REDUCTION OF Cd PLANT-AVAILABILITY ON PADDY SOIL

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Keywords: Cd, soil remediation, rice, silicon

Introduction

Cadmium (Cd^{2+}) is one of the most dangerous heavy metals that can accumulate in the cultivated plant tissues. One of the main sources of soil pollution by Cd is phosphorus fertilizer, where the Cd content may reach up to 300 ppm of Cd (Gupta et al., 2014). The accumulation of Cd by rice and other cultivated plants poses the risk for human health. Over the past few decades many authors reported that Si-rich substances can mitigate a negative influence of cadmium on growth of various plants (Dresler et al., 2015; Vaculik et al., 2015). The direct and indirect effects of Si-rich substances on Cd behavior in the plant were suggested. The indirect influence mostly relies on additional adsorption of mobile forms of Cd in the soil by applied Si-rich materials (Keller et al., 2005). The indirect mechanism can be explained by increasing the plant resistance against heavy metal toxicity as a result of Cd precipitation in the root apoplast and reduced translocation into leaves and grain (Shi et al., 2005). However, the mechanisms of the Si-based substance influence on Cd mobility in soil and accumulation by plants remain poorly investigated. The main aim of this study was to investigate the mechanism of reducing Cd adsorption by rice under improved plant Si nutrition.

Methods

Three types of commercial Si fertilizers were used in climatic chamber test and in field investigation with rice (*Oryza Sativa* L. vr. Japonica). There are (1) diatomaceous earth (DE) (Palkarra mine, North Queensland, Australia) with 48.3 ± 1.5 mg kg^{-1} of water-soluble Si and pH of 7.2, (2) silicon fertilizer (Si fertilizer) manufactured by the Elkem Materials (Norway) (Si fertilizer) with 91.4 ± 8 mg kg^{-1} of water-soluble Si and pH of 7.9, and (3) calcium-silicate slag (Slag) - iron slag from the Valin metallurgical enterprise (Loudi, Hunan Province, China), with 4.6 ± 1.5 mg kg^{-1} of water-soluble Si, pH of 8.2, particle size 1-2 mm. All substances didn't contain any pollutants and had 32.1, 8.2, and 19.3% of total Si, respectively. In the both experiments, the application rate of Si-rich materials was 500 kg ha^{-1} or 0.5 g kg^{-1} of soil. The soil had the following characteristics: loam, pH=6.4, Corg=1.2%, CEC=4.5. The volume of pot was 1L. Cd was applied at the rates 0, 100 and 500 mg kg-1 as $CdCl_2$. After application Cd and Si materials, 10 seeds of rice were planted in each pot. All pots were irrigated daily by 50 mL of distilled water. The air temperature in the climatic chamber was kept at 24 ± 2 ºC during the day and 20 ± 2 ºC during the night. The light period was 12 h; at intensity of 950 mmol photons m^{-2} s^{-1}. The relative air humidity was 45 ± 5 % during the day and 70 ± 5 % during the night. One-month-old barley plants were harvested. The roots and above-ground parts were dried at 65ºC and their biomass was weighted. Total Si and Cd were analyzed in the rice roots and shoots. The field test was conducted at the Beishan Agricultural Station located in the Hunan Province E -113º03'28.4"; W: 28º26'22.7". The soil had pH=5.2, Corg=0.44%, CEC=10.8 cmol(+) kg^{-1}, total Cd=1.03 mg kg^{-1}. After harvesting, total Cd and Si were tested in the roots, stems, leaves of rice. The soil was analyzed for bioavailable Cd.

Results

The obtained results have shown that optimization of the plant Si nutrition changed the accumulation and translocation of Cd in rice (Table1). It is important that total Cd in the roots was increased more than that in the leaves. The addition of Si-rich materials significantly reduced the Cd transport from roots to leaves.

The correlation coefficients between total Si and Cd in leaves were r=-0.86 and r=-0.98, accordingly for lower and higher pollution levels. The correlation between water-extractable Si in the tested materials and total content of Cd in leaves was negative (r=-0.89 and r=-0.74, accordingly for lower and higher pollution levels).

Table 1. The total content of Cd and Si in rice under different levels of pollution on dry weight.

Material	Si, %			Cd, mg kg^{-1}		
Level of pollution	O ppm Cd Roots/Leaves	100 ppm Cd Roots/Leaves	500 ppm Cd Roots/Leaves	O ppm Cd Roots/Leaves	100 ppm Cd Roots/Leaves	500 ppm Cd Roots/Leaves
Control	1.12/1.03	1.23/1.22	1.35/1.29	0.89/0.45	235.4/180.0	833.3/775.0
DE	1.38/1.27	1.89/1.44	2.03/1.87	0.79/0.43	322.3/45.6	1032.3/89.4
Si fertilizer	1.45/1.39	2.11/1.87	2.25/2.03	0.86/0.40	376.3/19.4	1233.2/8.3
Slag	1.25/1.11	1.35/1.33	1.44/1.43	0.76/0.42	310.2/125.8	1004.4/278.9

The Si-rich materials significantly increased the rice yield and root and leaf biomasses (Table 2). The contents of bioavailable Cd in the Si-treated soils were reduced from 0.33±0.01 in control to 0.26±0.01, 0.24±0.01, and 0.29±0.01 ppm of Cd, respectively for DE, Si fertilizer, and Slag. This parameter had a negative correlation with the content of water-extractable Si in the tested materials (r=-0.86).

Table 2. Biomass of rice and Cd content as influenced by Si-rich materials in field test.

Material	Biomass, t/ha			Cd, mg kg^{-1}		
Level of pollution	Roots	Leaves	Grain	Roots	Leaves	Grain
Control	0.77±0.03	1.09±0.10	4.79±0.21	1.36±0.07	0.73±0.05	0.20±0.01
DE	1.14±0.04	1.45±0.09	6.87±0.25	1.89±0.11	0.60±0.05	0.16±0.01
Si fertilizer	1.20±0.04	1.37±0.11	7.44±0.26	1.66±0.10	0.46±0.04	0.16±0.01
Slag	0.96±0.05	1.23±0.11	5.83±0.16	1.23±0.09	0.45±0.04	0.17±0.02

Conclusions

The obtained data has shown that the application of Si-rich materials can reduce the soil content of bioavailable Cd. The content of water-soluble Si in the test materials was negatively correlated with the soil bioavailable Cd. The optimization of the Si plant nutrition resulted in reduced translocation of Cd into leaves and grain of rice.

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Proceedings of the 18th International Conference on Heavy Metals in the Environment, 12 to 15 September 2016, Ghent, Belgium