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Environmental Impact Assessment of Vegetable Fields by the Heavy Metal Concentration in Yantai City of Shandong Province, China

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Scientific basis was presented to fertility management of soils in the vegetable field, and concentrations of selected heavy metals in them were measured, followed by the environmental impact assessment, for keeping quality and sustainable development in the vegetable production. For this purpose, surface and subsurface soil samples were collected from vegetable field at nine different sites of the three regions of Taochun, Haogezhuang and Jiajiazhongchun in Yantai City, Shandong Province, China.

The vegetable fields cultivated for 15 and 25 years showed a tendency of Cr accumulation and their total Cr concentrations were significantly higher at the 5% level than those of the vegetable fields cultivated for 7 years, although a possibility due to the regional difference remained. The total Cd concentration exceeded the soil environmental standard in all the fields with the simple pollution index of 9.90. The overall pollution index of the vegetable fields was 7.16, and they were designated as "severely polluted" in the classification of the soil pollution level. Measures for soil quality management and remediation of Cd pollution were proposed.

INTRODUCTION

Types and amounts of chemical substances added to agricultural land are rapidly increasing with development of industrial technology. As a result, soil pollution by heavy metals becomes conspicuous. At present, the area of cultivated land is around 30,000 ha in Yantai City with occupation of about 0.36% of the total cultivated land in China. Recent consumption of chemical fertilizers in Yantai City amounts to 11×10^8 kg, equivalent to 3.3% of the national consumption, and the application rate in Yantai City is about 9 times higher than the national average.

Yantai City is an important base for export of agricultural products. The export value in Yantai city was 1.77 billion US dollar in 2005 and was about 1/20 of the national value. Recently, vegetable production bases are constructed in Yantai City, and mass production of vegetables in a factory is advancing. Major destination for export of agricultural products is Japan, and it faces a difficult phase due to tightening of quality control standard for agricultural products in Japan. Therefore, quality control of agricultural products is essential, and soil quality management is most important for keeping quality of agricultural products.

In the present study, scientific data were presented for fertility management of soils in the vegetable field in Yantai City, Shandong Province, and heavy metal concentrations of the soils were measured to assess environmental impact for the purposes of maintenance of vegetable quality and sustainable development of vegetable production.

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MATERIALS AND METHODS

Soil samples

Soil samples collected from vegetables fields are briefly explained in Table 1. They were taken from depths of 0–20 cm (surface) and 20–40 cm (subsurface) at 9 different sites in the three regions of Taochun, Haogezhuang and Jiajiazhongchun. The duration of vegetable cultivation was 15 years for A1〜A3 and 25 years for B1〜B3 in Taochun, and 7 years for C1〜C2 and D1 in Haogezhuang and Jiajiazhongchun. Soil sam-

Table 1. Brief description of the soils used in the study

Region	Sample No	Duration for cultivation (year)	Depth (cm)
Taochun	A1	15	0–20
			20–40
	A2		0–20
			20–40
	A3		0–20
			20–40
	B1	25	0–20
			20–40
	B2		0–20
			20–40
	B3		0–20
			20–40
Haogezhuang	C1	7	0–20
			20–40
	C2		0–20
			20–40
Jiajiazhongchun	D1		0–20
			20–40

pling was done on the 26th of April, 2006. Collected soils were air–dried at room temperature and subjected to analyses of fundamental chemical properties and heavy metal concentration.

Chemical analyses

Chemical properties of soils were mainly analyzed according to the soil standard methods of analysis (Committee of Soil Standard Methods for Analyses and Measurements (ed), 1986). The pH was measured in the suspension having a soil:water ratio of 1:2.5. The organic carbon content was determined by the Tyurin method and multiplied by the coefficient of 1.724 to give the organic matter content. The total nitrogen content was determined by the Kjeldahl method. The total phosphorus content was determined by the ascorbic acid method after decomposition with perchloric acid. The soil was digested by the HF–HNO_3–$HClO_4$ acid treatment and analyzed for total potassium by an atomic absorption spectrophotometer.

