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The study was undertaken to examine effects of amendment of agricultural soil with river–sediment on the yield and heavy metal concentration of crops cultivated in it. Sediment was collected from the river in the industrialized and densely–populated area of Hanoi city and added to agricultural soil at the rates of 0, 10, 20, 30, 40 and 50%, followed by thorough mixing. White cabbage and beet were cultivated in pots at Hanoi Agricultural University. After harvest edible parts (leaf for white cabbage and root for beet) of both crops were weighed. The yield was highest at the soil with 30% addition of the sediment for both crops. The total concentration of heavy metals was higher for white cabbage than for beet and was not parallel with the percentage of sediment in the soil. Concentrations of Cd and Pb in white cabbage and Cd in beet were over the Vietnam standard for maximum permissible heavy metal concentration in vegetables.

INTRODUCTION

In the urbanized or industrialized area, application of sediment becomes concern for environment as well as for crop growth. The agricultural use of sediment provides environmental and economical benefits through reuse of essential and organic matter contained in this material (Smith, 1994). Upon land application, however, sediment has led to the accumulation of heavy metals in particular Cd, Cu, Pb and Zn in many agricultural soils. Sediment–borne trace elements may accumulate in plant tissue to cause crop injuries or to be harmful to consumers of the harvested crops (Chang *et al.*, 1987). In addition, agricultural application of sediment can be problematic because of the addition of harmful components such as pathogenic organics and chemical pollutants (van den Berg, 1993).

In the Red River delta area, farmers have used sediment of rivers and canals as organic amendment or fertilizer to keep soil fertility. But, industrialization and urbanization are rapidly processing in and around Hanoi city. In the previous study, the authors (Ho and Egashira, 1999b) found that the sediments from rivers flowing the industrialized and densely–populated area of Hanoi city were more or less strongly polluted with various heavy metals. In the present study, effects of amendment of agricultural soil with the sediment on the yield and heavy metal concentration of crops were investigated.

MATERIALS AND METHODS

1. Soil and sediment samples

Soil and sediment samples used in the study were taken in January, 1999, and air–dried before mixing. Soil sample was taken at the farm of Hanoi Agricultural University, located in Gialam district of Hanoi city, Vietnam. The soil is neutral alluvium by Vietnam soil classification and Eutric Fluvisol by FAO/UNESCO soil classification. Soil was collected from the surface 20 cm at the vegetable field. Sediment samples were collected at two sites of the Tolich River: one site is Congmoc in Thanhxuan prefecture and the other is Kimgiang in Thanhtri district (refer to the previous paper (Ho and Egashira, 1999a) for the map and river system of Hanoi city). They were mixed in an equal amount on the oven–dry basis. The sediment was then mixed with the soil and the proportion of the sediment in the soil–sediment mixture was 0, 10, 20, 30, 40 and 50%.

2. Pot experiment

White cabbage and beet were used in the study and were cultivated in pots inside an area enclosed by netting at Hanoi Agricultural University. The experimental design consisted of (2×6×5 or 4) factorial (2 crops, 6 mixing–rates, and 5 (white cabbage) or 4 (beet) replications) for total 60 and 48 pots. A pot (20 cm in diameter and 40 cm in height) was filled with 6 kg (oven–dry basis) of soil or soil–sediment mixture. Pot experiment was carried out in the spring season of 1999. One seedling of white cabbage was transplanted in each pot on January 20 and harvested on March 12. Two seeds of beet were seeded in each pot on January 20 and grown until March 16 before harvest. Amounts of fertilizer per pot were as follows: 0.15 g of N as urea, 0.34 g of P_2O_5 as super phosphate and 0.27 g of K_2O as muriate of potash. Half doses were basal–dressed before transplanting or seeding and the remaining half was top–dressed after one month from transplanting or seeding. Tap water was irrigated every two days with amounts of 500–600 mL per pot. After harvest edible parts of white cabbage (leaf) and beet (root) were collected and weight of the fresh matter was measured.

