Heavy Metals Pollution in Paddy-Soils near Ho Chi Minh City Caused by Wastewater Discharge and the Influence of Cadmium on Rice

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Abstract

Most of Ho Chi Minh City's industrial factories were founded 25 years ago. Their equipment and machinery is now outdated and there are no wastewater treatment systems. Wastewater flows directly into rice fields and pollutes water resources and the soil environment affecting agricultural production. This paper presents the results of a research project investigating 6 heavy metals (Cd, Cu, Zn, Pb, Hg, Cr) at 126 points in rice fields including 14 wards and villages of districts No.2, No.7, No.9, Binh Chanh, Thu Duc and Nha Be. The results indicate that the paddy soils are polluted by industrial and household wastewater and that there is a threat from Cd pollution. Concentrations of Cd in soil range from 4.7-10.3 mg kg^{-1}.

Addition of Cd to the soil at concentrations ranging from 5-40 mg kg^{-1} in dry soil shows that, Cd concentration in soil at levels > 25 mg kg^{-1} affects agricultural characteristics and crop yields. However, these influences depend on the rice variety. The content ratios of Cd in soil: roots: straw: brown rice was roughly 10:200:10:1. Accumulation of Cd in brown rice in field experiments is lower (10-20%) as compared with green house experiments. Cadmium concentrations in brown rice grown in areas that are affected by high Cd wastewaters of HCMC exceeds the internationally recognized Maximum Level (ML) for Cd in rice grain of 0.2 mg Cd kg^{-1} as established by the Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (CAC). This is of considerable concern as rice constitutes a major intake pathway of Cd with confirmed direct negative impacts on human health.

Introduction

Ho Chi Minh City (HCMC) is the largest city in Vietnam. It is located in a special geographical position where many favorable conditions for economic development converge. The city covers an area of 2,056km^2 and supports a population of 5,225 million. It has the highest rate of development in industry and handicrafts in Vietnam. In 2000 HCMC had 1,000 industrial factories, 28,500 handicraft foundations and 12 industrial zones. Most industrial zones have been operating since before 1975. They now find themselves with outdated equipment and without wastewater treatment systems. This wastewater is discharged into canals and flows directly to cultivated areas. This has resulted in serious pollution of soil and agricultural water, especially for the rice-fields and aquaculture areas of the suburbs. Although the HCMC government carried out monitoring and assessment of heavy metals in river water, groundwater, sludge from rivers and canals, vegetation, aquatic life heavy metal pollution in rice-fields and its influence on rice

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have not been studied. The research presented in this paper focuses on 6 heavy metals (Cd, Cu, Zn, Pb, Hg, and Cr). Samples were collected from 126 points in rice-fields polluted by wastewater from industrial and domestic activities. Sampling activities covered 14 wards and villages of 5 districts and counties, namely Nha Be and Binh Chanh Counties, District 2, District 7, District 9 and Thu Duc District.

Equipment and methodology

The selection of study areas and the collection of samples were based on UNESCAP and CCME methods. Soil samples were collected from rice-fields at a depth of 3-15cm. Consequently, soil samples were analyzed under controlled laboratory conditions. Heavy metals in soil were analyzed using the polarographic method and heavy metals in rice were determined by neutron activation. After analyzing for 6 heavy metals in soils, it was concluded that Cd has a high pollution potential for rice-fields in the areas investigated.

Determination of the influence of Cd in soil on the growth of rice was initially investigated in an experiment in which 6 rice plants were grown in the same pot with 4.5 kg of dried soil collected from the investigated areas. Cadmium was added to these soils at 0, 5, 10,15, 20, 25, 30, 35 and 40 mg kg^{-1}. De-ionized water was used for irrigation. The experiment used rice variety VND95-20, a popular variety, and was conducted in a green house in which humidity; temperature and light were standardized and controlled. Larger scale field based trials were also conducted to investigate the growth, development and accumulation of Cd in rice. These trials were conducted in Cd-polluted areas with two rice varieties VN95-20 (high production rice) and VD20 (aromatic rice). Soil samples were collected at Nha Be County and 5 levels of Cd were applied namely 0, 15, 20, 25, and 30mg kg^{-1} dried-soil. Mixed soil was poured into square wooden trays (100x100x30cm) containing a nylon liner large. Thirty rice plants per cultivated per tray. Data were analyzed as ANOVA standardization using MSTATC and IRSTAT 4.01

