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RESEARCH ARTICLE

Effects of long-term fertilization practices on heavy metal cadmium accumulation in the surface soil and rice plants of double-cropping rice system in Southern China

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Abstract

Fertilizer regime is playing an important role in heavy metal cadmium (Cd) accumulation in paddy soils and crop plant. It is necessary to assess the Cd accumulation in soils and rice (*Oryza sativa* L.) plants under long-term fertilization managements, and the results which help to assess the environmental and food risk in Southern China. However, the effects of different organic manure and chemical fertilizers on Cd accumulation in soils and rice plant remain unclear under intensively cultivated rice conditions. Therefore, the objective was to explore Cd accumulation in paddy soils and rice plant at mature stage under different long-term fertilization managements in the double-cropping rice system. Cd accumulation in the surface soils (0–20 cm) and rice plant with chemical fertilizer alone (MF), rice straw residue and chemical fertilizer (RF), 30% organic matter and 70% chemical fertilizer (LOM), 60% organic matter and 40% chemical fertilizer (HOM), and without fertilizer input (CK) basis on 32 years long-term fertilization experiment were analyzed. The results showed that the soil total Cd content was increased by 0.296 and 0.351 mg kg^{-1} and 0.261 and 0.340 mg kg^{-1} under LOM and HOM treatments at early and late rice mature stages, respectively, compared with the CK treatment. And the soil available Cd content was increased by 0.073 and 0.137 mg kg^{-1} and 0.102 and 0.160 mg kg^{-1} under LOM and HOM treatments at early and late rice mature stages, respectively, compared with the CK treatment. The bioconcentration factor of Cd across different parts of rice plant was the highest in root, followed by stem and grain, and the lowest in leaves. At early and late rice mature stages, the root Cd concentration of rice plant was increased by 0.689 and 0.608 mg kg^{-1} with HOM treatment, the stem Cd concentration of rice plant was increased by 0.666 and 0.758 mg kg^{-1} with RF treatment, and the leaf and grain Cd concentration of rice plant was increased 0.094 and 0.082 mg kg^{-1} and 0.086 and 0.083 mg kg^{-1} with LOM treatment, respectively, compared with the CK treatment. The soil Cd single-factor contaminant index (P_{Cd}) under different fertilization treatments was as the following HOM > LOM > RF > MF > CK. Meanwhile, the P_{Cd} with LOM and HOM treatments was higher than that of the MF, RF, and CK treatments, but there is no significant difference between that of MF and RF treatments. Therefore, long-term application of rice straw residue and chemical fertilizer had no obvious effect on the accumulation of Cd in paddy soils and grain, and soil Cd accumulation was increased as application of organic fertilizer.

Keywords Rice · Long-term fertilization · Heavy metal Cd · Paddy soil

Introduction

Fertilizer plays an important role in maintaining yield of crops, improving crop quality and soil quality (Duan et al. 2012). In recent years, the quality of soil environment and safety of agricultural products has attracted more attention from public concern along with the increasing amount of fertilizer (Jiao et al. 2012). During the stage of rice production, the application of fertilizers not only supplies nutrients for crops growth but also contains some toxic and harmful substances, such as heavy metal cadmium (Cd).

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Therefore, there is a close relationship between fertilization managements and accumulation of heavy metals in soils and crops (Uprety et al. 2009).

Cd is a common environmental pollutant, and a high soil Cd content would cause negative effect on animal or human health through the food chain (Schutze et al. 2003; Grant and Sheppard 2008). Some studies showed that the content of Cd in soil was influenced by many agricultural measures, such as soil tillage, cropping system, irrigation, and fertilizer regime (Schutze et al. 2003; Grant and Sheppard 2008; Mar et al. 2012). Among all of these agricultural practices, fertilizer is the key factor that affecting soil Cd content and accumulation in crops and soil (Casova et al. 2009). Mar et al. (2012) found that the application of phosphate (P) fertilizers containing Cd is a main source of Cd accumulation in paddy soils.