3. Chemical analyses

Air–dried soil and sediment samples were ground to pass through a 1–mm sieve. Edible parts of white cabbage and beet were rinsed with tap water and then deionized water, oven–dried at 65°C and pulverized to pass through a 1–mm sieve. After pretreatment, soil, sediment and plant samples were brought to Japan by air. All chemical analyses were done at Kyushu University. The pH of soil and sediment was measured in the suspension having a soil:water ratio of 1:2.5. Total carbon was determined by the dry combustion method. Total nitrogen was determined by the Kjeldahl method. Cation exchange capacity (CEC) was determined by the method proposed by Muramoto *et al.* (1992). One gram of soil and sediment was digested by the HF–HNO_3–$HClO_4$ acid treatment to determine the total concentration of heavy metals (Committee of Soil Standard Methods for Analyses and Measurements, 1986; Ho and Egashira, 1999a). One gram of plant was dissolved in 10 mL of conc. HNO_3, boiled until dryness, added with 10 mL of 30% H_2O_2, evaporated until dryness, and finally dissolved in 12.5 mL of 25% HNO_3 while heated, followed by dilution to 50 mL. Concentration of heavy metals in soil, sediment and plant was determined using AAS. Determination was made in duplicate and the relative deviation of the duplicate values was usually less than 5%.

RESULTS AND DISCUSSION

Chemical properties of soil and sediment

Chemical properties of soil and sediment used in the present study are given in Table 1. The soil and sediment were in a slightly alkaline condition with pH values of 7.5–7.6. Total C and N contents of the soil were 13.6 and 1.37 g/kg, respectively, with a C/N ratio of 9.9. The sediment showed the contents of total C and N higher than the soil. The higher total C and N contents of the sediment is an indication of usage as organic amendment or fertilizer to agricultural field. The C/N ratio of the sediment was 18.4. The CEC was around 10 cmol(+)/kg for both soil and sediment.

Table 1. Characterization of soil and sediment used in the study.

	pH	Total carbon (g/kg)	Total nitrogen (g/kg)	CEC (cmol(+)/kg)	Total heavy metal concentration (mg/kg)					
					Cd	Cr	Cu	Ni	Pb	Zn
Soil	7.65	13.6	1.37	9.2	0.33	90	42	40	32	93
Sediment	7.50	52.0	2.82	11.2	9.04	164	68	59	58	392

Concentration of heavy metals in soil, sediment, and soil amended with sediment

Concentrations of total Cd, Cr, Cu, Ni, Pb and Zn of the soil and the sediment are given in Table 1. Total heavy metal concentrations of the soil amended with sediment were calculated from the concentrations in the soil and sediment and the sediment percentage in the mixture and shown in Table 2. Background levels (BGL) of heavy metals in agricultural soils of Tuliem and Thanhtri districts of Hanoi city (Ho and Egashira, 1999a) and the maximum permissible levels to crop growth (MPLCG), quoted from Steve (1994), are also shown in Table 2. The soil of the present study was taken from a vegetable field of the farm of Hanoi Agricultural University, located in Gialam district. Gialam district is situated on the left side of the Red River, different from central Hanoi and Tuliem and Thanhtri districts which are on the right side of the Red River (refer to the map of Hanoi city of the previous paper (Ho and Egashira, 1999a)). Total concentrations of Cd, Cr, Cu, Ni, Pb and Zn of the present soil from Gialam district were all within BGL estimated for agricultural soils of Tuliem and Thanhtri districts.

The sediment of the present study was collected at two sites of the Tolich River and mixed in an equal amount. Total concentrations of Cr, Cu, Ni, Pb and Zn of the sediment were over BGL except for Ni but below MPLCG, and within the concentrations reported for the sediments of the Tolich River which were collected at the sites where one or more factories are located near (Ho and Egashira, 1999b). In contrast, the Cd concentration

Table 2. Calculated total heavy metal concentrations of the soil amended with sediment.

Sediment (%)	Total heavy metal concentration (mg/kg)					
	Cd	Cr	Cu	Ni	Pb	Zn
0	0.33	90	40	42	32	93
10	1.20	98	42	45	35	123
20	2.07	105	44	47	37	153
30	2.94	113	46	50	40	183
40	3.82	120	48	53	43	213
50	4.69	127	50	55	45	243
BGL #	0.16–0.36	63–113	40–50	34–66	32–45	98–137
MPLCG ## (at pH>7.0)	3	400 ###	200	110	300	450

BGL: Background levels of heavy metals in agricultural soils of Tuliem and Thanhtri districts of Hanoi city, Vietnam (Ho and Egashira, 1999a).
MPLCG: Maximum permissible concentrations of potentially toxic heavy metals in soil with arable crops after application of sewage sludge, quoted from Steve (1994).
This value is provisional.

exceeded MPLCG and was about the double of the highest concentration in the previous study (Ho and Egashira, 1999b). Among three rivers (Nhue, Tolich and Kimnguu) flowing central Hanoi and Tuliem and Thanhtri districts, sediments of the Kimnguu River were found to be most severely polluted with various heavy metals (Ho and Egashira, 1999b). The sediment from the Kimnguu River should be used in the experiment, but now it is difficult to collect large amounts of sediment from the Kimnguu River due to public control because of its severe pollution with organic chemicals as well as heavy metals (Ho *et al.*, 1998).

