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Effect of Water Holding Capacity on Sulfur, Cadmium and Arsenic Uptake by Rice

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Abstract: Soil potentially toxic elements contamination have been one of the most challenging pollution problems, such as cadmium (Cd) and arsenic (As). To understand the effects of 60%, 80%, and 100% of maximum holding water capacity (MHW), conventional irrigation and flooding during the whole growth stages on the polymetallic sulphides mining paddy soil Cd and As, a pot experiment was studied. Soil pH increased with increasing soil moisture content, while soil sulfur (S) and available S gradually decreased. The Cd content in rice organs decreased gradually with increasing soil holding water capacity, whereas As contents increased significantly. Compared with conventional irrigation treatment, brown rice Cd contents increased by 95.0% and 22.5% under 80% MHW and 100% MHW treatments, and As reduced by 66.3% and 32.5%, respectively. The rice grain Cd content reduced significantly by 26.0% under Flooding during the whole growth stages treatment reduced, whereas As content increased by 104.9%. Principal component analysis (PCA) showed that there was a positive correlation between soil S and brown rice Cd content, but negative correlation with brown rice As.

Keywords:Acid mine drainage, sulfur, potentially toxic element, rice, water holding capacity

I. INTRODUCTION

Soil potentially toxic elements contamination had become a serious environmental problem in world. The over-standard rates of arable soilwere 19.4% in China , among which the over-standard rates of Cd and As were 7.0% and 2.7%, respectively. Especially, the polymetallic sulphide mining, acid wastewater containing sulfate radical and potentially toxic elements caused acidification in farmland soil downstream of the mine. Previous study showed that soil remained large amounts of sulfate affected uptake and accumulation of potentially toxic metals in crops. Cadmium (Cd) and Arsenic (As) were two of the most toxic metals, which could pose a risk to human health by food chain. Rice was one of the most important food crops, and more than half of the people live on rice in the world. The Cd and As could be easily uptake by rice planted on the contaminated soils and exceed the Pollutants Standard in Food of China (GB 2762-2017). Moreover, there were antagonistic and synergistic effects between Cd and As elements in contaminated soil, which was difficult to remediated. Therefore, it was necessary to take effective measures to ensure the risk of rice production.

Soil remediation technologies for potential toxic elements had been developed in recently years. Water management was one of the effective methods by decreasing the bioavailability of Cd and As. Furthermore, rice growing was a cycle process of wet and dry states, which affected the uptake potential toxic elements of rice. For example, intermittent drainage treatment could reduced soil As content (Liu et al. 2020). Under flooding condition, the Cd and As contents in soil were decreased, whereas As content increased (Shi et al. 2019b; Cao et al. 2020). Besides, water holding capacity also affected the absorption of potential toxic

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elements by plants (Hu et al. 2015). In addition, some trace elements, such as S, could affected the Cd uptake by rice. However, the effect of water holding capacity on S, Cd and As uptake and transport in rice has rarely been reported.

The aims of the present study were to: (1) explore the impact of various water holding capacities on rhizosphere soil S, Cd and As contents and the transport of S, Cd and As in rice, (2) evaluate the relationship between the S, Cd and As contents in rhizosphere soil and rice and various water holding capacities by principal component analysis.

II. MATERIALS AND METHODS

1. Site description

Soil samples were collected at the polymetallic sulphides mining area, located in Southern China. Soil were gathered from the 0~20 cm topsoil. Table 1 showed the soil properties.

Table 1: The physical-chemical properties of soil.

Soil property	Value
pH	4.21
Cd mg/kg	0.297
As mg/kg	114.8
Zn mg/kg	345.24
Fe mg/kg	45.76
Mn mg/kg	112.09
Cr mg/kg	42.28
Pb mg/kg	227.43
Soil S mg/kg	753.93
Available S mg/kg	474.78

2. Pot experiment

4kg soil dried was added to a plastic pot, which was diameter 20 cm and height 20 cm. Soil was mixed with basal fertilizers (0.84g CO(NH2)2, 0.76 KH2PO4 and 0.22 g KCl). The plastic pot randomly arranged in a greenhouse with a temperature of 25 ± 5℃. The rice cultivar was Changxianggu. Treatments consisted of five water holding capacities using deionized water to maintain a soil moisture and five replicates for each treatment: Conventional irrigation, early stage flooding followed by intermittent irrigation using deionized water (CK); 60% MHW treatment; 80% MHW treatment; 100% MHW treatment; FW treatment (Flooding during the whole growth stages).

