Effects of Phosphorus and Iron on the Phytotoxicity o Lettuce in Arsenic-contaminated soil

Min-Suk Kim, Hyun-Gi Min, ByeongJoo Lee, Jeong-Gyu Kim*

College of Life Science & Biotechnology, Department of Environmental Science and Ecological Engineering, Korea Univ.

Abstract

Tailings containing the high level of arsenic (As) concentration that originated from mining activities have been recognized as a main anthropogenic source of As-contaminated soil. We investigated that the effect of phosphorus (P) and iron (Fe) on the phytotoxicity of lettuce in arsenic (As)-contaminated soil using response surface methodology (RSM). The model was used for the interpretation of the significant effects of P and Fe on the As mobility and As accumulation in lettuce. To stabilize arsenic and supply nutrient, Fe and P were applied, respectively. From a chemical assessment, As extractability was decreased by Fe but increased by P. From a biological assessment, phytotoxicity test, As in lettuce roots was negatively associated with not only root elongation but also P in roots. From a confirmation study, we could verify that the former result was not a passing phenomenon and Fe was necessarily needed to protect secondary pollution by exclusive usage of phosphorus fertilizer.

Introduction

Tailings containing the high level of arsenic (As) concentration that originated from mining activities have been recognized as a main anthropogenic source of As-contaminated soil (Bruce et al. 2003; Seidel et al. 2005). Many other studies related to remediation of As-contaminated soil have reported that chemical stabilization using various types of amendments has been identified as a low-cost and low input method than other physical and chemical methods (Lee et al. 2009; Koo et al. 2013). Kumpiene et al. (2008) reported that the type of amendments and those of mechanisms. Among the amendments for As stabilization in soil, iron (Fe) sources have been known as an effective and common agents for As and used widely more than other amendments (Bowell 1994; Warren et al. 2003; Lee et al. 2011; Koo et al. 2012).

Material and Methods

❖ Soil
- As concentration: 1.854 mg/kg
- pH: 8.41
- EC: 0.76 ds/m
- Total P: 1.10 g/kg
- Available P: 0.07 g/kg
- Oxalate extractable Al: 1.18 g/kg
- Oxalate extractable Fe: 13.4 g/kg
- Oxalate extractable Mn: 2.0 g/kg

❖ Second-order central composite rotate design (CCRD)
- 2^n (2^2=4: cube points) + 2n (2×2: star point) + 3 (central points)
- Multiple regression analysis

: $Y = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \beta_{12}\chi_1\chi_2 + \beta_{11}\chi_1^2 + \beta_{22}\chi_2^2$

Results and Discussion

Table 1. Experimental set-up used in the central composite rotate design (CCRD) and the effects of phosphorus (P) and iron (Fe) on the root elongation of lettuce (*Lactuca sativa* L.) seeds and the their As and P uptakes

	Treatment	Code levels		Actual levels (g kg^{-1})		RE[a]	As_{root}[b]	As_{shoot}[c]	P_{root}[d]	P_{shoot}[e]
		P	Fe	P	Fe					
Cube	T1	-1	-1	0.155	0.279	26.0±3.7	0.62±0.09	25±1.9	9.8±0.95	8.59±0.46
	T2	-1	1	0.155	0.838	29.2±2.7	0.45±0.06	22±1.1	7.6±0.88	7.15±0.49
	T3	1	-1	0.465	0.279	26.1±2.2	0.43±0.06	18±0.9	24.6±0.24	12.1±0.61
	T4	1	1	0.465	0.838	30.0±5.9	0.43±0.04	45±4.7	27.3±1.65	16.2±1.78
Star	T5	0	-1.41	0.310	0.165	28.4±3.9	0.46±0.06	36±6.7	19.6±3.35	13.1±1.59
	T6	0	1.41	0.310	0.952	25.8±0.9	0.45±0.04	16±3.9	13.0±0.29	10.0±1.09
	T7	-1.41	0	0.091	0.559	25.7±3.7	0.56±0.03	18±4.3	6.2±0.78	7.1±0.53
	T8	1.41	0	0.528	0.559	32.2±1.7	0.48±0.05	22±4.4	11.9±0.37	9.9±0.93
Contral	T9	0	0	0.310	0.559	29.6±2.9	0.44±0.02	23±0.3	15.2±0.49	11.1±0.31
	T10	0	0	0.310	0.559	27.4±4.6	0.46±0.03	24±1.1	14.6±2.51	12.0±1.26
	T11	0	0	0.310	0.559	36.8±1.3	0.41±0.09	26±2.3	19.8±3.31	11.4±0.27