Concerning the concentration of heavy metals in the soil amended with sediment (Table 2), it was below BGL in all sets of the sediment addition for Cu, Ni and Pb. The concentration of Cr was over BGL at 40 and 50% additions of the sediment but a little. The concentration of Zn was over BGL at 20 through 50% additions but considerably below MPLCG. For Cd, the concentration exceeded BGL at 10% addition and became equal to MPLCG at 30% addition, suggesting that Cd is the most controlling or effective element to crop growth in the present study.

Yield of white cabbage and beet

Fresh weight of edible parts of white cabbage and beet is given in Table 3, as a function of the percentage of sediment in the sediment–amended soil. Statistical analysis of the yield was performed by five and four fraction ANOVA followed by Fisher's PLSD. The yield of white cabbage was 242.0, 339.6, 314.6, 396.0, 281.0 and 135.6 g/pot for 0, 10, 20, 30, 40 and 50 of the sediment percentage. The corresponding values for beet were 78.0, 100.7, 119.0, 120.2, 92.5 and 67.7 g/pot. The yield was highest in the soil amended with 30% of the sediment for both white cabbage and beet. Increasing yield of white cabbage and beet with increasing addition of the sediment until 30% suggests that the

Table 3. Yield of edible parts of white cabbage and beet as a function of the percentage of sediment in the sediment–amended soil.

Sediment (%)	Yield (g fresh matter/pot)			
	White cabbage		Beet	
0	242.0 (± 6.8)	B	78.0 (± 2.1)	AB
10	339.6 (±17.6)	D	100.7 (±10.2)	CD
20	314.6 (±11.6)	CD	119.0 (± 3.7)	DE
30	396.0 (± 9.1)	E	120.2 (±14.1)	E
40	281.0 (±14.2)	BC	92.5 (±11.8)	BC
50	135.6 (± 6.9)	A	67.7 (± 5.6)	A

The number in parentheses represents the standard deviation of five and four replications for white cabbage and beet, respectively.
Values with different alphabets indicate significant difference ($p<0.01$) between them.

sediment was utilized as a source of nutrients for crop production (Bouldin *et al.*, 1985). Yield increase is probably due to increased available N from the sediment application (Rappaprot *et al.*, 1988), indicating the fertilizer effect of the sediment rich in organic matter. The yield of white cabbage and beet was decreased by addition of the sediment over 30% and was lowest for the soil amended with 50% of the sediment. Factors for the reduction of the crop yield by addition of excess sediment are not clear, but the following is can be considered: excess supply of N, harmful action of organic chemicals included in it and adverse effects of heavy metals.

Concentration of heavy metals in white cabbage and beet

While the sediment from the Tolich River was recognized as a fertilizer resource, the potential for excessive uptake of heavy metals continues to be an area of concern (Wolnik *et al.*, 1983). Total concentrations of heavy metals in edible parts of white cabbage and beet are shown in Table 4. The heavy metals can be regarded as due to the metal uptake by plants, because the plants were grown inside an area enclosed by netting and irrigated by tap water, so that the metals in plants were all absorbed from the soil. Concentrations in the edible part (leaf) of white cabbage ranged from 0.12 to 0.27, 0.05 to 0.07, 0.63 to 1.12, not–detected to 0.10, 0.52 to 1.03, and 9.1 to 11.5 mg/kg fresh matter for Cd, Cr, Cu, Ni, Pb, and Zn, respectively. The corresponding concentrations for the edible part (root) of beet were not–detected to 0.06, 0.05, 0.42 to 0.62, not–detected, 0.28 to 0.46, and 3.3 to 6.2 mg/kg fresh matter. In Cd, Cu, Pb and Zn, concentrations in the leaf of white cabbage were always higher than those in the root of beet, similar to the result of Boon and Soltanpour (1992). There was not found a close relationship between the metal concentrations in the edible part of a crop and the soil, like the report of Kuboi *et al.* (1986). In addition, no difference in the heavy metal concentration of the edible part between the soil and the soils amended with sediment was observed, except for Cd of white cabbage and Cd and Zn of beet which showed a tendency of accumulation in edible parts by amendment with sediment. Tendency of accumulation of Cd can be ascribed to the high Cd concentration in the sediment.

