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journal or publication title	Journal of Integrated Field Science
volume	4
page range	27-34
year	2007-03
URL	http://hdl.handle.net/10097/40349

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Keywords: Cadmium, Uptake, Water management, Soil ameliorators

Abstract

Objectives of this study were to determine the uptake and translocation of Cd in rice plant from soil with applying the water management and soil ameliorators and to investigate the correlations among heavy metal contents in the brown rice, soil pH and chemical species of Cd existing in soil by sequential extracting method with paddy soil contaminated with Cd near abandoned mine.

To identify the effect of soil ameliorators on Cd uptake in rice plants, compost and lime were treated. Plants were grown with irrigation water concentrated by 0.01 mg kg^{-1} of cadmium in two soil types (sandy loam and clay loam) with treatments of intermittent irrigation and continuous submersion conditions. Compared to intermittent irrigation plots, average Eh value in the continuous submersion plots was low at 136.7 mV whereas pH value was high at 0.3. Eh value was decreased in the treatment of soil ameliorator while pH value was increased by 0.2~0.3. Cd content of leaves and brown rice had significantly positive correlation with Eh value in soils while was negatively correlated with soil pH. At the harvest stage, Cd content in the leaves and brown rice was decreased in the continuous submersion plots by 30% relative to the intermittent irrigation plots. In case of soil ameliorator applied plots, Cd content of leaves and brown rice was lower by 35% than that of N, P, K fertilizer plots, respectively. Compared to the soil types, Cd content of leaves and brown rice in sandy loam soil was lower by 64 and 37% than that in clay loam soil, respectively. Order of reduction to Cd uptake was the compost and lime mixture plot>silicate plot>lime plot. However, the effect of Cd uptake reduction by soil ameliorator was decreased in the N, P, K+compost and N, P, K+phosphate plots. Cd uptake reduction by water management and soil ameliorator was more effective in the sandy loam soil than that in the clay loam soil.

1. Introduction

Increase of contaminants in agricultural ecosystem has become a social issue worldwide as it related with public health. International agencies, such as the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), are currently advocating compliance to permission criteria of pollutants in agricultural products. In Korea, heavy metal contamination in agricultural fields may have been caused by wastewater, dust and sewage sludge originating from industries, mines, smelters and metal processing industries (Jung *et al.*, 2002; Lee *et al.*, 2001; Oh, 1997). Generally, heavy metals accumulated slowly but continuously in paddy fields may damage crops by Cu, Pb, Zn and As directly and livestock and humans by Cd and Hg indirectly through food chain (Soil-Plant Barrier). One causes more serious toxicity than the other (Adriano, 1992; Fergusson, 1990; Kitagishi and Yamane, 1981). Several soil factors, such as soil pH, Eh, clay contents, Mn oxide and oxidized Fe, organic matter as well as cation exchange capacity, were involved with distribution of cadmium and their availability to plant in soils (de Matos *et al.*, 2000; Martinez and Motto, 2000; Mench *et al.*, 1997; Sterckeman *et al.*, 2000).

On the other hand, it was reported that translocation of Cd in the plant from rice paddy could be controlled by applying water management and soil ameliorators such as organic matter, lime, phosphorous and silicate fertilizer (Kim, 1987; McBride, 1995; Charlatchka and Cambier, 1997; Reddy and Patrick, 1971). Therefore, it was considered to be necessary to apply the water management and soil ameliorators for controlling the uptake and translocation of Cd in the plant from rice paddy in Korea. Objectives of this study were to study on uptake and translocation of Cd in rice plant from soil with applying the water management and soil ameliorators.

2. Materials and Methods

Studies on reduction of cadmium uptake in paddy rice by the irrigation of cadmium-enriched water (Pot experiment)