3. Sample collection and Analysis

Rice seedlings were cultivated for one week and transplanted to the pots. From the flowering stage, the water control began. The rice plant was harvested on August 5 and was rinsed with tap water, followed deionized water. Rice plants were divided into three parts, namely root, straw and brown rice which were placed in a 105oC for 30 min, and then samples were baked at 60°C until a constant weight. Then, samples were ground with a stainless-steel crusher. Soil samples around the rice root were collected by gently shaking method and dried at room temperature.

Soil pH was measured (water:soil ratio 2.5:1). Soil and plant samples were digested by the method of Shi et al.(2019a), then the Cd and As contents was determined by GFAAS and AFS instruments, respectively. Soil

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total S was measured by Zhang et al (2013). Soil available S was measured by the BaSO4 turbidimetric method (Blum et al. 2014).

4. Statistical analysis

The data was processed by Excel 2010 and Canoco 5. One-way analyses of variance were performed with SPSS 19.0 software.

III. RESULTS AND DISCUSSION

1. Impact of water holding capacity on Cd and As in soil

Under the FW treatment, soil pH value was higher than other treatments (Figure.1). But soil pH was no significant change under 60% MHW and 80% MHW treatments. Except flooding treatment, soil Cd content decreased as compared with the control. Likewise, soil As content was no significant effect by 60% MHW and FW treatment, whereas that decreased under 80% MHW and 100% MHW treatments. Soil pH increased with the increase of water holding capacity, which might attributed to the consumption of protons (Wan et al. 2019). Soil pH governed solid-solution equilibria of metals. Soil Cd contents decreased significantly with increased pH (Fig.1). Flooding treatment increased soil pH value, which promoted Cd adsorption onto colloids by rising variable negative charges. Moreover, SO_4^{2-} could be reduced to S^{2-} with increasing soil moisture, which could form precipitate CdS (Bingham et al. 1976). Likewise, soil moisture also affected the chemical redox of As (Liu et al. 2020). Generally, As(V) might be adsorbed onto minerals and iron oxides/hydroxides in soil (Yang et al. 2019). With soil water holding capacity increase, the adsorption sites on soil mineral surfaces decreased, which lead to the release of dissolved As.

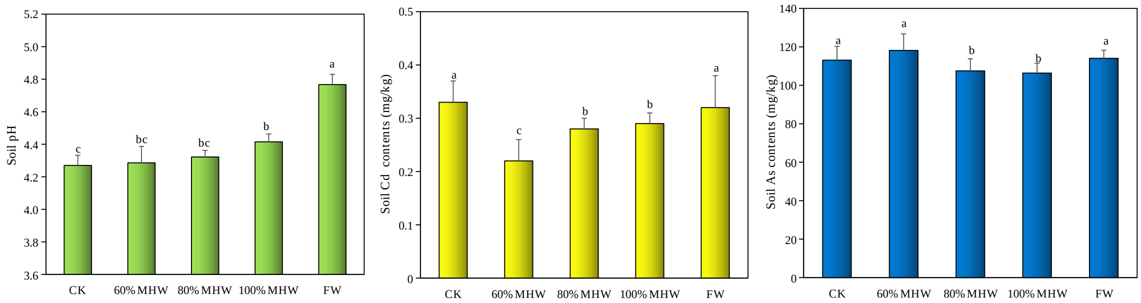

Fig.1: Soil pH values, Cd and As contents under various water holding capacities.

2 Effect of water holding capacity on soil total S and available S

Figure. 2 showed that soil total S and available S contents increased firstly and then decreased with increasing soil moisture. The highest soil S content was 1260.49 mg/kg under the 80% MHW treatment among five water holding capacity. Under flooding treatment, soil total S contents decreased significantly as compared with the control, which was 957.17 mg/kg. Likewise, soil available S content under the 80% MHW treatment was 706.05 mg/kg and more higher than other treatments. Compared with control soil available S content decreased significantly 33.7%, 19.4% and 50.4% under the 60% MHW, 100% MHW and FW treatments. The result showed the flooding treatment could reduce soil available S. Once field drying treatment, soil available S would increase due to S forms affected by moisture-driven soil oxidation status (Wu et al. 2019).