Previous studies showed that application of different fertilizer regimes, amounts, and kinds of fertilizer not only affected Cd accumulations in soil, but also resulted in changes on Cd concentration in crops (Zheng et al. 2015; Grüter et al. 2017). Ociepa (2011) reported that the Cd content in soil was increased by application of organic manure and was decreased by application of potassium (K) fertilizers in a long-term experiment. Selles et al. (2003) showed that the total and available Cd contents in soil were increased by application of chemical fertilizer, and the Cd uptake by crops was promoted. Duan et al. (2011) indicated that the Cd accumulation in grains of rice with organic matter treatment was higher than that with no organic matter input treatment. Wang et al. (2016) found that the Cd concentration in wheat straw and grains was increased, which depended on the kinds of manure applied. However, some researchers observed fertilizer regime did not affect Cd accumulation in wheat straw and grains after manure or compost application (Hamner and Kirchmann 2015; Tlustoš et al. 2016). Zheng et al. (2015) found that rice straw biochars reduced paddy soil Cd hazard quotients from 5.5 to 1.6. Bolan et al. (2003) showed that paddy field soils were at risk of pollution with application of excessive quantities of manure in a long-term condition.

The double-cropping rice system is one of the most important systems for crop production in China. In double-cropping rice production region, it is a traditional custom to apply organic manure as the main material source in rice production (Zhang and He 2004). In recent years, it was widely accepted that the combination of application on both rice straw residue and chemical fertilizer in rice production could enhance the paddy soil quality (Lal 2002), as the practice of rice residue returning to the paddy field is another vital nutrient source for rice production (Li et al. 2008). Compared with the application of chemical fertilizer alone, the application of manure or straw with chemical fertilizer is beneficial for maintaining both soil quality and grain yields (Blair et al. 2006). However, the fertilizer regime was changed in recent years, the application of chemical fertilizer was increased, and the application of organic fertilizer was decreased in rice production. Therefore, the paddy soil quality was affected under a changing fertilizer regime condition, such as the soil organic matter (SOM) content and soil microbial diversity and community (Du et al. 2009; Zhen et al. 2014).

The double-cropping rice production system is the main crop rotation in Southern China, and the fertilizer regime is very important for sustaining the rice production and paddy agroecosystems. Some researchers found that the continuous fertilizer application is an important source for potential threat of Cd accumulation in soils and crops (Xu et al. 2017). However, the impacts of long-term fertilization on Cd accumulation in paddy soils and Cd uptake by crop plant in double-cropping rice system are not well settled. We hypothesized that the accumulation of Cd in paddy soils and rice plant would have different accumulation characteristics with different fertilizer regimes after long-term fertilization. It is necessary to assess the changes of Cd accumulation in soil and plant under long-term fertilization managements, which would help to assess the environmental and food risk. Therefore, the objective of the present research was to explore the Cd accumulation in paddy soils and rice plant with different long-term fertilization managements in the double-cropping rice system.

Materials and methods

Experimental site

The long-term experiment was begun in 1986. It was located in NingXiang County (28° 07′ N, 112° 18′ E) of Hunan Province, China. Under a continental monsoon climate, the annual mean precipitation is 1553 mm and potential evapotranspiration is 1354 mm. The monthly mean temperature is 17.2 °C. The soil type is Fe–accumuli–Stagnic Anthrosol derived from Quaternary red clay (clay loam). Soil texture in the plow layer (0–20 cm) was silt clay loam with 13.71% sand and 57.73% silt. The climatic conditions of the experiment field, the physical and chemical properties of surface soil, and crop rotation systems were the same as described by Tang et al. (2016). There were three crops in a year, barley (*Hordeum vulgare* L.), early rice, and late rice (*Oryza sativa* L.). Barley was sown in the middle of November and harvested in early May of the following year. Early rice was then transplanted and harvested in the middle of July. The growing season of late transplanted rice lasted from late July to the end of October.

Experimental design

The experiment included five treatments: control (without fertilizer input, CK); chemical fertilizer alone (MF); rice straw residue and chemical fertilizer (RF); 30% organic matter and

70% chemical fertilizer (LOM); and 60% organic matter and 40% chemical fertilizer (HOM). A randomized block design was adopted in the plots, with three replications. And each plot size was 66.7 m^2 (10 m × 6.67 m). The total amounts of N, phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) were set to the same level across each fertilization treatment during the early and late rice growing seasons, respectively. The experiment ensured the same amounts of N, phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O) for all fertilization treatments during early and late rice growing seasons, respectively (Table 1). The barley variety Tong 0612 was used as the material in 2016–2017, and early rice variety (*Oryza sativa* L.) Xiangzaoxian 45 and late rice variety Yueyou 9113 were used as the materials in 2017. Detailed information about the fertilization managements and farming arrangements can be found in Tang et al. (2016).