Two-year pot experiment was done to investigate the effect of Cd uptake on the various agricultural managements. The variety used in the experiment was Ill-Pumbyeo, and the selected soils were sandy loam and clay loam soils that are originally representative soils at rice paddy in Korea. The rice was transplanted with three plants at each Wagner pot (1/2,000a), and amount of irrigated water with an intermittent irrigation and continuous submersion conditions were 100 ℓ and 120 ℓ per pot, respectively, during the whole cultivation period. Cadmium concentration of irrigation water was adjusted at 0.01 mg L^{-1} with cadmium chloride ($CdCl_2 \cdot H_2O$) as agricultural water standard (Ministry of Environment. 1999). For the soil ameliorators, increment of phosphorous was applied with 50 kg ha^{-1} of magnesium phosphate, 10 ton ha^{-1} of compost, lime with adjusted amount of pH 6.5, and silicate with 2 ton ha^{-1} of silicate fertilizer based on application of urea, magnesium phosphate and potassium chloride (110-70-80 kg ha^{-1}). The experimental design was split-split plot that consisted of main plot as management of irrigation water and sub-plot as soil ameliorators. Management of irrigation water consisted of an intermittent irrigation and continuous submersion conditions. Soil ameliorators were 7 plots applied with phosphorous, compost, lime, silicate, compost+lime, compost+silicate, compost+lime+silicate as relatives to the control (N.P.K). Cation exchange capacities and clay contents of sandy loam and clay loam soils were 9.1 and 20 $cmol^{+}$ kg^{-1}, and 104 and 345 g kg^{-1}, respectively (Table 1).

Soluble and total contents of Cd extracted with 0.1N-HCl in sandy loam and clay loam soils were 0.083 and 0.090 mg kg^{-1}, and 0.43, 0.57 mg kg^{-1}, respectively. It was observed that soluble Cd contents were lower than the average, and total contents of Cd were higher at five fold than the soluble Cd content of rice paddy in Korea.

pH and Eh of soil were measured with different growing stage, and Cd contents of stem and leaf, brown rice and soil after harvesting were analyzed. The relationship between the change of Eh and soil pH was affected by irrigation methods and soil ameliorators and the partial Cd content in rice plant were analyzed.

Soil chemical analysis

Soil samples were prepared and analyzed by Korean Soil Standard Method (NIAST, 2000) and by Ministry of Environment (2001). Soils were air-dried and crushed to pass through a 20-mesh sieve. Soil pH was measured in distilled water at 1:5 ratio of soil to water. The fraction of organic carbon was determined by the wet oxidation method (Tyurin). Available phosphate was calibrated by Lancaster method. Cation-exchange capacities were measured by 1N-ammonium acetate (pH 7.0) solution extraction. An experiment of available heavy metals in soil was conducted that 10 g of soil in 100 ml triangular-flask was shaken steadily in 0.1N-HCl 50 ml at 30°C for 1 hour and filtered by No. 5B filter paper (Ministry of Environment, 1999). Cadmium content in brown rice was assayed by dry-acid digestion, and cadmium content in stem and leaf was decomposed in ternary solution (HNO_3 : $HClO_4$: H_2SO_4= 10:4:1) using a hot plate (NIAST, 2000; Kim and Lee, 1995).

Table 1. Physico-chemical properties of the soils used

Soil texture	pH (1:5)	OM (g kg^{-1})	$Av.P_2O_5$ ---(mg kg^{-1})---	$Av.SiO_2$	CEC ($Cmol^{+}$ kg^{-1})	Clay (g kg^{-1})	Cd^{*} --(mg kg^{-1})--	T-Cd
SL	5.0	9	110	103	9.1	104	0.083	0.43
CL	5.2	19	24	240	20.4	345	0.090	0.57

* Extracted with 0.1N-HCl solution

3. *Results and Discussion*

Changes of Eh and pH values in sandy loam soil at the different sampling date with different water management and amelioration were described in table 2. The value of soil pH was highest at 60 days after rice transplanting in all treatments over rice cultivation period. It was observed that the average of Eh at the continuous submersion plot was low at 136.7 mV, but soil pH was high at 0.3 as compared to the intermittent irrigation. Therefore, the more reduction process and the higher soil pH by a continuous submersion were observed.

The values of Eh were not significantly different among the treatments of soil ameliorators, but generally low relative to the control. The values of soil pH were hardly different between the increment of phosphorous and the control. However, those were increased at 0.2-0.3 of soil pH by applying the lime, compost and silicate. Also, it was observed that the value of Eh was decreased and pH was increased with applying the combinations of compost with lime and compost with silicate.

Cadmium concentrations of stem with leaf, and root at 45 days after transplanting in sandy loam soil with different water management and amelioration were demonstrated in table 3. It was observed that cadmium concentrations of stem and leaf with continuous submersion were lower than that of the intermittent irrigation. The average concentrations of Cd in the stem with leaf and roots were 0.658 mg kg^{-1} and 2.51 mg kg^{-1} for the continuous submersion and 0.680 mg kg^{-1} and 2.81 mg kg^{-1} for the intermittent irrigation, respectively. On the other hand, those were significantly decreased with applying the soil amelioration. For the application of soil amelioration, the decreasing rates of Cd in stem with leaf and roots were 29.8% and 25.6% for the continuous submersion and 31.2% and 18.1% for the intermittent irrigation.

