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# Effects of Soil Water Management on Cadmium Concentration of Rice Grain

**Xuanhua Zhang, Kaiqiang Chu, Rongyan Shen, Jianguo Liu***

School of Environmental & Safety Engineering, Changzhou University, Changzhou, China

## Abstract

In order to investigate the effects of soil water control on grain Cd accumulation and grain yield of rice, soil water management regimes of slight dryness at different stages of rice growth were designed, and two rice cultivars with different Cd accumulation properties were used in this study. The results indicate that the grain Cd concentrations were increased significantly ($P < 0.05$) by slight soil dryness at grain filling stage, compared to the control (well-watered soil), with the increasing rates of 12.82% - 118.18%. But the grain yields were influenced little. For the slight dryness at panicle formation stage, the grain Cd concentrations decreased significantly ($P < 0.05$) with the decreasing rates of 27.27% - 53.85%, but the grain yields did not change significantly ($P > 0.05$). Under slight dryness during whole growth period of rice and at tillering stage, the grain Cd concentrations reduced significantly ($P < 0.05$) for the cultivar Yangdao 6, but changed little for Yu 44. And the grain yields of the two cultivars decreased significantly ($P < 0.05$). Therefore, with the combined consideration of grain Cd concentration (the principal control factor) and grain yield, the soil water management of slight dryness at panicle forming stage is the best choice for soil Cd-polluted areas.

## Keywords

Rice (*Oryza sativa* L.), Cadmium (Cd), Water Management, Grain, Yield

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## 1. Introduction

Owing to fast development of industry and economy, and rapid increase of population in recent decades, heavy metal pollution in agricultural soils has been becoming increasingly serious and widespread in many countries, including China [1]. The safety of crops grown in the polluted area is raising public concerns, specifically for rice production [2, 3].

Of the heavy metals, cadmium (Cd) is one of the most toxic metals for animals and plants [4]. It can be absorbed via the alimentary tract, penetrates through placenta during pregnancy, and damages membranes and DNA [5]. Cd is also one of the most important pollutants to be considered in terms of food-chain contamination, because it is readily taken up by plant and transferred into different plant organs, especially into human food organs [6]. Therefore, Cd accumulation in the environment and the further transport to human food chains is hazardous to humankind. It was presented that the food crops grown around mines would be probably polluted by heavy metals (specifically Cd and Pb), and will posed a great risk to the health of local residents by consuming contaminated crops and vegetables [7].

The sources of Cd emission into the environment are mainly as follows: metal-working industries, power stations, urban traffic, heating systems, waste incinerators, cement factories, and the application of phosphate fertilizers in agricultural soils [8-10]. Heavily contaminated soils with Cd concentrations of exceeding 100 mg/kg even were reported in France, China and other countries [11].

In general, metal mobility and availability in soil are the

* Corresponding author
E-mail address: liujianguo@cczu.edu.cn (Jianguo Liu)

important factors that determine metal absorption by plant root and the transfer into other organs. It was reported that soil water conditions would influence soil physical and chemical properties, specifically the oxidation-reduction status. As a result, the mobility and availability of metals in the soil would be changed, and metal uptake by plant root and translocation in the plant will be affected [12, 13].

Paddy rice is one of the most important crops in the world, especially in Asia. Former study indicated that controlling Cd level in rice food was very important because some health hazards have been proved associating with high Cd concentrations in rice diet [14]. However, the relationships between soil water condition and Cd accumulation in rice grain, and how to reduce Cd concentration in rice grain through soil water management are poorly understood. Based on our previous studies [15, 16], two rice cultivars with different Cd accumulation abilities were used in this experiment. The aims were to investigate: 1) Effects of soil water management regimes on grain yield in Cd-polluted soils; 2); Effects of soil water management regimes on grain Cd concentrations in Cd-polluted soils. The results will be useful for controlling Cd level in rice diet in soil Cd contamination areas.

# 2. Materials and Methods

## 2.1. Soil Preparation

The experiments were performed as a pot trial. The soil used was collected from an uncontaminated field (0-20 cm). After air-drying and passing through a 2 mm sieve, some properties were tested. The selected properties of the soil are presented in Table 1. Four kilograms of the soil was placed in each pot (18 cm in diameter and 20 cm in height).