Determination of heavy metal concentration

Digestion with the HF–HNO_3–$HClO_4$ acid treatment was used to determine total concentrations of heavy metals (Committee of Soil Standard Methods for Analyses and Measurements (ed), 1986). One g of the pulverized air–dry sample was weighed accurately into a teflon beaker, and 5 mL of the conc. $HClO_4$ solution and 5 mL of the conc. HNO_3 solution were added to the sample. The beaker was covered and heated for 3 h on a hot plate, and then heated without cover until dryness. After cooling and gradual addition of 5 mL of the conc. $HClO_4$ solution and 10 mL of the HF solution in this sequence, the beaker was heated for 15 min. Heating was stopped and then continued until dryness after addition of another 10 mL of the HF solution. The beaker was cooled, added with 5 mL of 6 M HCl and 1 mL of the conc. HNO_3 solution, and heated with cover for 1 h. The beaker was filled–up to two–thirds of the volume with water, covered, and heated to boiling for 2 h. The solution was transferred into a 50–mL volumetric flask and made up to the mark with water after cooling. The solution was quickly transferred into a plastic bottle and analyzed for Cd, Cr, Cu, Pb and Zn by an atomic absorption spectrophotometer.

Ten g of the air–dry sample was weighed accurately into a 100–mL wide–mouth bottle, added with 50.0 mL of 0.1 M HCl, shaken for 1 h with keeping temperature at 30 °C, and centrifuged. The heavy metal concentration in the supernatant was measured by an atomic absorption spectrophotometer to determine the concentration of soluble heavy metals in soil.

Calculation equation of simple and overall pollution indexes

The simple pollution index by a heavy metal was calculated by the equation of (measured heavy metal concentration/soil environmental standard). The overall pollution index by heavy metals was calculated by the equation of ($\sqrt{}$(square of the average of the simple pollution indexes＋square of the maximum simple pollution index)/ $\sqrt{2}$).

RESULTS

Vegetable cultivation

Main vegetables are cucumber, spinach, tomato, green onion and Chinese cabbage in Yantai City. After harvest next vegetable is consecutively cultivated, and more than two times of vegetable cultivation are carried out at the same field in a year. Compound fertilizer is applied in most cases. The amount of applied fertilizer

Table 2. Chemical properties of soils in the vegetable field

Region	Sample No	Depth (cm)	pH	Organic matter	Total N	Total P_2O_5	Total K_2O
				($g\ kg^{-1}$)			
Taochun	A1	0–20	4.7	25.4	1.01	2.57	1.76
		20–40	5.1	15.9	1.05	2.68	1.66
	A2	0–20	5.5	26.9	0.78	2.00	1.76
		20–40	5.8	13.5	1.08	2.37	2.17
	A3	0–20	5.3	23.5	0.94	2.26	1.70
		20–40	5.7	11.1	1.43	2.68	1.74
	B1	0–20	4.4	12.3	0.80	2.11	2.29
		20–40	4.7	8.4	0.53	1.43	2.06
	B2	0–20	4.2	13.8	0.91	1.52	2.29
		20–40	4.3	9.5	0.42	1.09	2.16
	B3	0–20	4.2	12.7	0.94	1.36	1.98
		20–40	4.5	14.1	0.49	1.10	1.91
Haogezhuang	C1	0–20	5.4	7.2	0.92	1.42	2.30
		20–40	5.4	3.7	0.49	1.07	2.24
	C2	0–20	5.0	7.3	0.73	1.10	2.23
		20–40	5.1	5.7	0.58	1.04	2.21
Jiajiazhongchun	D1	0–20	5.8	10.5	0.46	0.82	2.86
		20–40	6.2	7.8	0.11	0.71	1.12

varies with vegetables, but considerable amounts of fertilizer are usually applied.

Chemical properties of soils in the vegetable field

Chemical properties of soils in the vegetable field are shown in Table 2. The pH ranged from 4.2 to 6.2 throughout the soil samples and was in the strong to slight acidity. The pH was always lower for the surface soil than for the subsurface soil at the same site. Concerning the region, the pH of A1 through A3 in Taochun was in the acid range of 4.7 to 5.5 in the surface soil. It was a little higher in the subsurface soil with the values of 5.1 to 5.8 but was still in an acid range. The pH of B1 through B3 in Taochun was 4.2 to 4.4 in the surface soil and 4.3 to 4.7 in the subsurface soil, and both showed the strong acidity. The pH of C1 and C2 in Haogezhuang was 5.0 to 5.4 and was in the acid range. Soils in Shandong Province usually show the slightly acid to neutral reaction, and the low pH range observed in the soils in Taochun and Haogezhuang is considered to be caused by application of large amounts of chemical fertilizers to the vegetable field. The pH of D1 in Jiajiazhongchun was 5.8 and 6.2 for the surface and subsurface soils, respectively, and was in the slightly acid range. From the differences in the soil pH described in the above, considerable differences in the plant nutrition management practice between regions in Yantai City and between areas in a region are considered.