Results of research and discussion

Analyses of 6 heavy metals (Cd, Cu, Pb, Hg, Zn, and Cr) from 126 sampling points in rice-fields directly polluted by wastewater from HCMC are presented in Table.1. The results for Cr and Pb indicate some level of pollution, but compared to standards in use in some European countries they are just slightly in excess of acceptable limits. Hg and Cu were within limits. The concentration of these elements in soil was lower than the permissible standard (TCCP). The concentration of Zn was high in some cultivated areas, especially near some factories and industrial zones. In comparison, significantly elevated levels of Cd were observed with maximum concentrations ranging from 9.9 to 10.3 mg kg^{-1}. These rice-fields receive water directly from 3 systems namely the Tan Hoa - Lo Gom canals, the Te - Doi canals and the Tau Hu - Ben Nghe canals. Those canals are known by the local people in HCMC as "dead canal" and the "center of heavy metals". These canals receive wastewater from many sources of the city, domestic wastewater, industrial wastewater, wastewater from service activities and especially wastewater from textile factories and handicraft foundations. This wastewater has not been treated before being discharged into the drainage systems and rice-fields.

Table.1: Concentration of heavy metals in paddy soil, polluted by wastewater from HCMC (mg kg^{-1})

Location	Number of samples	Cd	Cu	Zn	Pb	Hg	Cr
Nha Be	88	9.9	28.6	110	61.7	0.09	125.3
District 7	4	4.7	22.7	233	39.0	0.05	115.4
Binh Chanh	10	10.3	31.0	197	58.0	0.21	119.0
District 2	10	5.5	33.1	435	43.6	0.34	44.8
District 9	6	4.9	29.5	568	40.5	0.03	54.3
Thu Duc	8	6.8	30.0	282	44.3	0.20	84.3
Maximum Permissible Levels							
Holland		1-5*	50-100	200-500*	50-150	0,5-2	100-250*
England		1-3	140	280	35	0 –1	0-100
Germany		3+	100+	300+	50+	2+	100+

In comparison, in 1996, the center for experimental analysis reported Cd levels in mud of the Nhieu Loc- Thi Nghe Canals ranging from 28-35 mg kg^{-1}. In addition, in 1998 the Institute for Environment and Resources reported that the average value of Cd concentration in the Sai Gon - Dong Nai River system was between 9.7-25 mg kg^{-1}. Also, Cd concentration in spinach fields at Vinh Loc, Binh Chanh County was 5.09 mg kg^{-1} (Bui Cach Tuyen, et al., 1994). Cadmium is one of the 8 elements that polluted the sludge of the Tan Hoa - Lo Gom Canals (Ngo Quang Huy, et al. 1999). A study of 8 soil types in Nha Be County (Table 2) shows that Zn and Cd occur in high concentrations in 3 soil types namely Pfm, Ppm and Sj2m. For the other 5 categories, the concentration of Cd and Zn decreases with the distance from the source of pollution (Kuo, et al., 1983).

Table 2. Distribution of heavy metals in some soil types in the research area (mg/kg)

	Soil type	Cd	Cu	Zn	Pb	Hg	Cr
1	Red-Yellow alluvial soil (Pfm)	16.7	27.5	130.0	78.1	0.19	133.1
2	Alluvial soil/ potential acid sulfate soil (Ppm)	14.0	29.4	102.4	63.8	0.07	136.5
3	Actual acid sulfate soil (Sj_2m)	14.5	28.7	102.1	66.8	0.15	133.8
4	Actual acid sulfate soil, read rusts (Sj_2Rm)	7.6	23.6	83.8	70.2	0.12	124.3
5	Actual acid sulfate soil, depth layer (Sp_2m)	12.4	27.7	92.7	59.4	0.12	129.7
6	Actual acid sulfate soil, organic (Sp_2hm)	7.8	18.6	97.2	67.1	0.11	121.3
7	Potential. AAS, Shallow acid layer (Sp_1m)	8.0	30.0	99.0	76.3	0.09	140.5
8	Potential. AAS, many organic (Sp_1hm)	8.0	23.2	87.7	71.2	0.08	120.5

Table 3 indicates that increasing soil Cd concentration delays rice plant growth. This may be due to the fact that Cd is toxic to rice roots. A total Cd concentration in soil above 20 mg kg^{-1} will restrict the growth process of rice, and decrease the length of the rice plant. This in turn leads to a decrease in biomass. However, this value is only provisional as in reality it is the bio-available Cd fraction that is critical.

