:5(w/v)	Organic Matters (%)	TN (%)	TP (mg kg^{-1})	TK (g kg^{-1})	CEC (me/100g)
BQ	6.72	0.64	3.30	764.49	13.55	182.28
PK	7.04	1.44	7.67	855.32	16.05	344.54
HQ	5.93	1.19	4.86	478.02	12.09	231.35
GT	5.82	0.78	3.06	334.51	12.96	202.77
SF	7.04	1.24	8.01	345.36	12.66	279.37
BZ	7.48	1.29	4.92	672.85	15.68	470.76
FS	7.24	0.68	3.21	349.67	14.37	345.87
TS	7.05	0.97	4.05	327.13	12.20	328.90
[b)] Average ± SD	6.79 ± 0.60	1.03% ± 0.99%	4.88% ± 1.96%	515.92 ± 216.57	13.69 ± 1.53	298.23 ± 94.50

[a)] Samping sites named after the first letter of corresponding sampling sites: BQ for the town of BanQiao, PK for PuKou, HQ for HuaQi, GT for GeTang, SF for ShangFang, BZ for BaguaZhou, FS for FangShan, and TS for TangShang.

[b)] Average values ± standard deviation (SD), total sampling numbers: n = 96.

tice or crystalline iron and manganese oxides were dissolved.

Enrichment Coefficient for Vegetable/Soil System

Enrichment coefficient (EC) was calculated to assess the accumulations of metals from soils to vegetables, and it is described as the following formula [26]:

$$EC = \frac{[M]_{vegetable}}{[M]_{soil}}$$

where: EC is the enrichment coefficient for vegetable/soil system;
$[M]_{vegetable}$ is the concentration of a metal in the tissue of vegetables (root or leaf), mg kg^{-1}, in dry matter;
$[M]_{soil}$ is the total concentrations of a metal in soils where this vegetable is grown, mg kg^{-1}, in dry matter.

Determination

A blank was also run at the same time. All reagents used were of supra-pure quality. All glassware and plastic containers were previously soaked overnight in suprapure nitric acid, and then rinsed with deionized water (18MΩ). The concentrations of Pb, Cu, Ni and Zn in different fractions of soils and vegetable digests were determined by ICP-AES.

Results and Discussion

Extractable Fractions of Pb, Cu, Ni and Zn in Soils

Results of the extractable fractions of Pb, Cu, Ni, and Zn in soils were shown in Fig. 2. Pb exhibited similar trends of chemical fraction distributions in all soils. The largest portion was in the residual fraction, accounting for 50% of total Pb, followed by the oxidizable fraction (35%) and the reducible fraction (10%), while the exchangeable fraction was no more than 0.2% of the total Pb concentrations in soils. A similar distribution pattern was found for Cu and Ni. For Cu in soils, 48%~72% of total Cu was in the residual fraction, 21%~48% in the oxidizable fraction, 1%~8% in the reducible fraction, and less than 2% in the exchangeable fraction. Ni presented a much higher percentage in the exchangeable fraction (6%~15% of total Ni) and a lower portion in the residual fraction (35%~60%) than those of Pb and Cu. With respect to Zn, no coherent distribution of chemical fractions was found among different soil samples. The biggest portion was in the oxidizable fraction, except for soils collected from BanQiao. The sum of the exchangeable fraction and the reducible fraction accounted for 18%~58% of total Zn in soils, and these fractions are normally recognized as the bio-available pool.