## 2.2. Rice Plant Materials

Based on our previous studies [15, 16], two rice cultivars of different genotypes with variable Cd accumulation abilities were used in this experiment, and they are Yangdao 6 (indica, a high grain Cd accumulator) and Yu 44 (japonica, a low grain Cd accumulator). Rice seeds were submerged in a water bath for about 48 h at room temperature (20-25°C) and germinated under moist condition for another 30 h. The germinated seeds were grown in uncontaminated soil for 30 days, and then the seedlings were transplanted into the pots (3 plants per pot).

**Table 1.** Selected Properties and Cd Concentration of the Soil Used.

| Soil Type | Particle Size (g/kg) | | | pH | OM (g/kg) | CEC (cmol/kg) | Cd Concentration (mg/kg) |
|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | |
| Paddy Soil | 537.1 | 249.5 | 213.4 | 7.3 | 26.4 | 14.7 | 0.17 |

Notes: OM, organic matter; CEC, cation exchange capacity.

## 2.3. Experimental Design

Two levels of soil Cd was designed, e.g. 5 and 10 mg/kg (dry weight). The solution of $CdCl_2$ was added to the soil to obtain the Cd levels. The Cd-treated soils were stored in pots and submerged in water (2-3 cm above the soil surface) for a month before rice seedlings were transplanted.

Two levels of soil water condition were designed: 1. well-watered, the soil was flooded with 2-3 cm water layer; 2. slight dryness, the soil water was drained and allowed to decrease gradually till the soil becomes slightly dry (soil surface becomes slightly hard, but no obvious crack), and then the soil was watered to saturation (but no obvious water layer) and let to try to slight dryness, and so on.

Combining soil water levels and treating times, six soil water management regimes were designed, and they are: A, well-watered during the whole growth period of rice (served as the control); B, slight dryness during the rice growth period (from 5th day after seedling transplant to grain maturity); C, slight dryness at rice tillering stage (from 5th day to 40th day after seedling transplant), well-watered in other times; D, slight dryness at panicle formation stage (from 41st day after seedling transplant to panicle heading), well-watered in other times; E, slight dryness at earlier stage of grain filling (from panicle heading to 20th day after panicle heading), well-watered in other times; F, slight dryness at later stage of grain filling (from 21st day after panicle heading to grain maturity), well-watered in other times.

The experiments were carried out under open-air condition. The pots were arranged in a randomized complete block design with three replicates.

## 2.4. Sample Preparation and Analytical Methods

Rice grains were harvested at maturity, and oven-dried at 70°C to a constant weight. The grain yield for each pot was weighed. Then, the dry grain samples were ground with a stainless steel grinder to pass through a 100-mesh sieve. Cd concentrations of the grain samples were determined with AAS.

Data were analyzed with the statistical package SPSS 16.0. Means were compared through one-way ANOVA using Tukey's test at $P < 0.05$.

# 3. Results and Discussion

## 3.1. Effects of Soil Water Managements on Grain Yield of Rice

There were significant differences ($P < 0.05$) among the soil water management regimes in grain yields of the rice cultivars (Table 2). Compared to the control (soil water management regime A, well-watered during whole growth period), the soil water deficiencies at different stages had different effects on grain yields.

**Table 2.** Rice grain yields of different soil water management regimes (g/pot).

| Soil water management regimes | Soil Cd concentration 5 mg/kg | | Soil Cd concentration 10 mg/kg | |
|---|---|---|---|---|
| | Yangdao 6 | Yu 44 | Yangdao 6 | Yu 44 |
| A (control) | 44.77 ab | 35.28 a | 45.86 a | 35.88 a |
| B | 29.18 d | 26.39 c | 29.71 c | 26.71 c |
| C | 34.70 c | 29.04 b | 35.27 b | 29.15 b |
| D | 42.64 b | 34.36 a | 43.58 a | 34.42 a |
| E | 45.33 ab | 34.92 a | 45.48 a | 35.57 a |
| F | 46.25 a | 34.74 a | 45.69 a | 35.25 a |

Notes: Different letters in a column indicate significant differences ($P < 0.05$) between the data.