The organic matter content of all the samples ranged from 7.2 to 26.9 g kg^{-1} in the surface soil and from 3.7 to 15.9 g kg^{-1} in the subsurface soil. The organic matter content of the surface soil of A1 through A3 in Taochun ranged from 23.5 to 26.9 g kg^{-1} and was noticeably higher than that of the surface soil of the other samples. It suggests relatively heavy application of organic fertilizers to A1 through A3 samples. In general, however, the organic matter content was below 30 g kg^{-1} of the desired value for improvement, and shortage of organic matter in soils of the vegetable field was manifested.

The total N content of A1 through A3 ranged from 0.78 to 1.01 g kg^{-1} in the surface soil and from 1.05 to 1.43 g kg^{-1} in the subsurface soil, and was higher for the subsurface soil than for the surface soil. In B1 through B3 in Taochun, C1 and C2 in Haogezhuang and D1 in Jiajiazhongchun, the total N content was higher for the surface soil than for the subsurface soil but all lower than 1.00 g kg^{-1}. The total P_2O_5 content of all the samples ranged from 0.82 to 2.57 g kg^{-1} in the surface soil and from 0.71 to 2.68 g kg^{-1} in the subsurface soil, and was always lower than 2.8 g kg^{-1} of the average total P_2O_5 content in the earth crust. The total P_2O_5 content of A1 through A3 was higher than that of the other samples, and was higher for the subsurface soil than for the surface soil, similar to the results obtained in the total N content. The total K_2O content ranged from 1.70 to 2.86 g kg^{-1} for the surface soil and from 1.12 to 2.24 g kg^{-1} for the subsurface soil in the whole sample.

Total heavy metal concentrations of soils in the vegetable filed

Total heavy metal concentrations of soils in the vegetable field are shown in Table 3. The total Cu concen-

Table 3. Total heavy metal concnetrations of soils in the vegetable field (mg kg^{-1})

Heavy metal		Cu	Zn	Cr	Pb	Cd
Depth(cm)		0–20	0–20	0–20	0–20	0–20
Taochun	A1	35.06	51.66	40.73	35.34	3.44
	A2	32.52	55.06	43.40	40.65	2.11
	A3	37.84	53.97	42.34	40.68	3.07
	B1	27.65	52.70	39.67	37.41	3.64
	B2	24.42	52.89	40.08	34.05	3.25
	B3	25.35	53.42	40.27	32.18	2.59
Haogezhuang	C1	22.71	24.28	33.73	42.37	3.29
	C2	31.15	21.66	23.06	45.05	2.92
Jiajiazhongchun	D1	28.92	24.38	18.66	41.53	2.46
Average±SD		29.51±1.69	43.33±4.99	35.77±2.98	38.81±1.43	2.97±0.17

Heavy metal		Cu	Zn	Cr	Pb	Cd
Depth(cm)		20–40	20–40	20–40	20–40	20–40
Taochun	A1	25.40	53.04	39.28	34.79	2.62
	A2	27.69	53.33	44.44	38.44	3.14
	A3	29.20	53.78	37.96	33.90	3.04
	B1	24.66	52.37	38.81	35.95	3.27
	B2	22.82	54.37	40.08	36.86	2.81
	B3	25.11	53.17	39.36	36.08	2.94
Haogezhuang	C1	17.51	21.23	31.29	36.78	2.98
	C2	21.01	29.14	22.94	39.69	1.75
Jiajiazhongchun	D1	19.81	18.70	15.78	21.43	1.35
Average±SD		23.69±1.26	43.23±5.14	34.44±3.12	34.88±1.78	2.66±0.22

tration varied from 22.71 to 37.84 mg kg^{-1} in the surface soil and from 17.51 to 29.20 mg kg^{-1} in the subsurface soil, and was higher for the surface soil than for the subsurface soil at the same field. The total Zn concentration ranged from 21.66 to 55.06 mg kg^{-1} in the surface soil and from 18.70 to 54.37 mg kg^{-1} in the subsurface soil, and the total Zn concentration of the soils in Taochun was about double of that of the soils in Haogezhuang and Jiajiazhongchun. The total Cr concentration was in a range between 18.66 and 43.40 mg kg^{-1} in the surface soil and between 15.78 and 44.44 mg kg^{-1} in the subsurface soil. The total Cr concentration of the soils in Taochun was more than double of that of the soil in Jiajiazhongchun. The total Pb concentration ranged from 32.18 to 45.05 mg kg^{-1} in the surface soil and from 21.43 to 39.69 mg kg^{-1} in the subsurface soil, and the total Cd concentration was in a range of 2.11 to 3.64 mg kg^{-1} in the surface soil and of 1.35 to 3.27 mg kg^{-1} in the subsurface soil.