Total concentration of a certain metal in specific soils was represented by the sum of concentrations of the four extractable fractions for each metal (total concentrations =F1+F2+F3+F4). Total concentrations of Zn, Pb, Cu, and

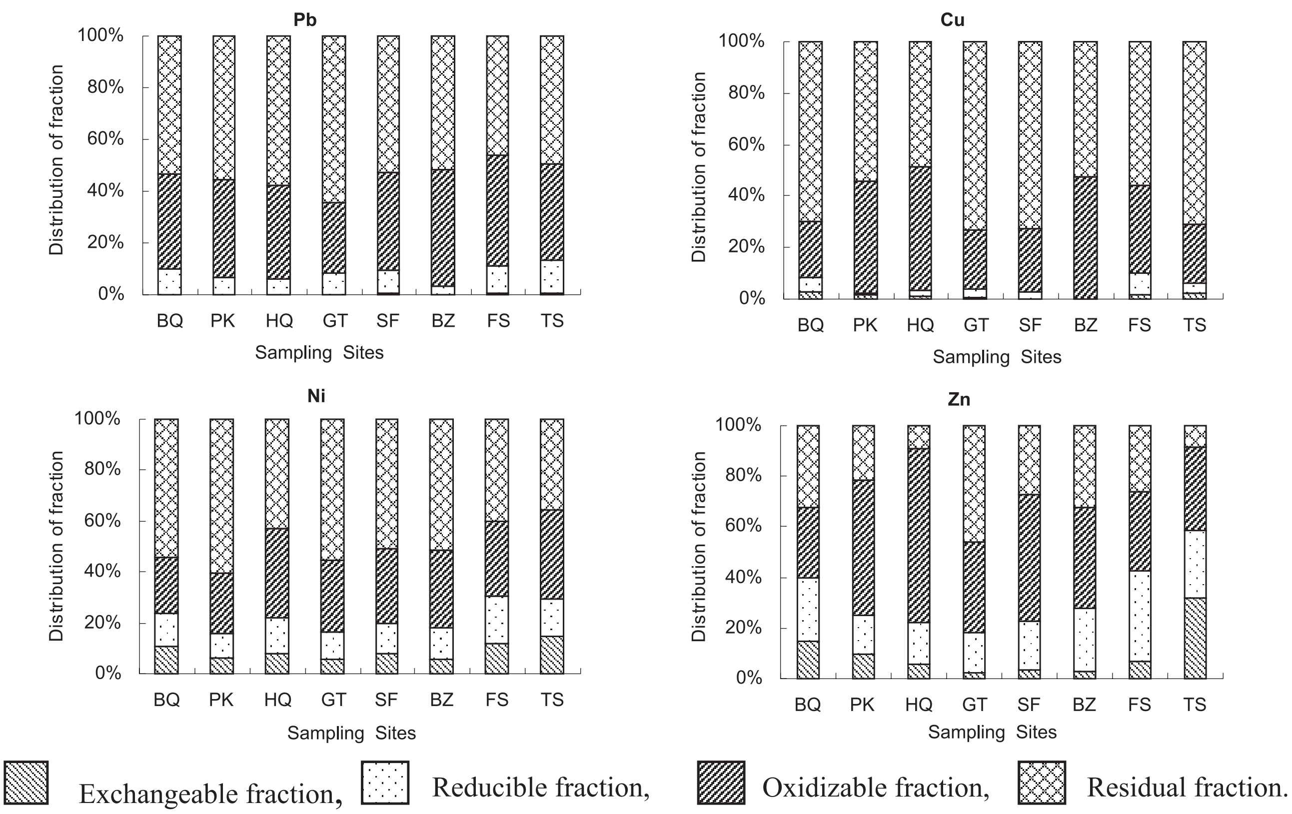

Fig. 2 The fraction distribution of Pb, Cu, Ni, and Zn in soils.

Ni in soils was 21.17~79.50, 24.36~40.69, 21.67~46.85, and 13.72~24.00 mg kg^{-1} (in dry matter), respectively. Compared to the published results in literature, the concentrations of metals in soils obtained in the present work were much lower than those of Wu *et al.* [6]. An explanation might be that these soils of the present study were collected from the suburb areas of Nanjing City, P.R. China, while those samples studied by Wu et al. were collected from the urban area of the same city.