Soil and plant tissue sampling

Soil samples were collected at the plow layer (0–20 cm) at mature stage for early and late rice in 2017, respectively. Three soil samples were taken from each plot at mature stage of early and late rice. The soil samples were air-dried and ground to pass through a 2-mm sieve, and stored in glass jars at room temperature until the measurement of soil properties. Root at soil depth of 0–20 cm, stem, leaf, and grain of the rice plants were collected at mature stage of early and late rice in 2017, respectively. Plant samples were rinsed with deionized water and dried at 75 °C for analyses.

Soil and plant tissue sample analysis

The physical and chemical properties of soil such as soil pH, soil organic carbon (SOC) content, total N, P, and K, available N, P, and K were analyzed according to Lu (2000). Soil and plant samples were ground to a size finer than 0.15 mm before determining the soil total Cd concentration (Lu 2000). And the soil available Cd concentration was determined using 0.005 M DTPA extracting solution (Soltanpour and Schwab 1977).

Data analysis

Bioconcentration factor

The bioconcentration factor (BCF) of Cd was calculated using the following formula:

$$\mathrm{BCF} = \mathrm{Cd\ concentration\ in\ plant\ tissues}\ \left(\mathrm{mg\ kg^{-1}}\right)\ \mathrm{at\ harvest/soil\ total\ Cd\ content}\ \left(\mathrm{mg\ kg^{-1}}\right)$$

Soil Cd single factor contaminant index

To assess the contamination level of Cd in the experiment area, soil Cd single-factor contaminant index (P_{Cd}) was calculated using the following formula (Zhang et al. 2011):

$$P_{Cd} = \mathrm{C_{Cd}}/\mathrm{S_{Cd}}$$

Where P_{Cd} is soil Cd single-factor contaminant index, C_{Cd} is the soil total Cd concentration (mg kg^{-1}), S_{Cd} is soil standardized values of Cd, and $S_{Cd} = 0.3$ mg kg^{-1}, the soil pH < 6.50 (Environmental quality standard for agricultural soils of China, GB15618-1995), $P_{Cd} < 1$ indicates no pollution, $1 < P_{Cd} < 2$ indicates slight pollution, $2 < P_{Cd} < 3$ indicates moderate pollution, and $P_{Cd} > 3$ indicates high pollution.

Table 1 Nutrient supply from rice straw, chicken manure, and chemical fertilizer under different fertilization treatments

Treatments	Early rice			Late rice			Total		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
CK	0 + 0*	0 + 0	0 + 0	0 + 0	0 + 0	0 + 0	0	0	0
MF	142.5 + 0	54.0 + 0	63.0 + 0	157.5 + 0	43.2 + 0	81.0 + 0	300.0	97.2	144.0
RF	124.4 + 18.1	50.4 + 3.6	38.3 + 24.7	133.0 + 24.5	37.8 + 5.4	48.2 + 32.8	300.0	97.2	144.0
LOM	96.0 + 46.5	33.0 + 21.0	33.6 + 29.4	110.2 + 47.3	21.8 + 21.4	51.1 + 29.9	300.0	97.2	144.0
HOM	49.6 + 92.9	12.0 + 42.0	4.2 + 58.8	63.0 + 94.5	0.5 + 42.7	21.2 + 59.8	300.0	97.2	144.0

The N, P, and K contents of air-dry early rice straw were 6.5, 1.3, and 8.9 g kg^{-1}. N, P, and K contents of air-dried late rice straw were 6.8, 1.5, and 9.1 g kg^{-1}, respectively. N, P, and K contents of decomposed chicken manure were 17.7, 8.0, and 11.2 g kg^{-1}, respectively. The cadmium concentrations in the chemical fertilizer, rice straw residue, and organic matter were 1.8, 0.63, and 0.55 mg kg^{-1}. For the RF treatment, rice straw return rate (air dry) was 2780 and 3600 kg hm^{-2} for early and late rice. For the LOM treatment, chicken manure application rate (decomposed) was 2625.0 and 2670.0 kg hm^{-2} for early and late rice. For the HOM treatment, chicken manure application rate (decomposed) was 5250.0 and 5340.0 kg hm^{-2} for early and late rice

N, nitrogen; *P_2O_5*, phosphorus pentoxide; *K_2O*, potassium oxide; *MF*, chemical fertilizer alone; *RF*, rice straw residue and chemical fertilizer; *LOM*, 30% organic matter and 70% chemical fertilizer; *HOM*, 60% organic matter and 40% chemical fertilizer; *CK*, without fertilizer input

*Input from chemical fertilizer + input from rice straw residue or organic manure. The numbers are in kg hm^{-2}

The results of every measured item were presented by average value and standard error. And analysis of variance (ANOVA) was conducted to determine the significance of differences between different treatments. All statistical analyses were calculated by using SAS statistical software (SAS Institute 2003) and between the means was compared by using the least significant difference test ($P < 0.05$).