[a]Root elongation of germinated lettuce seeds (mm seedling^{-1}); [b]As concentrations in lettuce roots (mg g^{-1}); [c]As concentrations in lettuce shoots (mg kg^{-1}); [d]P conce ntrations in lettuce roots (mg g^{-1}); [e]P concentrations in lettuce shoots (mg g^{-1})

Table 3. The effects of phosphorus (P) and iron (Fe) on As and P extractability in CCRD study

Treatment	Code levels		WS-As[a]	WS-P[b]
	P	Fe	mg kg^{-1}	mg kg^{-1}
T1	-1	-1	11.29±0.59	29±2.9
T2	-1	1	7.83±0.34	20±1.9
T3	1	-1	19.71±1.29	286±47.4
T4	1	1	18.31±1.14	247±21.8
T5	0	-1.41	15.54±0.79	126±11.8
T6	0	1.41	13.59±1.15	129±6.3
T7	-1.41	0	5.47±0.24	14±1.1
T8	1.41	0	10.41±0.88	59±6.3
T9	0	0	14.43±1.69	131±13.2
T10	0	0	14.40±1.27	115±17.9
T11	0	0	11.39±0.61	116±3.6

[a]Water soluble As extracted by deionized water; [b]water soluble P extracted by deionized water

Table 2. Experimental setup used in the confirmation experiment and the effects of phosphorus (P) and iron (Fe) on the root elongation of lettuce (*Lactuca sativa* L.) seeds and the their AS and P uptakes

Treatment	Code levels		Actual levels (g kg^{-1})		RE[a]	As_{root}[b]	As_{shoot}[c]	P_{root}[d]	P_{shoot}[e]
	P	Fe	P	Fe					
T21	-1	-2	0.155	0.000	38.6±6.3	0.44±0.08	29±6.0	17.3±3.22	9.97±1.85
T23	1	-2	0.465	0.000	40.6±1.1	0.37±0.05	17±1.0	23.5±1.10	11.37±0.25
T25	0	-2	0.310	0.000	38.2±4.5	0.40±0.07	30±7.9	23.1±1.45	11.31±0.71
T27	-1.41	-2	0.091	0.000	38.1±2.9	0.44±0.04	27±6.2	6.6±0.64	6.20±0.35
T28	1.41	-2	0.528	0.000	38.4±0.4	0.42±0.04	23±5.3	24.1±3.13	12.30±1.76

[a]Root elongation of germinated lettuce seeds (mm seedling^{-1}); [b]As concentrations in lettuce roots (mg g^{-1}); [c]As concentrations in lettuce shoots (mg kg^{-1}); [d]P concentrations in lettuce roots (mg g^{-1}); [e]P concentrations in lettuce shoots (mg g^{-1})

Table 4. Correlation coefficients (r) among the experimental results of the CCRD study

	RE[a]	As_{root}[b]	As_{shoot}[c]	P_{root}[d]	P_{shoot}[e]	FW_{root}[f]	FW_{shoot}[g]
P_{trt}[h]	0.3883	-0.5918	0.2926	0.7049*	0.6892*	0.5632	0.6485*
Fe_{trt}[i]	0.0737	-0.3293	-0.0538	-0.1466	-0.0721	0.4926	0.5114
As_{root}	-0.4698		-0.2056	-0.6434*	-0.5745	-0.7675**	-0.7296*
As_{shoot}	0.3649			0.5986	0.7460**	-0.1049	0.4253
P_{root}	0.3068				0.9251***	0.3219	0.5497
P_{shoot}	0.2773					0.1779	0.5762

Asteriske (*,**, and ***) indicate $P < 0.05$, 0.01, and 0.001, respectively

[a]Root elongation of lettuce; [b]As concentrations in lettuce roots; [c]As concentrations in lettuce shoots; [d]P concentrations in lettuce roots; [e]P concentrations in lettuce shoots; [f]freash weights of lettuce roots; [g]freash weights of lettuce shoots; [h]P treatment contents in soils; [i]Fe treatment contents in soils

Conclusion

This study evaluated the effects of P and Fe on the extractability of As and P and phytotoxicity in mine tailing soil highly contaminated by As. Under an incorporation of both P and Fe, the P treatment content increased root elongation of lettuce by supplying nutrient source and decreased As absorption in lettuce root by suppressing the uptake of As. Under only the presence of P condition, the P treatment content increased the contents of available P more than that of available As, which resulted in the deceases in As toxicity toward lettuce, more effectively. Nevertheless, only the application of P could cause increases in As mobility, leading deterioration of environmental health. Also this study used limited environmental soil sample and chemical reagents. Thus, further study seems to be needed for the application of P and Fe to field scale using various adaptable P fertilizers and Fe sources.

Acknowledgments

This work was supported by “Climate Change Correspondence Program” (2015001310008) provided by Ministry of Environment, Korea.

Korea University