Metal Concentrations in Vegetables

The concentrations of metals in vegetables were summarized in Table 2. The concentrations of metals in vegetables varied greatly from one vegetable to another, and the variation also existed among different sampling sites for the same vegetable species.

Vegetable is one of the Pb exposure sources for habitants of Nanjing city, and the exposure to Pb is of the main concern because of its possible detrimental effects on intelligence. The *garlic* and *cole* contained higher concentrations of Pb than that of *celery* and *spinach*, with 0.43~4.72 mg kg^{-1} in roots and 0.65~6.67 mg kg^{-1} in leaves for *garlic*, and 0.94~2.74 mg kg^{-1} in roots and 0.74~3.59 mg kg^{-1} in leaves for *cole*. The *spinach* presented the lowest concentrations of Pb among the four kinds of vegetables, with 0.48~1.86 mg kg^{-1} in roots and 0.75~4.12 mg kg^{-1} in leaves. The concentrations of Pb in roots and leaves of *celery* were 0.73~3.28 mg kg^{-1} and 0.75~4.12 mg kg^{-1}, respectively. This indicated that the accumulation of Pb in vegetables was influenced by the vegetable species. However, it was evident from Table 2 that the differences of Pb concentrations in vegetable were caused more significantly by different sampling sites than by the vegetable species.

Zn and Cu are essential nutrients for plants (e.g. 15.0~30.0 mg Zn kg^{-1} of dry plant matter satisfies physiological needs of plants), but concentrations higher than 20.0~30.0 mg kg^{-1} for Cu and 50.0~60.0 mg kg^{-1} for Zn can be toxic, and lead to the plant growth inhibition [1]. The concentration of Cu was 4.34~31.27, 4.60~15.65, 4.24~9.30, and 6.98~26.09 mg kg^{-1} in roots, and 3.83~11.42, 2.75~4.92, 1.96~5.75, and 5.59~9.03 mg kg^{-1} in leaves for *celery*, *garlic*, *cole*, and *spinach*, respectively. The increasing order of the average concentrations of Cu for these vegetables was *celery* > *spinach* > *garlic* > *cole*.

Zn was the most abundant metal among these four metals in vegetables studied in this work. On average, *spinach* contained the highest Zn concentration among the four vegetables, with 14.35~33.28 mg kg^{-1} in roots and 13.20~31.69 mg kg^{-1} in leaves, and the least Zn concentration was found in *garlic*, with the concentrations of 6.39~24.80 mg kg^{-1} in roots and 3.81~11.46 mg kg^{-1} in leaves. The concentration range of Zn was from 13.01 to 29.87 mg kg^{-1} in roots and from 0.32 to 22.47 mg kg^{-1} in leaves for c*elery*, and from 6.62 to 49.44 mg kg^{-1} in roots and from 7.25 to 38.68 mg kg^{-1} in leaves for *cole*.

With respect to Ni, little differences of concentrations were found among different vegetable species sampled, with the average concentrations of 5.41, 5.38, 5.66, and 4.27 mg kg^{-1} in roots, and 2.59, 2.09, 2.56, and 2.54 mg kg^{-1} in leaves for *celery*, *garlic*, *cole*, and *Spinach*, respectively. However, the Ni concentrations of the same vegetable species differed significantly from one sampling site to another.