Results

Soil physicochemical properties

The effects of long-term fertilizer applications on soil properties were shown in Table 2. Soil N, P, and K contents in all fertilization treatments changed significantly after 32-year application of fertilization practices. Compared to the CK (without fertilizer input), high levels of soil major nutrients (N, P, K) were also sustained in the RF (rice straw residue and chemical fertilizer), LOM (30% organic matter and 70% chemical fertilizer), and HOM (60% organic matter and 40% chemical fertilizer) treatments (Table 2), in which organic manure and rice straw residue had been applied for more than 32 years. The general soil fertility was improved by the application of organic manure and rice straw residue.

Total and available contents of Cd in soil

There was a significant Cd accumulation in soils with all fertilization treatments after 32 years of long-term experiments. The application of manure along with chemical fertilizer significantly increased total Cd content in soil ($P < 0.05$), while following an application of rice straw residue with chemical fertilizer. The total Cd content was higher in soil with MF (chemical fertilizer alone), RF, LOM, and HOM treatments as compared to that with CK at early and late rice mature stages, respectively. Compared with the CK, the total Cd contents were increased 0.053, 0.098, 0.296, and 0.351 mg kg^{-1} in soil with MF, RF, LOM, and HOM treatments at mature stages of early rice, and were increased 0.075, 0.079, 0.261, and 0.340 mg kg^{-1} with MF, RF, LOM, and HOM treatments at mature stages of late rice (Fig. 1).

The combined application of manure with chemical fertilizer significantly increased available Cd content in soil ($P < 0.05$), while following an application of rice straw residue with chemical fertilizer. The available Cd contents in soil with MF, RF, LOM, and HOM treatments were significantly higher ($P < 0.05$) than that of the CK at early and late rice mature stages, respectively. But, the available Cd content was not significantly different in soil between MF and RF treatments at early and late rice mature stages ($P > 0.05$), respectively. Compared with the CK, the available Cd contents were increased 0.006, 0.016, 0.073, and 0.137 mg kg^{-1} in soil with MF, RF, LOM, and HOM treatments at mature stages of early rice, and were increased 0.016, 0.025, 0.102, and 0.160 mg kg^{-1} with MF, RF, LOM, and HOM treatments at mature stages of late rice (Fig. 2).

Cd accumulation in different parts of rice plants

The application of fertilizer had effect on Cd concentrations in stem, leaf, and grain of rice plants at early and late rice mature stages, respectively (Table 3). The root Cd concentrations with MF, RF, LOM, and HOM treatments were significantly higher ($P < 0.05$) than that of the CK at early and late rice mature stages, respectively. But, there is no significant difference in root Cd concentration among MF, RF, LOM, and HOM treatments at early and late rice mature stages ($P > 0.05$), respectively. The stem Cd concentrations with RF and LOM treatments were significant higher ($P < 0.05$) than that of the MF, HOM, and CK treatments at early and late rice mature stages, respectively. And the leaf and grain Cd concentrations with LOM treatment were significantly higher ($P < 0.05$) than that of the MF, RF, HOM, and CK treatments at early and late rice mature stages, respectively.

Bioconcentration factor of Cd in different parts of rice plant

BCF was known as the soil to plant uptake factor (Bose and Bhattacharyya 2008). At early and late rice mature stages, the BCF of Cd in different parts of rice plant occurred in the following sequence: root>stem>grain>leaves. Thus, the Cd accumulated in rice plant root and stem in very high levels accompanied by time and the accumulation were greater in the

Table 2 Dynamic change of soil physicochemical properties under different long-term fertilization management conditions (0–20 cm)