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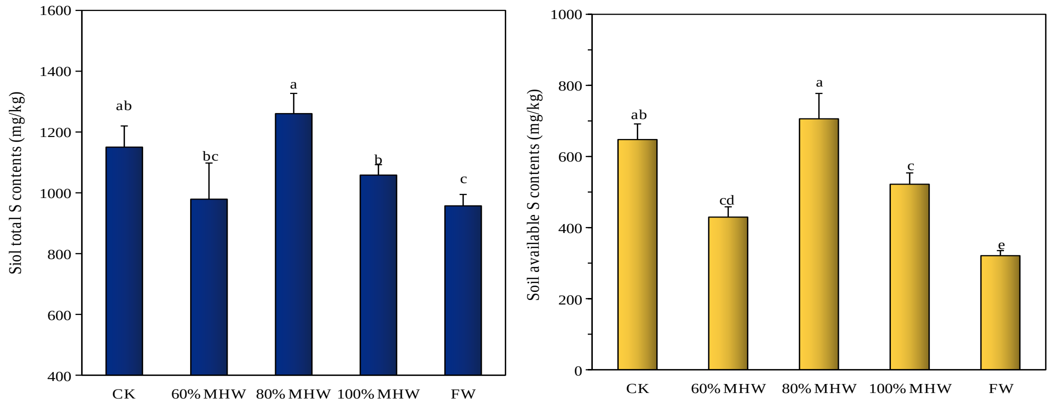

Fig 2: Soil total S and available S contents under different water holding capacity treatments.

3. Effect of water holding capacity on S, Cd, As uptake by rice

Figure. 3 show the S, Cd, As contents in rice organs. The order of S content in different rice organs. The 60% MHW treatment increased rice root S contents compared to the control group, whereas the 100% MHW treatment decreased straw S contents. Rice grain S contents no significant change. However, under the flooding treatment rice grain S contents was higher than the 60% MHW and 100% MHW treatments.

The water holding capacity treatment affected Cd and As accumulation in rice. In root, straw and rice grain Cd contents were 0.60 – 2.63, 0.32 – 3.15 and 0.28 – 0.75 mg/kg, respectively. The order of Cd contents in root and straw was: 80% MHW > 60% MHW > 100% MHW > CK > FW. Compared with CK, FW treatment reduced Cd contents in roots, whereas that increased Cd contents under 60% MHW, 80% MHW and 100% MHW treatments. In contrast, compared with CK, rice root As contents reduced 70.6%, 67.9% and 49.2% under 60% MHW, 80% MHW and 100% MHW treatments, respectively, that in flooding treatment increased by 54.0%. The changes of rice straw Cd and As contents were consistent with that rice root. Under FW treatment rice grain Cd content reduced by 26.0% compared with conventional irrigation treatment, whereas As content increased by 104.9%. Under 80% MHW and 100% MHW treatments rice grain Cd contents increased by 95.0% and 22.5%, and As reduced by 66.3% and 32.5%, respectively.