Soluble heavy metal concentrations of soils in the vegetable field

Soluble heavy metal concentrations of soils in the vegetable field are shown in Table 4. The soluble Cu concentration varied from 0.13 to 0.69 mg kg^{-1} in the surface soil and accounted for 0.5 to 2.6% of the total Cu concentration. It varied from 0.12 to 0.86 mg kg^{-1} in the subsurface soil and accounted for 0.4 to 3.1% of the total Cu concentration. The soluble Zn concentration ranged from 0.16 to 1.08 mg kg^{-1} in the surface soil, accounting for 0.3 to 4.0% of the total Zn concentration, and from 0.14 to 1.64 mg kg^{-1} in the subsurface soil, accounting 0.3 to 3.1% of the total Zn concentration. The soluble Cr concentration was in a range between 0.09 and 0.35 mg kg^{-1} in the surface soil and between 0.08 and 0.41mg kg^{-1} in the subsurface soil, and accounted for 0.2 to 0.9% and 0.2 to1.0% of the total Cr concentration, respectively. The soluble Pb concentration ranged from 0.34 to 0.50 mg kg^{-1} in the surface soil and from 0.28 to 0.49 mg kg^{-1} in the subsurface soil, and it accounted for 0.9 to 1.2% in the surface soil and 0.8 to 1.6% in the subsurface soil, of the total Pb concentration. The soluble Cd concentration was in a range of 0.01 to 0.08 mg kg^{-1} in the surface soil and of 0.01 to 0.06 mg kg^{-1} in the subsurface soil, accounting for 0.3 to 2.8% and 0.3 to 4.4% of the total Cd concentration, respectively.

Roughly speaking, the ratio of the soluble to total concentrations was somewhat higher for the soils in Haogezhuang and Jiajiazhongchun and lower for B1 through B3 in Taochun. Among A1, A2 and A3 in Taochun, A1 and A2 were similar to the soils in Haogezhuang and Jiajiazhongchun in their heavy metal solubility, while A3 was rather similar to B1 through B3. However, the ratio of the soluble to total concentrations measured for the soils in the vegetable field was considerably low compared with that for the orchard soils (Han *et al.*, 2007), although the reason was not identified.

DISCUSSION

According to the pH variation with soils in the veg-

Table 4. Soluble heavy metal concentrations of soils in the vegetable field (mg kg^{-1})

Heavy metal		Cu	Zn	Cr	Pb	Cd
Depth(cm)		0–20	0–20	0–20	0–20	0–20
Taochun	A1	0.37 (1.1)[1)]	0.66 (1.3)	0.30 (0.7)	0.39 (1.1)	0.02 (0.6)
	A2	0.69 (2.1)	1.08 (2.0)	0.16 (0.4)	0.50 (1.2)	0.04 (1.9)
	A3	0.22 (0.6)	0.42 (0.8)	0.09 (0.2)	0.35 (0.9)	0.01 (0.3)
	B1	0.19 (0.7)	0.27 (0.5)	0.26 (0.7)	0.34 (0.9)	0.02 (0.5)
	B2	0.14 (0.6)	0.17 (0.3)	0.35 (0.9)	0.37 (1.1)	0.02 (0.6)
	B3	0.13 (0.5)	0.16 (0.3)	0.32 (0.8)	0.38 (1.2)	0.02 (0.8)
Haogezhuang	C1	0.58 (2.6)	0.91 (1.7)	0.23 (0.7)	0.50 (1.2)	0.08 (2.4)
	C2	0.49 (1.6)	0.87 (4.0)	0.21 (0.5)	0.43 (1.0)	0.07 (2.4)
Jiajiazhongchun	D1	0.46 (1.6)	0.78 (3.2)	0.23 (0.9)	0.38 (0.9)	0.07 (2.8)
Average±SD		0.36±0.07	0.59±0.12	0.24±0.03	0.40±0.02	0.04±0.009