In order to investigate the different accumulation in various parts of vegetables, transfer coefficient (TC) of leaf/root system was calculated for each vegetable species (Seen in Table 2), which described as, TC=ML/MR, and ML and MR represent metal concentrations in leaves and roots, respectively. In regard to the TC for the same metal in different vegetables, *spinach* showed the highest TCs for every metal among the four vegetables. This might be due to the rather bigger surface areas of leaves of spinach than that of other vegetables. And this could be further conformed by the fact that *garlic*, with the minimum surface areas of leaves of these four vegetables, exhibited the lowest TC values of all vegetables. Sinha *et al.* [22] also found that the accumulation of metals in edible parts was higher in the leafy vegetables (chloroplast rich) than that in non-leafy vegetables/crops. With respect to the TC for different metals in the same vegetable species, Pb exhibited the highest TC value among the four metals, indicating that Pb was more likely to be transferred from roots to leaves than Cu, Zn, and Ni. Another reason for higher accumulation in leaves might be related to atmospheric deposition. It had been reported that the Pb and Zn concentration in the air of suburban areas of Nanjing City in 2003 were as high as 0.53 and 0.99 μg m^{-3} [27]. From the TC values shown in Table 2, it could be concluded that Pb was mainly accumulated in the leaves of vegetables, while Cu, Zn, and Ni were mainly retained in the roots of these vegetables.

Relationship of Metals in Soils and Vegetables

The concentrations of metals in vegetables were generally lower than that of the corresponding soils. This might be attributed to the roots, which seems to act as a barrier to the translocation of metals [28, 29]. In order to evaluate the accumulating capacity of heavy metals from soils to plants, a quantitative evaluation of the relationship between metal concentrations in vegetables and in corresponding soils was made by calculating the enrichment coefficients (ECs) for the vegetable/soil system (Table 3).

The highest mean EC value was found for Pb in *garlic* (0.14), for Zn in *spinach* (1.48), and for Cu and Ni in *celery* (0.63 and 0.47, respectively). The lowest average TC values of Pb and Ni were both found in *spinach* with the value of 0.09 and 0.42, respectively. *Cole* and *garlic* exhibited the lowest average TC values for Cu (0.33) and Zn (0.69). The EC value of same metal differed from one

Table 2. Metals in vegetables and the transfer coefficients (TC) for leaf/root systems (mg kg^{-1}, in dry matter).