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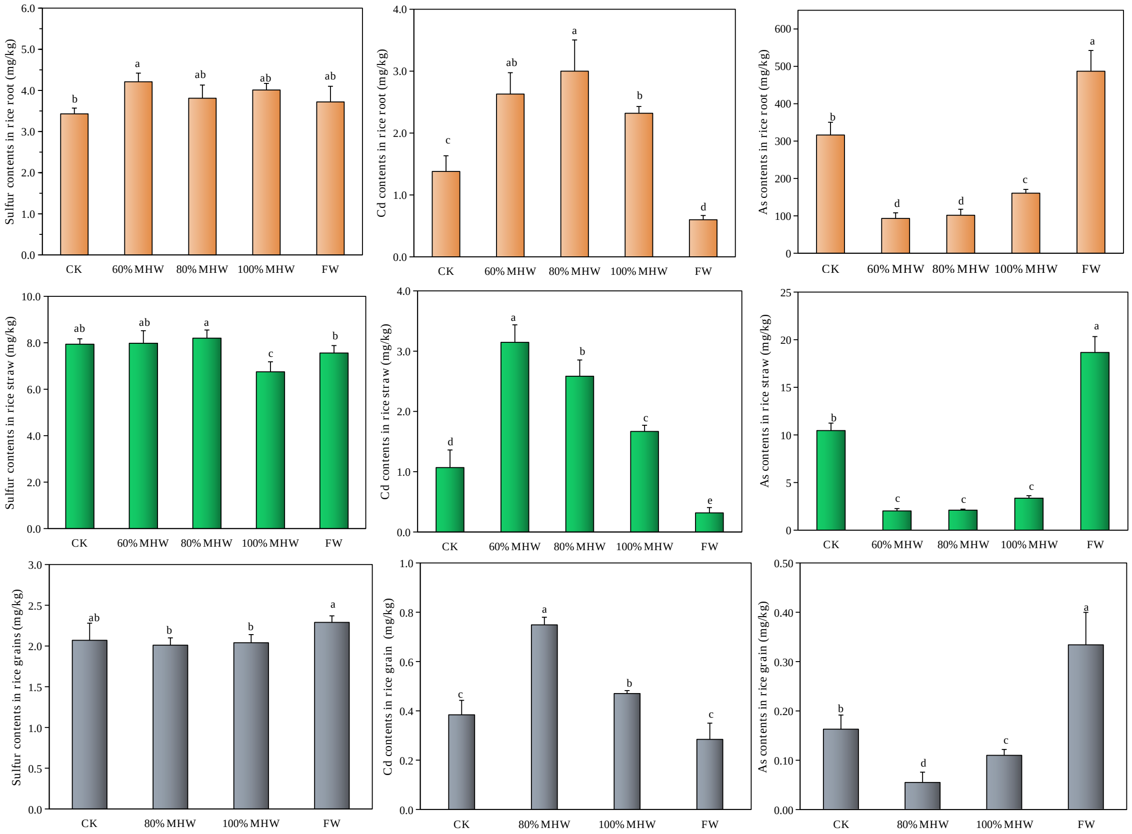

Fig. 3: The concentration of S, Cd and As in rice organs under different water holding capacity treatments.

Plant uptake factor (PUF) were the ratio of potentially toxic element content in edible part to the soil content. Transport factor (TF) refered to the ratio of potentially toxic element content in latter part the plant to that in the former part. PUF and TF were used to estimate the transfer of potentially toxic element. PUF-S and PUF-As values were increased with increasing soil moisture, whereas PUF-Cd values were decreased in Table 2. Similarly, except the TFr-s-S under the flooding treatment, TFr-s showed the same changing trend with PUF (Table 2). Low moisture treatment, such as 80% MHW treatment, could decrease the transportation of S and Cd content from straw to brown rice whereas the transport of As content was increased with increasing soil moisture.

Table 2: The PUF and TF coefficients of Cd and As in rice plants

Treatment	PUF			$TF_{r\text{-}s}$			$TF_{s\text{-}g}$		
	S	Cd	As	S	Cd	As	S	Cd	As
CK	0.00274	1.29	0.00142	2.31	0.775	0.0331	0.261	0.359	0.0156
60%MHW	-	-	-	1.90	1.20	0.0217	-	-	-
80%MHW	0.00267	2.52	0.000479	2.15	0.861	0.0207	0.245	0.290	0.0262
MHW	0.00271	1.59	0.000958	1.68	0.719	0.0209	0.302	0.282	0.0328
FW	0.00304	0.96	0.00291	2.03	0.528	0.0383	0.303	0.897	0.0179

The change of Cd and As contents in rice organs was consistent with soil moisture and the soil S and available S content (Fig. 2 and Fig. 3), indicating that the transport of Cd and As in rice were affected by water holding capacity and S content. Previous research reported that As content in grains of rice increased

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while Cd content decreased from intermittent irrigation to constantly flooding (Hu et al. 2015). Li et al. (2017) also found that compared to traditional irrigation, the Cd content reduced by 37.9% in brown rice under flooding treatment, whereas increased by 31.0% under wetting irrigation. Yang et al. (2019) reported that brown rice As contents under alternate wetting and drying treatments were 43.3%-85.0% lower than continuous flooding. Moreover, S element for inhibiting the translocation of heavy metal in rice plant had also been reported (Liu et al. 2020; Cao et al. 2020). The results might contribute to the reasons as follows: Firstly, the iron plaque of rice root in anaerobic environment prevented the As and Cd uptake by rcie from soil; On the other hand, the S content might decreased the expression of OsLsi1, OsLsi2a or OsHMA3 while promoted the production of thiol-containing glutathione or phytochelatins, which are responsible for the transport of heavy metal in plants (Liu, et al. 2020).