Heavy metal		Cu	Zn	Cr	Pb	Cd
Depth(cm)		20–40	20–40	20–40	20–40	20–40
Taochun	A1	0.56 (2.2)	0.96 (1.8)	0.24 (0.6)	0.38 (1.1)	0.06 (2.3)
	A2	0.86 (3.1)	1.64 (3.1)	0.16 (0.4)	0.49 (1.3)	0.04 (1.3)
	A3	0.12 (0.4)	0.24 (0.4)	0.08 (0.2)	0.28 (0.8)	0.01 (0.3)
	B1	0.17 (0.7)	0.19 (0.4)	0.19 (0.5)	0.30 (0.9)	0.01 (0.3)
	B2	0.16 (0.7)	0.14 (0.3)	0.41 (1.0)	0.33 (0.9)	0.02 (0.7)
	B3	0.19 (0.8)	0.20 (0.4)	0.15 (0.4)	0.33 (0.9)	0.02 (0.7)
Haogezhuang	C1	0.37 (2.1)	0.68 (1.6)	0.18 (0.6)	0.43 (1.2)	0.06 (2.0)
	C2	0.36 (1.7)	0.57 (2.0)	0.12 (0.5)	0.41 (1.0)	0.05 (2.9)
Jiajiazhongchun	D1	0.32 (1.6)	0.49 (2.6)	0.16 (1.0)	0.35 (1.6)	0.06 (4.4)
Average±SD		0.35±0.08	0.57±0.16	0.19±0.03	0.37±0.02	0.04±0.007

[1)] The ratio to the total concentration (%).

etable field, B1 through B3 in Taochun where vegetable cultivation has been continued for 25 years showed the strong acidity, whereas C1 and C2 in Haogezhuang and D1 in Jiajiazhongchun where vegetable cultivation remains for 7 years were in the acid to slightly acid range. These results suggest advancement of soil acidity with increasing duration of vegetable cultivation probably caused by application of a large amount of chemical fertilizers.

T–test was done to analyze significance in the difference of total heavy metal concentrations between surface and subsurface soils. The results are shown in Table 5. A significant difference was observed on Cu at the 5% level, and the total Cu concentration was higher for the surface soil than for the subsurface soil. However, the total Cu concentration in the surface soil was around 30 mg kg^{-1} which is usually recognized as the total Cu concentration in soil. In addition, the total Cu concentration in the surface soil of the vegetable fields was considerably lower than that measured for the orchard soils in Yantai City in which Cu accumulation in the surface soil was pointed out (Han *et al.*, 2007). Therefore, accumulation or pollution of the vegetable fields by Cu is doubtful in the present situation. No significant difference was recognized in the total concentrations of Zn, Cr, Pb and Cd between surface and subsurface soils.

F–test was carried out to analyze the effect of the duration of vegetable cultivation on the total heavy metal concentration in the surface soil. The significant difference in the total heavy metal concentration between different years of vegetable cultivation was recognized only to Cr, as the analytical result is shown in Table 6. Then, Duncan's multiple range test was carried out to analyze variation of the total Cr concentration with the three different years of vegetable cultivation. The result is shown in Table 7. There was observed no significant difference between 25 years and 15 years, but the significant difference at the 5% level was recognized between 25 and 15 years and 7 years. However, such temporal effect on the total Cr concentration has a possibility to be due to a regional effect, because 25 and 15 years of cultivation correspond to the Taochun region and 7 yeas of cultivation to the Haogezhuang and Jiajiazhongchun regions. The temporal or regional effect should be detected to the total Zn concentration.

The soils in the vegetable field were evaluated in reference to the total heavy metal concentration for effective field management and safe production of vegetables. The total concentration in the surface soil (Table 3) was compared with its soil environmental standard (Table 8) in different heavy metals. Total concentrations of Cu, Zn, Cr and Pb were within their soil environmental standards in the second standard, and the vegetable fields were judged to be not polluted by those heavy metals. The total Cu, Zn, Cr and Pb concentrations were equal to11～19, 9～22, 6～14 and 11～15% of the soil environmental standards, respectively. Only the total Cd concentration exceeded by 7 to 12 times the soil environmental standard, showing extensive pollution of the vegetable field by Cd. This specula-

Table 7. Duncan's multiple range test to the total Cr concentration in the surface soil of different years of vegetable cultivation

Cultivation year	Average (mg kg^{-1})	Significant level (5%)
25	40.00	a
15	42.16	a
7	25.15	b

Different alphabets mean the difference at the 5% significant level.