The grain yields were mostly and significantly ($P < 0.05$) reduced by water management regime B (slight dryness during the rice growth period), and the decreasing rates ranged from 25.20% to 35.22%. The grain yields were also decreased by water management regime C (slight dryness at tillering stage) significantly ($P < 0.05$), and the reducing rates were 17.69% - 23.09%. But the grain yields were little and insignificantly ($P > 0.05$) influenced by water management regime E (slight dryness at earlier stage of grain filling) and F (slight dryness at later stage of grain filling), and the changing rates were -0.83% -- 3.31%. The grain yields of water management regime D (slight dryness at panicle formation stage) reduced somewhat but insignificantly ($P > 0.05$), and the decreasing rates were 2.61% - 4.97%.

It was presented that short-term water management at early filling stage changed rice performance [17]. He and Serraj reported that the grain yield of rice was reduced by 80% by drought-stressed treatment at 10-15 days before heading, compared to that of well-watered condition. The inhibitation of peduncle elongation under water stress was the key parameter that affected rice grain yield [18]. In soil intermittent drought treatment, the reduction rate of 23%-33% in rice grain yield was also reported by Monkham et al. [19]. Water stress at reproductive stage of rice growth may lead to evapotranspiration reduction, and it further resulted in grain yield reduction [20].

Our present study showed that soil slight dryness treatment at different stage of rice growth had different effects on grain yield. Compared to well-watered condition (the control), the grain yields were reduced significantly ($P < 0.05$) by the slight drought during the whole growth period and at tillering stage. But the grain yields were influenced little by the slight drought at grain filling stage. The grain yields were decreased somewhat but insignificantly ($P > 0.05$) by the slight drought at panicle formation stage.

## 3.2. Effects of Soil Water Managements on Cadmium Concentrations of Rice Grain

Effects of soil water managements on grain Cd concentrations differed greatly with water managements, soil Cd levels and the cultivars.

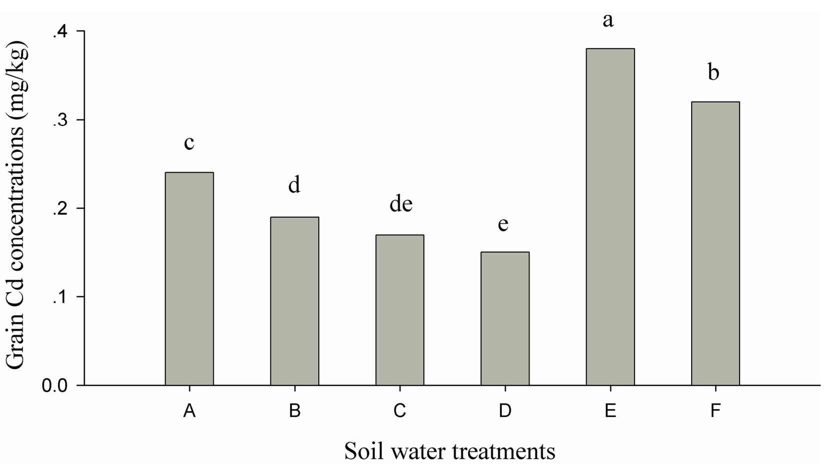


**Figure 1.** Effects of Soil Water Treatments on Grain Cd Concentrations of Yangdao 6 under Soil Cd Level of 5 mg/kg Different Letters Indicate Significant Differences ($P < 0.05$) between the Soil Water Treatments.

Under soil Cd level of 5 mg/kg, the grain Cd concentrations of Yangdao 6 were significantly ($P < 0.05$) raised by water management regimes E and F, compared to the control, and the increasing rates were 58.33% and 33.33% respectively (Figure 1). But they were significantly ($P < 0.05$) decreased by water management regimes B, C and D, and the decreasing rates were 20.83%, 29.17% and 37.50% respectively. The grain Cd concentrations of Yu 44 were also increased by water management regimes E and F significantly ($P < 0.05$), and the increasing rates were 88.89% and 44.44% respectively (Figure 2). The grain Cd concentration of Yu 44 was also reduced by water management regime D significantly ($P < 0.05$), and the decreasing rate was 33.33%. But the grain Cd concentrations of Yu 44 were little and insignificantly ($P > 0.05$) influenced by the water management regimes B and C.