Treatments	Soil organic matter (g kg^{-1})	pH	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K(mg kg^{-1})
MF	32.53 ± 0.94 cd	6.58 ± 0.19a	2.01 ± 0.10c	0.67 ± 0.07c	19.0 ± 0.54a	149.5 ± 7.23d	6.83 ± 0.20c	31.3 ± 1.44c
RF	36.15 ± 1.04c	6.17 ± 0.18a	2.28 ± 0.09b	0.65 ± 0.05c	19.3 ± 0.56a	185.1 ± 6.13c	5.48 ± 0.16c	35.8 ± 1.03b
LOM	45.37 ± 1.31b	6.09 ± 0.17a	2.77 ± 0.07b	1.76 ± 0.02b	18.6 ± 0.57a	212.5 ± 5.34b	91.6 ± 2.64b	34.5 ± 1.02b
HOM	52.93 ± 1.53a	6.32 ± 0.18a	3.41 ± 0.06a	2.55 ± 0.02a	19.7 ± 0.55a	250.4 ± 4.32a	167.5 ± 4.84a	49.8 ± 0.90a
CK	30.45 ± 0.88d	6.48 ± 0.19a	1.87 ± 0.05d	0.49 ± 0.01d	18.5 ± 0.53a	125.2 ± 3.61e	3.68 ± 0.11c	28.2 ± 0.81d

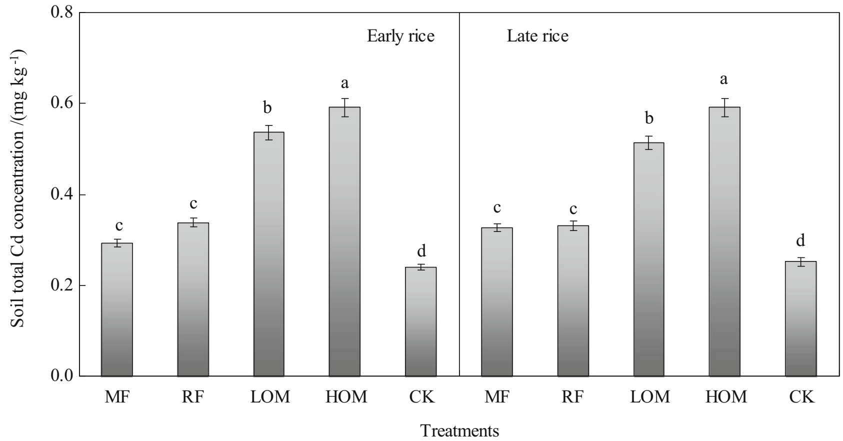

Fig. 1 Effects of long-term fertilization managements on soil total Cd content at early and late rice mature stages. MF, chemical fertilizer alone; RF, rice straw residue and chemical fertilizer; LOM, 30% organic matter and 70% chemical fertilizer; HOM, 60% organic matter and 40% chemical fertilizer; CK, without fertilizer input. Bars represent standard deviation (S.D.) of three replicates. Different letters indicate significance at $P < 0.05$ among the fertilization treatments according to the least significant difference test

root and stem than that in the grain and leaves of the rice plant (Table 4).

Soil Cd single-factor contaminant index

The soil Cd single-factor contaminant index (P_{Cd}) was evaluated as depending on the local soil environmental quality background values and the secondary soil environmental quality standards GB15618-1995. The range of P_{Cd} with MF, RF, LOM, and HOM treatments was 1.003 to 1.973, which indicated that the soil of experiment area reached a slight pollution level. The P_{Cd} of different fertilization treatments was followed by HOM > LOM > RF > MF > CK. Compared with the CK, the P_{Cd} increased by 123.33 and 146.25% with LOM and HOM treatments at early rice mature stages, and by 103.57 and 134.92% with LOM and HOM treatments at late rice mature stages, respectively. Meanwhile, compared with the HOM treatment, the P_{Cd} decreased 42.81 and 44.09% under RF treatment at early and late rice mature stages, respectively (Fig. 3).

Relationship between soil physicochemical properties and soil total and available Cd contents

The total Cd content was positively correlated with the pH, organic matter, total N, total P, available N, and available P contents in soil. And the soil total Cd content was positively and significantly correlated with the soil pH, total N, and total P contents ($P < 0.05$), while the soil total Cd content was negatively correlated with the soil total K and available K contents. The soil available Cd content was positively correlated with the soil organic matter, total N, total P, available N, and available P contents. And there were significant positively correlations between the soil available Cd content and the soil total N, total P, and available N contents ($P < 0.05$), while the soil available Cd content was negatively correlated with the soil pH, total K, and available K contents (Table 5).

