하수처리수의 농업용수 재이용이 토양 및 작물의 중금속 함량에 미치는 영향 분석

Impact of Reclaimed Wastewater Irrigation on Heavy Metal Contamination in Soil and Vegetables

김학관[*]·장태일[**]·이은정[***]·박승우[****]

Hak Kwan Kim·Tae Il Jang·Eun Jung Lee·Seung woo Park

Abstract

In this study, the effects of reclaimed wastewater irrigation on the concentration of heavy metals such as lead, zinc, cadmium, and copper in soil and vegetables were investigated by monitoring an experimental area irrigated with reclaimed wastewater. Three treatments and three replications on 10× 2-m plots were installed and heavy metal concentrations in soil and vegetables were monitored from 2005 to 2007. The treatments applied in this study were groundwater irrigation (control treatment), wastewater irrigation, and irrigation with filtered reclaimed wastewater treated with ultraviolet light. The monitored results showed that the concentrations of Cu, Cd, and Pb in soil during the experimental period were lower than initial soil levels before irrigation, whereas Zn increased in all treatment plots. However, the ranges of Zn, Cu, Cd and Pb in soil were below the soil pollution standards in the Republic of Korea. Heavy metal concentrations in vegetables showed insignificant variations for all treatments.

Key words : Wastewater reuse, Irrigation, Heavy metal, Contamination

1. Introduction

Wastewater reuse for irrigation is a common procedure in freshwater stressed countries (Anderson, 2003) because irrigation does not require high-quality water, and effluents contain nutrients that are of value to crops (Melloul et al., 2002). Wastewater reuse is also recognized to confer some benefits, such as nutrient recovery, reduction of fertilizer application, and effluent disposal (Angelakis et al., 1999). It is reported that at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater and an estimated 80% of wastewater in developing countries may be reused for upland crop irrigation (Cooper, 1991;

* 정회원·서울대학교 지역시스템공학과 박사수료·E-mail : kwans2@snu.ac.kr

** 정회원·서울대학교 지역시스템공학과 박사수료·E-mail : uriduri7@snu.ac.kr

*** 정회원·서울대학교 지역시스템공학과 박사과정·E-mail : tweety45@snu.ac.kr

**** 정회원·서울대학교 지역시스템공학과 교수·E-mail : swpark@snu.ac.kr

Hussain et al., 2002).

However, the application of wastewater may be limited by potential health hazards. Wastewater irrigation contributes to the heavy metal content of soils and may lead to contamination of irrigated soils and vegetables (Singh et al., 2004). As a consequence, it is necessary to establish guidelines or criteria for wastewater reuse in agriculture, which can allow the practice to be adopted with complete health and environmental security.

The objectives of this study were to assess the impacts of reclaimed wastewater irrigation on the concentration of heavy metals such as lead (Pb), zinc (Zn), cadmium (Cd), and copper (Cu) in soil and vegetables by monitoring experimental areas where reclaimed wastewater was used for irrigation.

2. Materials and methods

The experimental plots were located near the Suwon wastewater treatment plant in Gyeonggi-do, Republic of Korea. A block design was used, with three treatments and three replications, on 10×2-m plots. The three treatments were separated according to the irrigation water used: groundwater (GW), wastewater (WW), and wastewater filtered with a synthetic dual-medium filter and treated with ultraviolet rays (FUV). A small-scale wastewater reclamation system with a synthetic dual-medium filter, ultraviolet treatment unit, pipelines to supply irrigation water from the wastewater effluents, and a groundwater well was installed for the experiment. A drip irrigation system was used to supply water directly to the soil instead of to the vegetables.

Vegetables grown were lettuce (*Lactuca sativa* L.), squash (*Cucurbita*spp.), cucumber (*Cucumis sativus* L.), tomato (*Lycopersicon esculentum* Mill.), Chinese cabbage (*Brassica campestris* var. *pekinensis* Makino), and radish (*Raphanus sativus*L.). Experiments were performed from May 2005 to November 2007. All vegetables were cultivated in a covered experimental field to prevent rain from affecting the experiment.

Two-way analysis of variance (ANOVA) at 1% and 5% significance levels was used to compare the mean heavy metal concentrations in soil and irrigation water for treatments and years. One-way ANOVA with the least significant differences (LSD) test was used to assess the significance of differences for each treatment between mean concentrations of heavy metal in vegetables.