Vegetable	Sample Sites	Pb			Cu			Zn			Ni		
		root	leaf	TC	root	leaf	TC	root	leaf	TC	root	leaf	TC
Celery	BQ	1.99	1.57	0.79	18.89	11.42	0.60	29.87	13.90	0.47	4.49	1.99	0.44
	PK	2.61	2.04	0.78	9.81	5.50	0.56	13.24	0.32	0.02	3.73	3.11	0.83
	HQ	1.00	1.34	1.34	4.34	3.83	0.88	29.30	20.26	0.69	3.97	2.39	0.60
	GT	0.73	0.75	1.03	15.42	7.75	0.50	22.43	13.09	0.58	11.67	5.17	0.44
	SF	3.28	1.03	0.31	31.27	5.58	0.18	13.01	7.36	0.57	11.01	2.27	0.21
	BZ	2.29	4.12	1.80	13.90	5.03	0.36	26.24	22.47	0.86	2.75	2.00	0.73
	FS	0.81	1.72	2.12	6.44	3.86	0.60	25.87	11.95	0.46	3.53	2.49	0.71
	TS	1.29	0.85	0.66	7.81	6.19	0.79	18.66	8.16	0.44	2.15	1.30	0.60
	Average	1.75	1.68	0.96	13.48	6.14	0.46	22.33	12.19	0.55	5.41	2.59	0.48
Garlic	BQ	1.45	3.67	2.53	6.50	2.95	0.45	13.60	6.68	0.49	5.25	1.70	0.32
	PK	3.84	0.65	0.17	7.85	4.81	0.61	24.80	11.46	0.46	7.17	2.85	0.40
	HQ	1.23	0.68	0.55	9.76	3.00	0.31	14.30	3.81	0.27	4.30	1.86	0.43
	GT	0.94	0.94	1.00	5.73	3.75	0.65	23.80	9.62	0.40	9.53	4.07	0.43
	SF	1.62	1.41	0.87	10.39	4.92	0.47	6.39	5.83	0.91	4.65	1.37	0.29
	BZ	1.98	1.30	0.66	15.65	3.64	0.23	3.12	10.89	3.49	2.04	1.37	0.67
	FS	4.72	6.67	1.41	4.48	2.75	0.61	19.38	3.92	0.20	8.16	2.00	0.25
	TS	0.43	0.93	2.16	4.60	2.79	0.61	24.43	6.32	0.26	1.96	1.48	0.76
	Average	2.03	2.03	1.00	8.12	3.58	0.44	16.23	7.32	0.45	5.38	2.09	0.39
Cole	BQ	2.06	2.98	1.45	8.01	1.96	0.24	16.68	11.12	0.67	2.90	1.38	0.48
	PK	2.34	2.86	1.22	5.63	2.86	0.51	21.22	7.25	0.34	6.84	1.81	0.26
	HQ	2.74	0.74	0.27	9.30	5.75	0.62	49.44	24.78	0.50	8.48	4.51	0.53
	GT	2.61	2.44	0.93	6.55	2.42	0.37	15.28	15.74	1.03	5.54	1.84	0.33
	SF	0.94	3.59	3.82	6.64	4.02	0.61	17.60	38.68	2.20	8.29	5.80	0.70
	BZ	2.15	1.82	0.85	5.03	2.29	0.46	6.62	9.69	1.46	7.14	1.17	0.16
	FS	2.05	1.82	0.89	5.87	2.29	0.39	25.37	9.69	0.38	3.75	1.17	0.31
	TS	1.41	1.23	0.87	4.24	2.08	0.49	37.17	10.09	0.27	2.37	2.79	1.18
	Average	2.04	2.19	1.07	6.41	2.96	0.46	23.67	15.88	0.67	5.66	2.56	0.45
Spinach	BQ	1.86	2.07	1.11	9.35	6.87	0.73	14.35	24.83	1.73	8.04	2.79	0.35
	HQ	0.63	2.89	4.59	9.00	8.47	0.94	19.71	13.20	0.67	3.44	2.74	0.80
	GT	0.77	1.47	1.91	7.62	9.03	1.19	23.68	21.95	0.93	4.25	4.54	1.07
	SF	0.48	0.87	1.81	26.09	7.20	0.28	22.71	24.50	1.08	2.34	1.46	0.62
	BZ	1.69	1.18	0.70	10.54	6.99	0.66	30.25	19.38	0.64	1.36	0.99	0.73
	FS	1.44	1.49	1.03	8.87	5.83	0.66	33.28	24.10	0.72	5.88	3.34	0.57
	TS	0.57	0.90	1.58	6.98	5.59	0.80	27.52	31.69	1.15	4.62	1.95	0.42
	Average	1.06	1.55	1.46	11.21	7.14	0.64	24.50	22.81	0.93	4.27	2.54	0.59

Table 3. Enrichment coefficients (EC) for the vegetable/soil system.

metal	Vegetable	[a)]Sampling sites									
		BQ	PK	HQ	GT	SF	BZ	FS	TS	[b)]Average	[c)]SD
Pb	Celery	0.11	0.11	0.09	0.04	0.12	0.17	0.10	0.07	0.10	0.04
	Garlic	0.16	0.11	0.08	0.05	0.08	0.09	0.47	0.04	0.14	0.14
	Cole	0.15	0.13	0.14	0.15	0.12	0.11	0.16	0.09	0.13	0.02
	Spinach	0.12	/	0.14	0.06	0.04	0.08	0.12	0.05	0.09	0.04
Cu	Celery	0.65	0.71	0.31	0.79	1.09	0.58	0.48	0.46	0.63	0.24
	Garlic	0.20	0.59	0.48	0.32	0.45	0.59	0.34	0.24	0.40	0.15
	Cole	0.21	0.40	0.56	0.31	0.32	0.22	0.38	0.21	0.33	0.12
	Spinach	0.35	/	0.65	0.57	0.99	0.54	0.69	0.41	0.60	0.21
Zn	Celery	1.48	0.28	0.62	1.68	0.85	1.26	1.40	0.49	1.01	0.52
	Garlic	0.69	0.75	0.23	1.58	0.51	0.36	0.86	0.56	0.69	0.41
	Cole	0.94	0.59	0.93	1.47	2.34	0.42	1.30	0.87	1.11	0.60
	Spinach	1.33	/	0.41	2.16	1.96	1.29	2.12	1.09	1.48	0.64
Ni	Celery	0.47	0.28	0.33	1.04	0.87	0.23	0.35	0.19	0.47	0.31
	Garlic	0.51	0.42	0.32	0.84	0.39	0.16	0.59	0.19	0.43	0.22
	Cole	0.31	0.36	0.68	0.46	0.92	0.40	0.29	0.28	0.46	0.23
	Spinach	0.79	/	0.32	0.54	0.25	0.11	0.54	0.36	0.42	0.22