Table 5 gives the absorption rate of heavy metals, calculated as (total amounts in crop ×100/total amounts in soil), in edible parts of white cabbage and beet. The absorption rate tended to decrease with increasing addition of the sediment to the soil and was

Table 4. Total heavy metal concentrations in edible parts of white cabbage and beet as a function of the percentage of sediment in the sediment–amended soil.

Crop	Sediment (%)	Total heavy metal concentration (mg/kg fresh matter)					
		Cd	Cr	Cu	Ni	Pb	Zn
White cabbage	0	0.13	0.07	1.12	0.10	1.03	11.5
	10	0.15	0.06	0.79	0.08	0.67	9.2
	20	0.12	0.05	0.63	ND#	0.60	9.1
	30	0.22	0.06	0.75	ND	0.70	9.1
	40	0.18	0.06	0.81	ND	0.71	9.9
	50	0.27	0.05	0.78	ND	0.52	10.0
Beet	0	ND	0.05	0.49	ND	0.39	3.3
	10	0.01	0.05	0.58	ND	0.37	5.9
	20	ND	0.05	0.42	ND	0.28	4.1
	30	0.06	0.05	0.50	ND	0.46	4.9
	40	0.05	0.05	0.62	ND	0.44	6.2
	50	0.02	0.05	0.49	ND	0.46	5.5
Maximum permissible heavy metal concentration in fresh vegetables ###		0.03	NA##	2.0	3.0	0.6	30.0

ND: Not detected.
NA: Not available.
Standard in Vietnam, quoted from Ministry of Agriculture and Rural Development, Vietnam (1996).

Table 5. Absorption rate of heavy metals in edible parts of white cabbage and beet.

Crop	Sediment (%)	Absorption rate (%)					
		Cd	Cr	Cu	Ni	Pb	Zn
White cabbage	0	1.59	0.003	0.11	0.01	0.13	0.50
	10	0.71	0.003	0.11	0.01	0.11	0.42
	20	0.30	0.002	0.08	0(#)	0.09	0.31
	30	0.49	0.004	0.11	0	0.12	0.33
	40	0.22	0.002	0.08	0	0.08	0.22
	50	0.13	0.001	0.04	0	0.03	0.09
Beet	0	0	0.001	0.02	0	0.02	0.05
	10	0.01	0.001	0.02	0	0.02	0.08
	20	0	0.001	0.02	0	0.02	0.05
	30	0.04	0.001	0.02	0	0.02	0.05
	40	0.02	0.001	0.02	0	0.02	0.04
	50	0.01	0.001	0.01	0	0.01	0.03

Not detected in plant.

higher for white cabbage than for beet. It was higher for Cd and Zn than for the other four metals at the specified percentage of sediment for both crops. This can be ascribed to the highest mobility of Cd in soil followed by Zn, which was estimated from the sequential fractionation of heavy metals in the sediments collected from three rivers in central Hanoi and Tuliem and Thanhtri districts (Ho and Egashira, 1999b).

In comparison of the heavy metal concentration in the edible part of crops with the maximum permissible heavy metal concentration in fresh vegetables established by Ministry of Agriculture and Rural Development, Vietnam (1996) (Table 4), it was revealed that Cd and Pb in white cabbage and Cd in beet exceeded the established permissible levels. In this case, the Cd and Pb concentrations in white cabbage were over the permissible levels even in the soil without sediment. If this is true, cultivation of white cabbage should be avoided in the Red River delta area. More critical experiments may be needed.

CONCLUSIONS

Yield of white cabbage and beet was definitely affected by addition of the river–sediment, which was collected from the Tolich River, Hanoi, to the agricultural soil taken at the farm of Hanoi Agricultural University. The yield was highest at 30% addition of the sediment to the soil, indicating the fertilizer effect of the sediment, and decreased distinctly by addition of the sediment over 30%. Effect of addition of the sediment on the total heavy metal concentration in crops was not clear, but tendency of accumulation of Cd was noticed.

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