3. Results and discussion

3.1 Concentration of heavy metals in irrigation water

ANOVA showed that variations in heavy metal concentrations in irrigation water were not significant between treatments for Zn, Cu, Cd, and Pb at the 1% significance level (Table 1). However, variation by years was significant for Zn, Cu, Cd, and Pb at the 1% significance level (Table 1). The mean concentrations in irrigation water for each treatment during the experimental period are summarized in Table 2. The mean concentrations of Zn in irrigation water in 2006 and 2007 were decreased by approximately 22% and 58% for the GW plot, 31% and 21% for the WW plot, and 47% and 71% for the FUV plot compared to the concentration in 2005, respectively. For Cu and Cd, maximum concentrations were recorded in 2006, while Cu and Cd were not detected in 2005 and 2007. The concentration of Pb showed a similar trend for each plot, except the WW plot in 2005. In comparison to the standard guidelines for irrigation water (Pescod, 1992), the mean Zn, Cu, Cd, and Pb concentrations of irrigation water in all treatment plots did not exceed the safe limit (Table 2). The highest mean concentrations were recorded for Zn in all treatments, followed by Cu and Pb, and the minimum was observed for Cd.

Table 1. Results of two-way ANOVA for mean heavy metal concentrations in irrigation water and soil at the experiemetal sites

Variation	degrees of freedom	Zn	Cu	Cd	Pb
Irrigation water					
Treatment	2	1.031^{NS}	1.000^{NS}	1.000^{NS}	2.352^{NS}
Year	2	7.909^{**}	4141.926^{**}	33.352^{**}	91.446^{**}
Soil					
Treatment	2	6.436^{*}	6.857^{*}	6.027^{*}	3.088^{NS}
Year	3	17.417^{**}	46.872^{**}	62.697^{**}	14.826^{**}

NS: not significant. $^{*}P<0.05$, $^{**}P<0.01$.

Table 2. Heavy metal concentrations (mg L^{-1}) in irrigation water for each treatment during the experimental period.

Year	Classification	Zn			Cu			Cd			Pb		
		GW	WW	FUV	GW	WW	FUV	GW	WW	FUV	GW	WW	FUV
2005 (n=11)	Mean	1.07	0.90	1.00	ND	ND	ND	ND	ND	ND	ND	0.00	ND
	Maximum	1.75	2.72	2.00	ND	ND	ND	ND	ND	ND	ND	0.03	ND
	Minimum	0.10	0.19	0.38	ND	ND	ND	ND	ND	ND	ND	ND	ND
2006 (n=14)	Mean	0.83	0.62	0.53	0.04	0.04	0.04	0.00	0.00	0.00	0.01	0.02	0.02
	Maximum	2.65	1.31	1.16	0.16	0.15	0.16	0.01	0.01	0.01	0.06	0.08	0.06
	Minimum	0.19	0.15	0.05	ND	ND	ND	ND	ND	ND	ND	ND	ND
2007 (n=16)	Mean	0.45	0.71	0.29	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Maximum	0.86	1.48	0.57	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Minimum	0.05	0.07	0.09	ND	ND	ND	ND	ND	ND	ND	ND	ND
Safe criteria (Pescod, 1992)		2.00			0.20			0.01			0.5		

ND : not detected.

3.2 Concentration of heavy metals in soil

The sampled soil of the experimental site was loamy sand with 78.1% of sand, 15.4% of silt, and 6.5% of clay according to United States Department of Agriculture (USDA) textural classification which was defined by particle size distribution. In the initial soil, i.e., before irrigation, the concentrations (mg kg^{-1} dry weight) of heavy metals were 81.13 for Zn, 5.94 for Cu, 0.07 for Cd, and 5.24 for Pb. Jung et al. (1998) reported that the concentrations (mg kg^{-1} dry weight) in soil used for crop cultivation in the Republic of Korea were 10.7 Zn, 2.77 Cu, 0.135 Cd, and 3.47 Pb. Thus, the mean concentrations of Zn, Cu, and Pb in this study were higher than the values reported by Jung et al. (1998), but the Cd concentration was lower. Heavy metal concentrations in soil showed significant variation between treatments and years. However, the variation in each treatment was not significant for Pb (Table 1). Table 3 shows the concentrations of heavy metals in soil after irrigation. The concentrations of all heavy metals were higher in the GW plot than in the other plots. The mean concentrations of Cu, Cd, and Pb during the experimental period were lower than initial soil levels before irrigation, whereas Zn increased in all treatment plots. The maximum and minimum increase rate of Zn was approximately 65% in the GW plot in 2006 and 4% in the FUV plot in 2005. The range of concentrations of Zn, Cu, Cd, and Pb in soil was below the soil pollution standards in the Republic of Korea (MOE, 2005).