Fig. 2 Effects of long-term fertilization managements on soil available Cd content at early and late rice mature stages. Bars represent standard deviation (S.D.) of three replicates. Different letters indicate significance at $P < 0.05$ among the fertilization treatments according to the least significant difference test

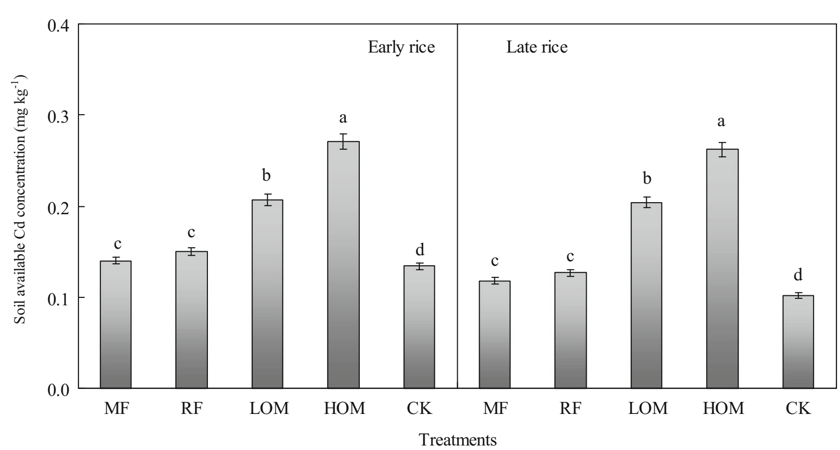

Table 3 Effects of long-term fertilization managements on Cd accumulation in different parts of early and late rice plants

Rice	Treatments	Parts (mg kg^{-1})			
		Root	Stem	Leaf	Grain
Early rice	MF	1.547 ± 0.044a	1.072 ± 0.043b	0.113 ± 0.003b	0.144 ± 0.003c
	RF	1.533 ± 0.046a	1.504 ± 0.024a	0.101 ± 0.002c	0.123 ± 0.005d
	LOM	1.583 ± 0.045a	1.430 ± 0.031a	0.146 ± 0.002a	0.181 ± 0.003a
	HOM	1.674 ± 0.028a	1.039 ± 0.041b	0.098 ± 0.004c	0.165 ± 0.004b
	CK	0.985 ± 0.048b	0.838 ± 0.03c	0.052 ± 0.003d	0.099 ± 0.004e
Late rice	MF	1.535 ± 0.043a	1.029 ± 0.043c	0.123 ± 0.003b	0.162 ± 0.003c
	RF	1.517 ± 0.045a	1.502 ± 0.021a	0.114 ± 0.003c	0.127 ± 0.006d
	LOM	1.558 ± 0.044a	1.254 ± 0.029b	0.152 ± 0.004a	0.191 ± 0.006a
	HOM	1.584 ± 0.028a	0.906 ± 0.036c	0.107 ± 0.004c	0.188 ± 0.005b
	CK	0.976 ± 0.046b	0.744 ± 0.026d	0.066 ± 0.003d	0.108 ± 0.005e

MF, chemical fertilizer alone; *RF*, rice straw residue and chemical fertilizer; *LOM*, 30% organic matter and 70% chemical fertilizer; *HOM*, 60% organic matter and 40% chemical fertilizer; *CK*, without fertilizer input

Different letters indicate significance at 0.05 level among the fertilization treatments according to the least significant difference test

Discussion

Soil total and available Cd contents and fertilization managements

In rice agroecological system, the total and available Cd contents in soil were affected by many factors, such as the soil physical and chemical properties, soil tillage, crop systems, atmospheric deposition, irrigation, and fertilizers (Abdelhafez et al. 2012; Cheng 2003). Some studies showed that the soil Cd content was increased by application of organic manure and chemical fertilizer in a long-term experiment (Wang et al. 2014). In the present study, the result indicated that the soil total and available Cd contents were significantly increased by application of organic matter and chemical fertilizer practices, which were mainly attributed to the incorporation of organic fertilizer (chicken manure). The reason may be that the chicken manure come from intensive farms, and the feed additive for chicken contains heavy metal Cd, Zn, Cu, As, and other metal elements (Zheng et al. 2015; Abdelhafez et al. 2012). The Cd content in chicken manure applied was 0.55 mg kg^{-1} in this study; therefore, the Cd content in paddy field soils was increased by application of organic matter practices in a long-term experiment condition. Thus, the Cd content in paddy field soils with organic manure treatments (HOM and LOM treatments) was increasing. Soil pH was another important factor that affects Cd content and its availability in soils (Cakmak et al. 2010; Kostandi et al. 2012). Compared to the HOM and LOM treatments, the soil total and available Cd contents were decreased by application of rice straw residue and chemical fertilizer (RF) and chemical fertilizer treatments (MF), which were mainly attributed to the application of phosphate fertilizer containing low Cd content in the experiment area (Xu et al. 2017); on the other hand, the amounts rice shoots and grains absorbed from paddy field were increased by application of rice straw residue and chemical fertilizer, resulting in the higher amount of Cd in plant absorbed from the paddy field than that of the chemical fertilizer applied. Therefore, the soil Cd accumulation was decreased in the long-term experiment condition; similar results were found in paddy field (Franklin et al. 2005).