[a)] Names of sampling sites were the same as described in Table 1; [b)] Average values; [c)]SD, Standard Deviation; /--Lack of spinach in Pukou (PK).

vegetable to another, suggesting a selectivity of the plants in absorbing elements from soils.

Zn showed the highest EC values among these four metals in all vegetables, while Pb showed the lowest, indicating that Zn was more capable of accumulating from soils to vegetables than Cu, Ni, and Pb. The EC value of a certan metal in the same vegetable exhibited a great variation among different sampling sites, which probably resulted from different chemical fraction distributions of metals and different soil properties of these soils.

The EC values of Cu had been reported to be 0.13 for celery [30] and 0.319 for spinach [19]. Fytianos *et al.* [23] found that the EC values of Pb, Cu, Zn and Ni for *spinach* was 0.46, 0.37, 0.36 and 0.07, respectively, and those for *celery* was 0.30, 0.24, 0.38 and 0.16, respectively. Kachenk and Singh [31] claimed high mean transfer coefficients in *leek* (0.90), *spinach* (0.64) and *lettuce* (0.46) for Cu, and in *cabbage* (1.38), *lettuce* (0.84) and *mint* (0.30) for Pb. Compared the EC values obtained from the present study, the differences might be attributed to the differences of soil properties.

The accumulation of metals from soils to plants depends on many factors, such as metal forms, plant species and parts, and soil properties [32]. The Enrichment coefficient quantifies the relative differences in bioavailability of metals to plants and is a function of both soil and plant properties [31]. Therefore, the enrichment coefficient (ECs) of plant/soil system could provide more useful inherent information on the accumulation of metal from soil to plants. Some statistic analysis methods, such as the Pearson correlation coefficient and the linear regression process, were conducted to investigate the relationships among the metal concentrations in vegetables, enrichment coefficients, chemical fractions of metals in soils, and the physicochemical properties of soils. However, no significant correlation was found among them, suggesting that the relationships among enrichment coefficients of plant/soil system, vegetable species, soil types and properties, metal chemical fractions were far more complicated than simple linear relationship.

Conclusions

The three-step BCR extraction procedure was carried out to characterize the chemical fractions of Pb, Cu, Zn, and Ni in soils. The results showed that dominant proportion was bounded in the residual fraction for Pb, Cu and Ni, whereas for Zn in oxidizable fraction. Translocation coefficients (TCs) for leaf/root systems showed that Cu, Zn and Ni were mainly accumulated in roots, whereas Pb mainly accumulated in leaves of the vegetables. The results of enrichment coefficients (ECs) for the vegetable/soil system revealed that Zn could be accumulated in the vegetables more easily than Pb, Cu, and Ni from soil. Relationship statistical analysis among the metals in vegetables, enrichment coefficients, chemical fraction of metals in soils, and the physicochemical properties of soils resulted in no significant correlation, suggesting the complexity of the relationship among those factors.

Acknowledgements

This work was funded by the National Key Basic Research Support Foundation of China (No.2002CB412303), and the Natural Science Foundation of Jiangsu province, P.R. China (No. BK2004115).

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