The decreasing efficiencies of Cd uptake were appeared in the stem with leaf among the soil ameliorators, but greatly observed in root with applying the compost and silicate. Therefore, it was demonstrated that the Cd uptake of rice with decreasing the solubility of Cd in soil by increasing pH and stimulating the reduction with applying the lime, compost and sili-

Table 2. Changes in soil Eh and pH values at the different sampling date with different water management and amelioration

Treatment		Days after transplanting							
Irrigation methods	**Amelioration**	**44**	**60**	**74**	**93**	**44**	**60**	**74**	**93**
		Eh (mV)				pH			
Intermittent irrigation	Control (NPK)	243	270	178	107	5.8	7.0	6.2	6.3
	NPK+Phosphate	252	239	170	74	5.9	6.9	6.2	6.3
	NPK+Lime (L.)	189	95	92	22	6.5	7.3	6.4	6.4
	NPK+Compost (C.)	240	230	111	76	6.0	7.2	6.5	6.5
	NPK+Silicate (S.)	223	206	98	46	6.4	7.1	6.5	6.5
	NPK+C.+L.	160	79	62	76	6.8	7.0	6.7	6.9
	NPK+C.+S.	187	231	60	64	6.5	7.0	6.7	7.0
Continuous submersion	Control (NPK)	154	28	53	9	6.4	7.4	6.5	6.5
	NPK+Phosphate	125	-39	12	-11	6.5	7.4	6.5	6.7
	NPK+Lime (L.)	97	-55	11	-31	6.7	7.9	6.5	6.8
	NPK+Compost (C.)	94	-43	17	-41	6.5	7.6	6.7	6.8
	NPK+Silicate (S.)	97	-48	6	-65	7.0	7.8	6.6	6.8
	NPK+C.+L.	90	-48	-36	-61	6.8	7.6	6.9	7.2
	NPK+C.+S.	90	-65	-11	-76	6.6	7.7	6.9	7.1

Table 3. Cadmium content in stem with leaf and root at 45 days after transplanting with different water management and amelioration (Unit : mg kg^{-1})

Treatments	Stem & leaf		Root	
	Intermittent irrigation	Continuous submersion	Intermittent irrigation	Continuous submersion
Control (NPK)	0.928 a[1)]	0.884 a	3.33 a	3.23 a
NPK+Phosphate	0.625 b	0.629 c	3.13 ab	3.03 ab
NPK+Lime	0.613 b	0.595 c	2.73 c	2.52 c
NPK+Compost	0.656 b	0.572 c	2.22 d	2.12 d
NPK+Silicate	0.663 b	0.605 c	2.32 d	1.92 d
NPK+Compost+Lime	0.568 b	0.621 c	2.73 c	2.63 c
NPK+Compost+Silicate	0.707 b	0.703 b	3.24 a	2.12 d

[1)] Column values followed by the same letter are not significantly different.
(DMRT, 0.05 Significant level).

Table 4. Cadmium content in the stem with leaf and brown rice in sandy loam soil with different water management and amelioration at the harvest stage (Unit : mg kg^{-1})

Treatment		1st year		2nd year	
Irrigation methods	Amelioration	Stem & leaf	Brown rice	Stem & leaf	Brown rice
Intermittent irrigation	Control (NPK)	2.07 a[1)]	0.198 a	2.29 a	0.241 a
	NPK+Phosphate	1.90 a	0.185 b	1.76 b	0.149 c
	NPK+Lime (L.)	1.32 c	0.091 e	1.37 c	0.134 cd
	NPK+Compost (C.)	1.68 b	0.191 ab	1.65 b	0.177 b
	NPK+Silicate (S.)	1.30 c	0.115 d	0.91 d	0.100 d
	NPK+C.+L.	0.89 d	0.069 f	0.60 e	0.082 e
	NPK+C.+S.	1.30 c	0.127 c	0.84 de	0.105 d
Continuous submersion	Control (NPK)	1.36 a	0.125 a	1.40 a	0.141 a
	NPK+Phosphate	1.04 b	0.095 c	1.21 b	0.112 b
	NPK+Lime (L.)	0.82 c	0.076 d	0.82 c	0.079 c
	NPK+Compost (C.)	0.95 bc	0.105 b	1.26 ab	0.125 ab
	NPK+Silicate (S.)	0.81 c	0.074 d	0.80 c	0.082 c
	NPK+C.+L.	0.69 d	0.066 d	0.51 d	0.072 c
	NPK+C.+S.	0.92 bc	0.071 d	0.63 cd	0.077 c

[1)] Column values followed by the same letter are not significantly different
(DMRT, 0.05 Significant level).

cate under the continuous submersion was decreased.