Table 4 Bioconcentration factor (BCF) of Cd in different parts of early and late rice plants under different fertilization managements

Rice	Treatments	Parts			
		Root	Stem	Leaf	Grain
Early rice	MF	5.280	3.659	0.386	0.491
	RF	4.536	4.450	0.299	0.364
	LOM	2.953	2.668	0.272	0.338
	HOM	2.832	1.758	0.166	0.279
	CK	4.104	3.492	0.217	0.413
Late rice	MF	4.694	3.147	0.376	0.495
	RF	4.583	4.538	0.344	0.384
	LOM	3.037	2.444	0.296	0.372
	HOM	2.276	1.530	0.181	0.318
	CK	3.873	2.952	0.262	0.429

In this study, the correlation analysis results indicated that the total and available Cd contents in soil were positively correlated with the soil organic matter, total N, total P, available N, and available P contents. The reason may be that sorption of Cd was increased by higher SOM content, which is probably caused by a higher level of humification of organic matter or by smaller part of dissolved organic matter in SOM composition under

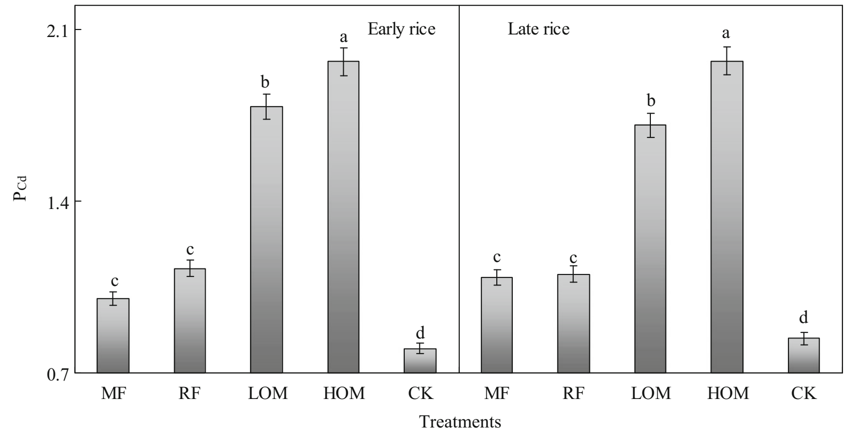

Fig. 3 The soil Cd single-factor contaminant index under different fertilization managements. Bars represent standard deviation (S.D.) of three replicates. Different letters indicate significance at $P < 0.05$ among the fertilization treatments according to the least significant difference test

long-term fertilization conditions (Sprynkyy et al. 2011). However, the soil total and available Cd contents were negative correlated with the soil pH, total K, and available K contents which indicates at least that increasing the soil pH, total K, and available K contents will decease Cd mobility in soils, and the lower pH value of the paddy soil also decreases the total amount of sorbed Cd by organic matter content (Vega et al. 2010). These results indicated that both the soil nutrient content and soil total and available Cd contents were increased by application of fertilization managements. Furthermore, the soil total and available Cd contents were decreased under higher K content condition. The P_{Cd} with four fertilizer applied treatments was larger than 1, which indicated that the soil of experiment area reached a slight pollution level. The reason for this change is closely related to soil Cd accumulation increased by long-term application of chicken manure; thus, the P_{Cd} with HOM and LOM treatments was higher than that of the other treatments, indicating that the soil was substantially polluted by application of chicken manure. Although chicken manure increased the rice yield and enhanced the soil quality and soil nutrient contents, the potential risk of Cd in soil and rice plant pollution should be noted in the rice production.