Table 3. Effect of soil Cd concentration applied as Cd salts on the agro-characteristics and the dry yield of rice

Cd (mg kg^{-1})	Duration (days)	Length (cm)	Dried Biomass (g/pot)$^{(*)}$
0	108	82.8	17.7
5	107	84.0	17.4
10	107	80.2	17.2
15	106	79.7	16.5
20	108	76.2	15.6
25	110	70.8	14.4
30	113	61.2	13.6
35	115	60.7	13.3
40	116	60.0	11.7
CV (%)	-	2.48	10.02
$LSD_{0,01}$	-	4.85	419

(*) at 64 days after planting

Table 4 shows that high concentrations of Cd in soil decrease the number of rice ears per pot. Cd concentrations > than 30 mg kg^{-1} resulted in a > 40% decrease in the number of rice pannicles per pot. This infers a significant reduction in yield. Table 4 also indicates that concentrations of Cd in soil between 25-30 mg kg^{-1} will cause productivity decreases ranging from 31.6-32.0 % and soil Cd concentrations between 35-30 mg kg^{-1} will cause a 40.1-53.8 % decrease in productivity. This is confirmed by greenhouse experiments on VND95-20 rice.

To confirm these results, the project carried out field experiments with five concentrations of artificially applied Cd namely 0, 15, 20, 25, 30 mg kg^{-1} and two rice varieties namely VND950-20 and VD20.

Table 4. Effect of soil Cd concentration applied as Cd salts on the number of ears and the yield of rice

Cd (mg kg^{-1})	No. panicles pot	1000 grain weight (g)	Unfilled grain (%)	Yield (g pot^{-1})	% as compared with control
0	17.0	23.6	29.2	29.6	100
5	16.0	23.2	30.2	30.6	103.6
10	15.0	22.8	29.5	27.1	91.6
15	13.7	22.8	31.7	24.0	81.2
20	11.7	21.7	35.3	23.7	80.3
25	11.7	20.5	35.8	20.1	67.9
30	11.0	20.5	42.2	20.2	68.4
35	9.7	19.9	50.2	17.7	59.9
40	9.0	19.4	44.4	13.6	46.2
CV (%)	12.26	8.56	8.01	5.49	-
LSD <0.01	4.28	2.83	8.01	3.47	-

Table 5 demonstrates that for VD20 rice variety the number of ears/m^2 decreases at Cd concentrations >15 mg kg^{-1}. The influence on VND95-20 rice at this concentration is not clear. However, at soil Cd concentrations >25 mg kg^{-1} the number of empty rice-grains per ear of VND95-20 rice variety increased. Similar findings were observed for VD20 at soil Cd concentrations >30 mg kg^{-1}.

At soil Cd concentrations >20 mg kg^{-1} the productivity of VND 95-20 rice decreased to between 630-1730 kg ha^{-1}. In contrast, the productivity of VD20 decreased only at soil Cd concentrations >30 mg kg^{-1}. In addition, from a grain quality perspective increasing soil Cd content results in variety specific alterations in the protein and amylase content of rice-grains (Table 6).

Table 5: Effect of soil Cd concentration applied as Cd salts on the yield of aromatic rice variety VN20 and the high yield variety VND95-20

Cd (mg kg^{-1})	No. Panicles /m^2		Grains per ear		Estimated yield (t ha^{-1})	
	VND 95-20	VD 20	VND 95-20	VD 20	VND 95-20	VD 20
0	225	214	99	129	5.31	4.51
15	203	182	101	132	4.90	4.53
20	200	168	100	122	4.68	4.35
25	217	171	77	136	3.90	3.13
30	202	165	73		3.58	3.77
CV (%)	7.10		8.98		8.33	
LSD $_{<0.05}$	22.13		15.40		5.82	

Table 6. Effects of soil Cd concentration applied as Cd salts on the rice grain protein and amylase contents of aromatic rice variety VN20 and the high yield variety VND95-20