It was reported that uptake and translocation of heavy metals in plant, and their adsorption in soil were affected by change of Eh in rice paddy (Kitagishi & Yamane, 1981; Charlatchka & Cambier, 1997). Also, Choi *et al.* (1991) and de Matos *et al.* (2000) described that an exchangeable Cd concentration was decreased by applying the soil amelioration as lime and reductant under the continuous submersion in the contaminated soil.

Over the review of comprehensive results to the experiment, decreasing rates of Cd uptake were 29.6% in the stem with leaf and 30.5% in the brown rice at a continuous submersion as compared to the intermittent irrigation (Table 4). For relatives to the control, those were 48.1% and 37.7% in the stem with leaf and 48.3% and 35.3% in the brown rice at the intermittent irrigation and a continuous submersion, respectively. Order of decreasing rate of Cd uptake was the combination of compost and lime>silicate or lime>the increment of phosphorous and only compost.

As a result, the concentration of Cd in a plant at the intermittent irrigation was lower than that of the continuous submersion in respect of irrigation methods with applying the soil amelioration. This result was agreement with Pb uptake (Kim *et al.*, 1986), but opposite to Cu and As uptake (Kim *et al.*, 1985; Lee and Lim, 1987) in the plant.

Correlation coefficients among soil Eh, pH and cadmium concentration of stem with leaf and brown rice in sandy loam soil during the cultivation period were presented in table 5. It was shown that concentrations of Cd in stem with leaf and brown rice had significantly a positive correlation with soil Eh, but a negative correlation with soil pH. Degree of correlation was highest at 74 days after transplanting for Eh and 44 days after transplanting for pH. However, degree of correlation among soil Eh, pH and cadmium concentration of brown rice was generally highest at 74 days, but lowest at 60 days after transplanting.

Soil pH was increased with applying the soil amelioration relative to the control (Table 6). Especially, it was more affected by the application of lime and silicate than the phosphorous and compost. However, there were not differences between a continuous submersion and the intermittent irrigation.

The decreasing rate of Cd uptake in sandy loam soil was 63.9% in the stem with leaf and 36.9% in the brown rice as compared to clay loam soil, but 31.7% in the stem with leaf and 31.2% in the brown rice at continuous submersion relatives to the intermittent irrigation (Fig. 1). As compared to the control, order of decreasing rate of Cd uptake with applying soil ameliorators was the combination of compost and lime>lime>the only compost. Overall, it was observed that the decreasing efficiency of Cd uptake in rice was great at sandy loam for soil textures, a

Table 5. Correlation coefficients among soil Eh, pH and cadmium content in stem with leaf and brown rice (n=28) at different sampling date

	Days after transplanting			
	44	60	74	93
	Stem & leaf			
Eh	0.652**	0.751**	0.773**	0.664**
pH	-0.846**	-0.585**	-0.814**	-0.694**
	Brown rice			
Eh	0.536**	0.728**	0.739**	0.630**
pH	-0.814**	-0.541**	-0.762**	-0.716**

** Significant at 1%.

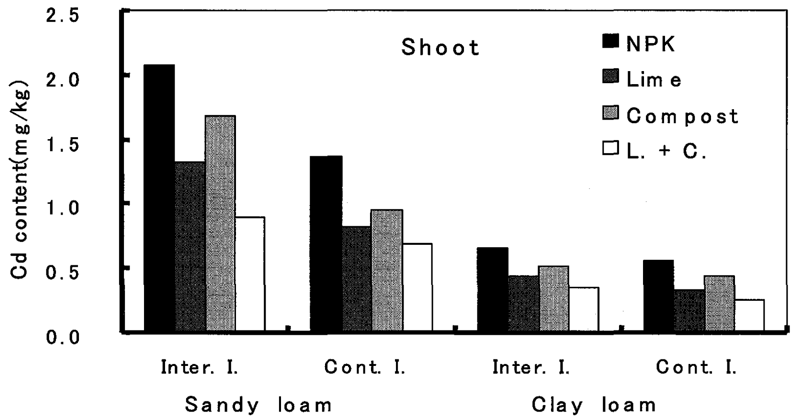
Table 6. pH value and cadmium content (0.1N-HCl extractable) in soil after harvest with different water management and amelioration