Table 3. Heavy metal concentrations (mg kg^{-1} dry weight) in soil of each treatment plot during the experiment

Year	Classification	Zn			Cu			Cd			Pb		
		GW	WW	FUV	GW	WW	FUV	GW	WW	FUV	GW	WW	FUV
2005 (n=15)	Mean	99.96	93.44	84.70	4.81	4.38	4.53	0.04	0.03	0.03	5.17	4.09	4.15
	Maximum	105.68	106.68	96.38	6.05	3.23	3.19	0.06	0.06	0.06	7.84	4.57	3.51
	Minimum	97.63	76.84	76.11	3.44	6.40	6.58	ND	ND	ND	4.07	3.59	4.53
2006 (n=12)	Mean	133.76	113.31	107.92	5.19	4.55	4.65	0.08	0.07	0.07	4.59	4.13	4.13
	Maximum	181.21	140.98	136.48	6.08	4.84	5.26	0.13	0.12	0.13	5.22	3.45	3.47
	Minimum	107.03	86.22	83.97	4.77	4.15	3.65	0.06	0.04	0.04	4.13	5.34	5.39
2007 (n=15)	Mean	109.25	92.20	88.54	5.10	4.58	4.88	0.05	0.04	0.04	3.87	3.76	3.72
	Maximum	103.55	83.89	85.95	5.74	4.07	5.31	0.08	0.08	0.07	2.27	2.47	4.66
	Minimum	113.53	102.23	95.60	4.53	5.15	4.23	ND	ND	ND	4.05	5.64	1.97
Limit in the Republic of Korea (MOE, 2005)		300			50			1.5			100		

ND : not detected.

Table 4. Mean heavy metal concentrations (mg kg^{-1} dry weight) of vegetables in each treatment

Vegetable	Zn			Cu			Cd			Pb		
	GW	WW	FUV	GW	WW	FUV	GW	WW	FUV	GW	WW	FUV
Lettuce (n=6)	60.03	55.85	59.86	3.45	3.68	6.48	0.03	0.02	0.03	0.36	1.06	1.06
Squash (n=3)	27.54	16.93	19.82	9.71	9.53	9.99	ND	ND	ND	ND	ND	ND
Cucumber (n=3)	39.41	38.96	37.97	6.80	8.10	5.61	ND	ND	ND	ND	ND	ND
Tomato (n=3)	36.58	29.84	5.57	6.99	6.72	5.96	ND	ND	ND	ND	ND	ND
Chinese cabbage (n=3)	9.17	11.18	28.16	ND	4.38	1.14	ND	ND	ND	ND	ND	ND
Radish (n=3)	16.66	16.69	43.02	1.15	1.18	1.28	ND	ND	ND	ND	ND	ND

ND : not detected.

3.3 Concentration of heavy metals in vegetables

The mean concentrations (mg kg^{-1} dry weight) of heavy metals in vegetables for three treatments varied from 9.17 to 60.03 for Zn and 0.00 to 9.99 for Cu (Table 4). Cd and Pb were not detected in any vegetables except lettuce. ANOVA showed insignificant variations at the 5% significance level in vegetables among the three treatments for Zn,Cu, Cd, and Pb. The highest concentrations of Zn, Cd, and Pb were observed in lettuce, while the maximum Cu was found in squash.

4. Conclusions

Despite concerns about using treated wastewater, we found that heavy metal concentrations (Zn, Cu, Cd, and Pb) in reclaimed wastewater irrigation water did not exceed the wastewater quality guidelines recommended by the Food and Agriculture Organization (Pescod, 1992) for wastewater use in agriculture. In comparison to the soil pollution standards of the Republic of Korea (MOE, 2005), the ranges of Zn, Cu, Cd, and Pb in soil observed in this study were also below the safe limits. However, Zn did accumulate in the soil. Thus, heavy metals like Zn must be monitored periodically and managed carefully to prevent damage due to accumulation. Variations in heavy metal concentrations in vegetables were not significant among treatments. This study may provide a valuable basis for guiding further activities aimed at preventing excess exposure of humans to heavy metals, through monitoring and control of irrigation water and/or amelioration of metal uptake in vegetables.

Acknowledgments

This research was supported by a grant (code# 4-5-3) from Sustainable Water Resources Center of 21st Century Frontier Research Program.

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