Cd (mg kg^{-1})	Protein (%)		Amylase (%)	
	VD20	VND95-20	VD20	VND95-20
0	6.95	8.58	12.92	17.90
15	6.56	8.43	11.80	15.70
20	6.94	8.28	11.63	17.77
25	7.13	8.08	12.75	14.66
30	737	7.94	12.92	16.82

Table 7 shows the concentration of Cd accumulated in the different parts of the rice plant as a result of cadmium uptake from soils. Accumulations are highest in roots, about 20-30 times higher than in stems and leaves and about 100-200 times higher than in grains. Roughly this translates to a ratio for Cd in soil: roots: stems and leaves: rice grains of 10:200:10:1. In addition, the results indicate that at similar total soil Cd concentrations the accumulative capacity of Cd in brown rice in the fields is much lower as compared to that in the greenhouse experiments (Table 7). The results also indicate that under both field and greenhouse conditions all brown rice Cd concentrations exceed the internationally recognized Maximum Level (ML) for Cd in rice grain of 0.2 mg Cd kg^{-1}.

This ML is established by the Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (CAC). Specifically, MLs are established by the Codex Committee on Food Additives and Contaminants (CCFAC) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The ML is based on the 'safe' lifetime consumption of rice and the level recommended by the Codex Alimentarius Commission (CAC) to ensure the free movement of rice in international trade.

Table 7. Relationship between soil Cd concentration applied as Cd salts and accumulation of Cd in different parts of rice plants.

Cd in soil (mg kg^{-1})	Cd in rice plant (mg kg^{-1} dried biomass)			
	Roots	Straw, leaves	Brown rice	
			Green house	Field
0	39	3.57	0.35	0.32
5	205	10.89	1.08	-
10	323	27.40	2.66	-
15	376	38.21	4.21	0.54
20	652	44.80	5.77	1.17
25	756	45.20	8.23	2.02
30	814	46.80	9.65	2.21
35	1275	57.22	9.56	-
40	1402	56.54	9.30	-

Note: Internationally established ML for Cd in rice grain is 0.2 mg Cd kg^{-1} as established by the 34th Session of the CCFAC (Rotterdam, The Netherlands 11-15th March 2002).

Table 8. Concentration of Cd in rice grains growing on polluted soil at Bình Chaùnh District, HCMC, Vietnam

Sampling Location	Cd in soil (mg kg^{-1})	Cd in rice (mg kg^{-1})	
		Straw, leaves	Brown rice
BC3	7.6	1.26	0.38
BC5	9.8	2.03	0.52
BC9	14.5	2.37	0.55
BC12	10.3	2.09	0.56
BC13	9.6	1.96	0.55
BC14	9.9	1.28	0.41
BC32	10.3	2.33	0.48

Note: Internationally established ML for Cd in rice grain is 0.2 mg Cd kg^{-1} as established by the 34th Session of the CCFAC (Rotterdam, The Netherlands 11-15th March 2002).

It is important to note that Cd concentrations in all the rice grain samples collected from Bình Chaùnh District, HCMC exceed the internationally recognized Maximum Level (ML) for Cd in rice grain of 0.2 mg Cd kg^{-1}.

Conclusions and recommendations

Rice fields south of HCMC are polluted by wastewater high in contents of several heavy metals, especially Cd. Concentrations of Cd in soil range from 4.7-10.3 mg kg^{-1} exceeding European country MP levels by a factor of 2 - 3. Cadmium accumulates easily in red-yellow alluvial soil, in alluvial soil on acid sulfate soil and in alluvial soil on actual acid sulfate soil. Cadmium concentrations above 25 mg kg^{-1} applied as Cd-salts affect the agronomical characteristics of cultivated rice and cause decreases in productivity. Increases in the concentration of Cd in soils cause higher levels of Cd in rice. The ratio of Cd in soil: roots: stem/ leaves: and brown rice is approximately 10:200:10:1. The accumulation of Cd in rice under field experiments is much lower than the accumulation in greenhouse experiments. Cadmium concentrations in brown rice grown in areas that are affected by high Cd wastewaters of HCMC exceeds the internationally recognized Maximum Level (ML) for Cd in rice grain of 0.2 mg Cd kg^{-1} as established by the Joint FAO/WHO Food Standards Programme, Codex Alimentarius Commission (CAC). This is of considerable concern as rice constitutes a major intake pathway of Cd with confirmed direct negative impacts on human health.

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