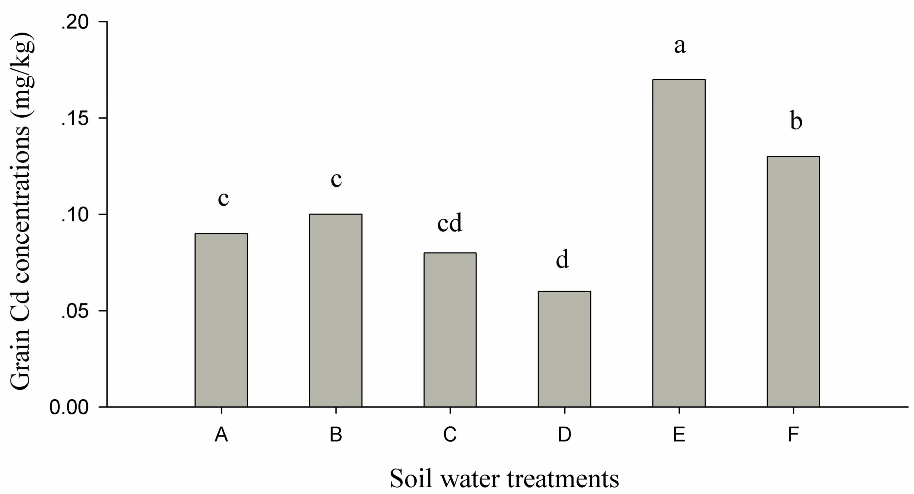


**Figure 2.** Effects of Soil Water Treatments on Grain Cd Concentrations of Yu 44 under Soil Cd Level of 5 mg/kg Different Letters Indicate Significant Differences ($P < 0.05$) between the Soil Water Treatments.

Under soil Cd level of 10 mg/kg, the grain Cd concentrations of Yangdao 6 were elevated significantly ($P < 0.05$) by water management regimes E and F, and the increasing rates were 43.59% and 12.82%, but reduced by water management regimes B, C and D significantly ($P < 0.05$) with the decreasing rates of 33.33%, 41.03% and 53.85% respectively (Figure 3). The grain Cd concentrations of Yu 44 were also increased significantly ($P < 0.05$) by water management regimes E and F with the increasing rates of 118.18% and 63.64% (Figure 4). The grain Cd concentration of Yu 44 was also decreased significantly ($P < 0.05$) by water management regime D with the decreasing rate of 27.27%. But the grain Cd concentrations of Yu 44 were influenced little and insignificantly ($P > 0.05$) by the water management regimes B and C.

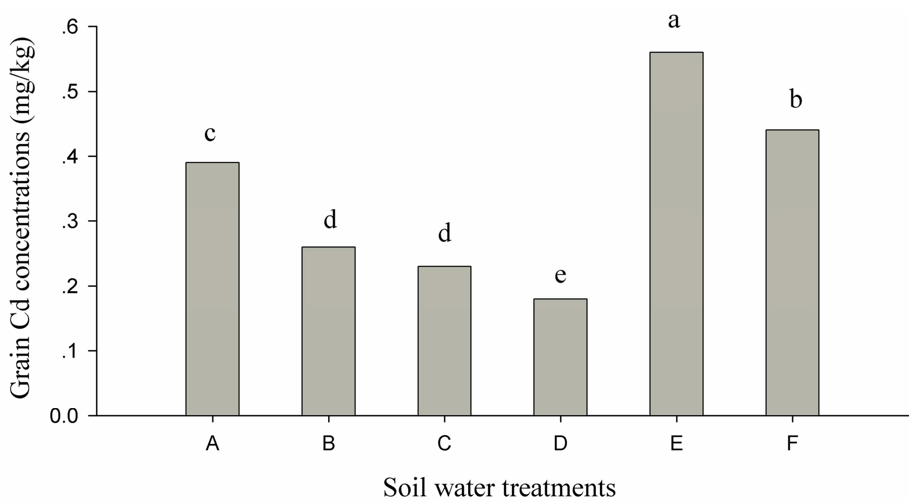


**Figure 3.** Effects of Soil Water Treatments on Grain Cd Concentrations of Yangdao 6 under Soil Cd Level of 10 mg/kg Different Letters Indicate Significant Differences ($P < 0.05$) between the Soil Water Treatments.