Table 5. T–test on significance in the difference of total heavy metal concentrations between surface and subsurface soils

Heavy metal	t	$t_{0.05,16}$	Significant level
Cu	2.77	2.12	*
Zn	0.46	2.12	(o)
Cr	0.55	2.12	(o)
Pb	1.72	2.12	(o)
Cd	1.15	2.12	(o)

*: significance at the 5% level.
(o): no significance.

Table 8. The simple pollution index of the surface soil by the total heavy metal concentration for different heavy metals

Heavy metal	Average±SD (mg kg^{-1})	Soil environemtal standard (mg kg^{-1})	Simple pollution index
Cu	29.51±1.69	150	0.20
Zn	43.33±4.99	200	0.22
Cr	35.77±2.98	150	0.24
Pb	38.81±1.43	100	0.39
Cd	2.97±0.17	0.30	9.90

Table 6. The result of F–test done to the total Cr concentration in the surface soil between different years of vegetable cultivation

Factor	DF	SS	MS	F	$F_{0.05}$	Significant level
Between sets	2	27.94	13.97	0.57	6.94	
During treatments	2	514.31	257.16	10.54		*
Error	4	97.65	24.41			
Total variation	8	639.9				

*: significance at the 5% level.

Table 9. Classification of the soil pollution level by heavy metals based on the overall pollution index

Pollution level	Overall pollution index (P)	Status of pollution	Effect on soil and crops
1	$P \leqq 0.7$	Hardly polluted	Nothing
2	$0.7 < P \leqq 1.0$	Near the pollution level	Scarcely affected
3	$1.0 < P \leqq 2.0$	Slightly polluted	Some crops start to be suffered from pollution
4	$2.0 < P \leqq 3.0$	Fairly polluted	Soil and crops are suffered from the middle degree of pollution
5	$P > 3.0$	Severely polluted	Soil and crops are suffered from severe pollution

tion, however, has some unidentified or insecure aspect, because no significant difference between surface and subsurface soils and no temporal or regional variation were observed in the total Cd concentration.

The simple and overall pollution indexes by the total heavy metal concentrations were evaluated for the environmental impact assessment of the soils in the vegetable field. The simple pollution index is shown in Table 8. It was 0.20, 0.22, 0.24 and 0.39 for Cu, Zn, Cr and Pb, respectively, and all were within 0.3. In contrast, the simple pollution index for Cd was 9.90 and quite high compared with the values for the other heavy metals, suggesting severe pollution of the vegetable field by Cd. The overall pollution index of the soils examined was calculated to be 7.16, and they were designated as the pollution level of “5” or “severely polluted” according to the classification of the soil pollution level based on the overall pollution index (Table 9). Contribution of Cd is great to the overall pollution index of 7.16. The crop growth is predicted to be suffered severely from pollution by heavy metals under the pollution status of “severely polluted”, although some unidentified or insecure aspect is remaining to conclude like this to the vegetable field in Yantai City as stated already.

Based on the above discussion, it is mentioned that the vegetable field in Yantai City is already polluted seriously by Cd and that Cd pollution of soil affects adversely growth of vegetables and quality of products and retards sustainable vegetable production without proper and scientific field management practice. It is an urgent task to take measures for remediation of Cd pollution on the practice of field management in the vegetable field.

On the fertilizer application, the fertilizer use efficiency should be improved and simultaneously the amount of fertilizer applied should be reduced. In addition, it is desirable to use organic fertilizer of the environmental preservation type containing little heavy metals. Use of biological control agent is recommended, which exerts little pollution to the environment, when pesticide is applied. In the cultivation technique, mixed or rotational cropping of vegetables and upland crops is desirable for remediation of Cd pollution by absorption of Cd by upland crops as much as possible. Biological remediation by cultivation of hyperaccumlater of heavy metals is preferable for removal of Cd.

CONCLUSIONS AND PROPOSAL

Severe Cd pollution was recognized to the soils of the vegetable field in Yantai City, Shandong Province, China, by that the total Cd concentration remarkably exceeded the soil environmental standard. The simple pollution index was highest and considerably over 1.00 for Cd, whereas it was less than 0.40 for Cu, Zn, Cr and Pb. The vegetable field was recognized as “severely polluted” according to the magnitude of the overall pollution index. Quality of vegetable products is determined greatly by the Cd concentration in them, and it is a controlling factor to limit sustainable agricultural production. Removal of Cd by biological remediation is essential to the improved management of the vegetable field.

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