Treatments	pH (1:5)		0.1N-HCl extractable Cd (mg kg^{-1})	
	Intermittent irrigation	Continuous submersion	Intermittent irrigation	Continuous submersion
Control (NPK)	5.3	5.0	0.312	0.304
NPK+Phosphate	5.4	5.3	0.324	0.312
NPK+Lime	6.5	6.4	0.252	0.228
NPK+Compost	6.0	5.8	0.235	0.224
NPK+Silicate	6.9	6.9	0.246	0.222
NPK+Compost+Lime	7.3	7.2	0.250	0.230
NPK+Compost+Silicate	7.3	7.2	0.238	0.228

continuous submersion for irrigation methods and the combination of compost and lime for soil ameliorators. It was reported that it was great at a continuous submersion for the decreasing efficiency of Cd uptake in rice (Choi *et al.*, 1991; Naidu *et al.*, 1997). Therefore, it might be considered that soil addition was important to restore the contamination site with heavy metals.

Concentration of Cd had a positive correlation with Eh, but the negative correlation with pH in both sandy loam and clay loam soils (Table 7). Degree of correlation was highest at 74 days after transplanting in both soils. Overall, it was considered that soil textures, irrigation methods, organic matter content and soil pH is very important to uptake and translocation of Cd. Therefore, the uptake of Cd could be decreased in case of considering the above factors for rice cultivation in the contaminated field with Cd.

Fig. 1. Cadmium content in the stem with leaf and brown rice grown in paddy soils treated with different soil textures, water management and amelioration (adopted from Jung, 2001).



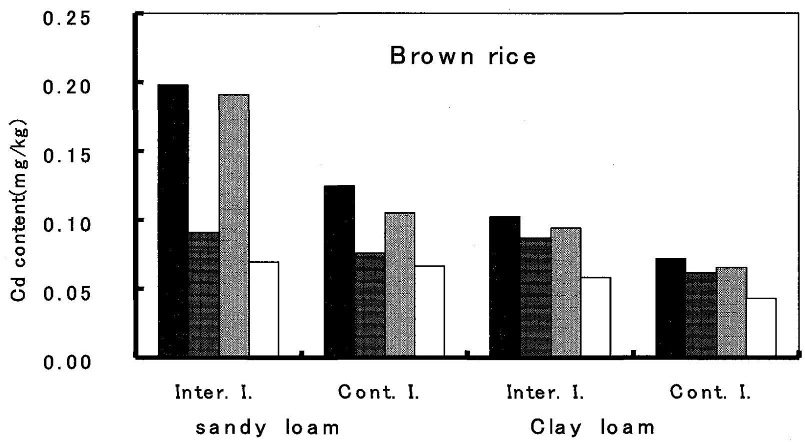


Table 7. Correlation coefficients between soil Eh, pH at different sampling date and cadmium content in stem and leaf, brown rice (n=8) at the harvest stage

Soil Textures		Days after transplanting 74	93	74	93
		— Stem & leaf —		— Brown rice —	
Sandy loam	Eh	0.936**	0.853**	0.914**	0.784*
	pH	-0.723*	-0.679 NS	-0.816*	-0.624NS
Clay loam	Eh	0.806*	0.522 NS	0.907**	0.735*
	pH	-0.933**	-0.812*	-0.871**	-0.752*

*, ** Significant at 5%, 1%. NS : not significant.

4. Conclusion

The community problem, which is related with safety of crop production and crop injury by contamination of heavy metals from an industrial complex and metal mine, occurs. Recently, it is described that threshold and intervention values of soils are 1.5, 4.0 mg kg^{-1} for Cd on Soil Environmental Conservation Act in Korea (1996). The threshold levels of soil contamination are criteria to require the regulation of land use and facility installation because the soil contamination causes the serious damage of plant, animal and human health. Its intervention levels are the criteria to prevent the soil contamination with concentration at more 40% of soil contamination concentration than its threshold levels. In Korea, for polluted soils over the threshold values of heavy metals, the fine red soil dressing, land reconsolidation, and soil amelioration such as lime, phosphate, organic matter, and submerging are recommended. For the corrective action area, cultivation of non-edible crops such as garden trees, flowers, and fiber crops, land reformation and fine red soil dressing (up to 30 cm) were strongly recommended. Also, the level of cadmium concentration in the brown rice was restricted at 0.2 mg kg^{-1}. Therefore, agricultural management as the irrigation methods and application of soil ameliorators is interesting subject in order to decrease the Cd uptake in rice as main cereal crop in Korea.

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