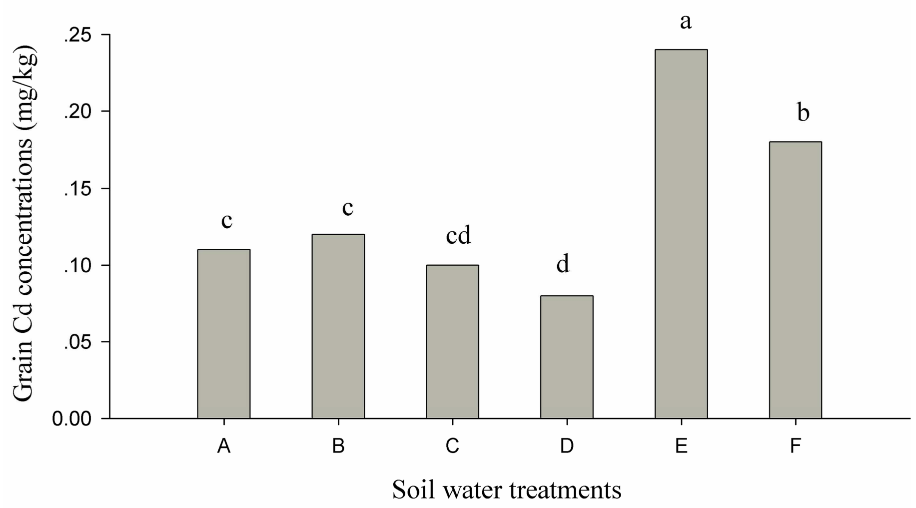


**Figure 4.** Effects of Soil Water Treatments on Grain Cd Concentrations of Yu 44 under Soil Cd Level of 10 mg/kg Different Letters Indicate Significant Differences ($P < 0.05$) between the Soil Water Treatments.

It was reported that soil redox condition is one of the important factors that affect chemical forms of heavy metals in the soil. Heavy metals present mostly as sulphide-bound species in reduction state (Eh -150 mV), but exist mainly in exchangeable and oxide-bound species in oxidation state (Eh 100 mV) [21]. Heavy metal uptake by plant roots and translocation within plants are greatly influenced by the chemical forms, mobility, solubility and bio-availability of the metals in the soil [22, 23]. Flooding before and after heading is effective for reducing Cd uptake by rice [24]. It was presented that arsenic concentrations were reduced by 23.33%, 13.84% and 19.84% in root, shoot and leaf respectively by intermittent ponding at panicle initiation stage, compared to continuous ponding. Arsenic accumulation by plants could be reduced by effective management of irrigation water [25]. Alternate wetting and drying reduced Pb concentrations in the grains up to 37% - 52% in fragrant rice cultivars [26]. Therefore, metal absorption by rice root from soil and the translocation from root to other organs could be controlled by soil water management.

Our present research indicates that grain Cd concentrations of rice were raised largely and significantly ($P < 0.05$) by soil slight dryness at grain filling stage (the water management regimes E and F), compared to the control (water management regime A), but reduced largely and significantly ($P < 0.05$) by soil slight dryness at panicle forming stage (water management regime D), irrespective of the rice cultivars and soil Cd levels. Under the soil water treatments of slight dryness during the whole growth period and at tillering stage (water management regimes B and C), the grain Cd concentrations decreased significantly ($P < 0.05$) for the rice cultivar Yangdao 6, but changed little and insignificantly ($P > 0.05$) for the cultivar Yu 44.

# 4. Conclusion

The soil water managements of slight dryness at different stages of rice growth had different effects on grain yields and grain Cd concentrations, and the effects were greater on grain Cd concentrations than on grain yields. The effects also varied with rice cultivars and soil Cd levels. Under soil water management of slight dryness at grain filling stage, the grain Cd concentrations increased largely and significantly ($P < 0.05$), but the grain yields changed little. Under soil water management of slight dryness at panicle formation stage, the grain Cd concentrations decreased highly and significantly ($P < 0.05$), and the grain yields reduced a little but insignificantly ($P > 0.05$). For the soil water management of slight dryness during whole growth period of rice and at tillering stage, the grain Cd concentrations reduced significantly ($P < 0.05$) for the cultivar Yangdao 6, but changed little for Yu 44. The grain yields decreased significantly ($P < 0.05$) for the two cultivars.

With the combined consideration of grain yields and grain Cd concentrations (the principal control factor) of rice, the soil water management regime of slight dryness at panicle forming stage is the best choice for soil Cd-polluted areas. The soil water management could reduce grain Cd concentration significantly, and has no significant influence on grain yield.

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