In conclusion, compared with other water holding capacity treatments, flooding treatment could reduce Cd content in rice, whereas that might result in higher As content. However, of the five water holding capacities, traditional irrigation could maintain lower Cd and As content in rice grain than other treatments.

4. Principal Component Analysis

The 23 indicators were reduced to four main components, which variance contribution rates were 76.2%, 21.5%, 0.02% and 0.01%. The variance contribution rate of PC1 and PC2 was 97.7%, reflecting the eigenvalues well (Fig. 4). Furthermore, the treatments representing the CK, 100%MHW and FW treatments changed along the PC1 axis in Fig. 4. The indicators closely related to the PC1 axis were the straw-Cd, PUF-As and rice grain-As, respectively, indicating that the impact of soil moisture was significant. The indicator consistent with soil moisture condition changes were soil pH and root-Cd, suggesting that there was large variation of soil pH and root-Cd with the changes of soil moisture. Furthermore, between soil pH and root Cd content was a significant negative correlation. Likewise, along the PC2 axis the CK treatment occurred deviation, significantly. the PUF-Cd and grain-Cd were closely related with the PC2, indicating that the CK treatment played an important role for the PUF-Cd and grain-Cd indicators. Moreover, the change of soil As in the indices was most opposite trends of the affected CK treatment, which further shows the influence of the treatment.

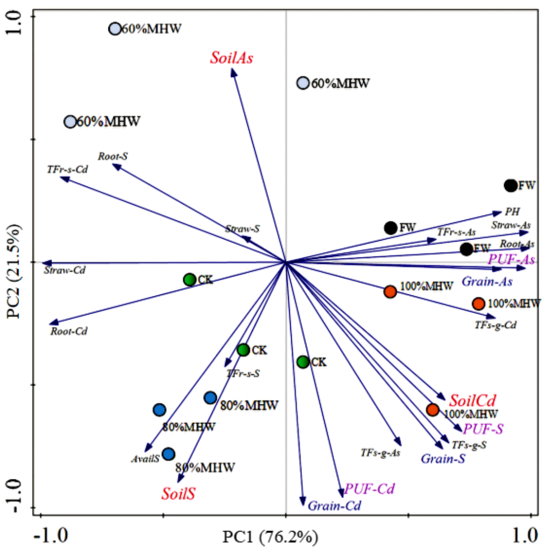

Fig. 4: The first two PCA axes based on the effect of water holding capacity on S, Cd, As in soil and rice.

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There was a positive association between soil total S, available S, and grain Cd (Fig. 4). When it came to the connections between soil S and accessible S and rice Cd content, the association between available S and Cd content in rice root and straw was substantially greater. Conversely, soil total S and available S were a significant negative correlation with As contents in rice organs. Similarly, the S contents in root and straw were positive correlation with the transport of Cd, whereas As content showed the reverse trend (Fig. 4). But, the S was positively related with both Cd and As in grain, which indicating that the grain S might promote transport of Cd and As of rice grain. The result was consistent with the changes of S, Cd and As contents in rice organs. However, the transport process of Cd and As in rice was complex and the specific mechanism needed further study.

IV. CONCLUSION

In this work, we investigated that soil pH increased with the increasing water holding capacity, while soil total sulfur and available sulfur gradually decreased. Water holding capacity significantly affected Cd and As contents of rice grain but in opposite directions in polymetallic sulphides mining soil.The rice grain Cd content reduced significantly by 26.0% under Flooding during the whole growth stages treatment reduced, whereas As content increased by 104.9%. The reason may be related to the S, As and Cd translocation in rice by PCA. Further research was required to elucidate the mechanisms. Moreover, compared with other water holding capacity treatments, flooding treatment could reduce Cd content in rice, whereas that might result in higher As content. Of the five water holding capacities, conventional irrigation could maintain low Cd and As content in rice grain.

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