Cd accumulation in rice plants under fertilization managements

The effects of different fertilization treatments on Cd accumulation in crops are complex and there is no definite conclusion. That is, the Cd accumulation in different parts of crop is affected by many factors, such as the soil type, soil pH, crop species, kinds of fertilizer, and so on (Selles et al. 2003; Grant and Sheppard 2008; Duan et al. 2011). Reuss et al. (1978) reported that the Cd accumulation in lettuce, pea, and radish was increased by application of heavy superphosphate. Duan et al. (2012) showed that the Cd accumulation in grains of rice was increased with application of P fertilizer and organic manure. In the present study, the different long-term fertilization managements (32 years) had strong impacts on Cd accumulation in different parts of rice. The results showed that the Cd concentrations in root, stem, leaf, and grain of rice with organic manure and chemical fertilizer were higher than non-fertilizer input treatment under long-term experiment condition. The reason may be that the applications of organic fertilizer in paddy field, on the one hand, increased the content of Cd in paddy soils under long-term application of organic with chemical fertilizer conditions, thus increasing the Cd concentrations in different parts of rice. On the other hand, the soil structure and soil nutrient contents were increased under combined application of organic with chemical fertilizer conditions (Du et al. 2009); the growth of rice and absorption of nutrient elements from soil were promoted. Therefore, potential Cd contamination in grain of rice after long-term application of chicken manure would be a matter of increasing concern. Farmers in double-cropping rice areas traditionally apply livestock manures to the paddy field and this leads to soil contamination with metal Cd. But, the Cd concentration in

Table 5 Analysis of the relationship across soil physicochemical properties and soil total and available Cd contents

Factors	Soil organic matter (g kg^{-1})	pH	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
Soil total Cd content (mg kg^{-1})	0.353	0.515*	0.658**	0.586*	−0.472	0.375	0.305	−0.596*
Soil available Cd content (mg kg^{-1})	0.445	−0.825**	0.675**	0.634**	−0.325	0.706**	0.335	−0.436

* Significant 0.05 level; ** significant 0.01 level ($n = 3$)

grain of rice has not exceeded the maximum levels specified by the National Food Safety Standard of Contaminants in Foods (GB2762-2012). The reason may be that the soil physical structure and the Cd accumulation in different parts of rice plant were affected under long-term fertilization conditions (Li et al. 2007; Yang et al. 2016), which promotes Cd accumulation in roots and stems of rice plant and decreases Cd accumulation in grain of rice plant (Table 3). Here, these results provide evidences to control the amount of organic manure and Cd content in organic manure to help decrease the risk of Cd contamination in the crop production system (Horta et al. 2015).

The uptake of Cd by crops was closely related to its available content in soils, which was affected by soil physical and chemical properties (Li et al. 2007). In the present study, the Cd contaminations in different parts of rice plant were changed under long-term application of fertilization conditions. Our results indicated that the Cd contamination in stem was increased, while in grain it was decreased under long-term application of rice straw residue practices. The explainable reason is closely related to the change of soil structure and physical and chemical characteristics of field soils after long-term rice straw returning to paddy field (Du et al. 2009), which affected the Cd absorption and distribution in different parts of rice. This confirmed that it was beneficial to decrease Cd accumulation in grain of rice under long-term application of rice straw residue practice condition. Therefore, it is an effective way to recycle Cd accumulation using the rice straws and to decrease the Cd accumulation in grain of rice by application of rice straw residue practices.

For the application of chemical fertilizer alone (MF) treatment, the soil available nutrient concentrations were higher than that of the without fertilizer input (CK) treatment and the concentration of Cd in different parts of rice plant with MF treatment was higher than that of the CK treatment; the reason may be that the incorporation of chemical fertilizer into paddy soils increases the supply of valuable soil nutrients, and the input of stubble and root residues, and increasing the activities of soil microorganisms, which favored increasing the absorption of Cd and concentration of Cd in rice plant; the result coincides with Li et al. (2007). In this study, the content of Cd in different part of rice plant followed the sequence root>stem>grain>leaves under all the fertilization treatments. And similar results reported that the concentration of Cd in wheat root was significantly higher than those in wheat straw or grain under different fertilization treatments (Wang et al. 2014).

Conclusions

The results showed that the total and available Cd contents in soil were significantly increased ($P < 0.05$) by application of organic matter and chemical fertilizer, but there is no significantly difference ($P > 0.05$) as the application of rice straw residue and chemical fertilizer. The accumulation of Cd in the paddy soils was mainly attributed to the incorporation of organic fertilizer. The content of Cd in different parts of rice plant followed the sequence root>stem>grain>leaves under all the fertilization treatments. The Cd concentration in roots, leaves, and grains of rice were increased by application of 30% organic matter and 70% chemical fertilizer, compared with other fertilization treatments. It is beneficial to decrease the Cd concentration in grains of rice plants, while the Cd concentration in stems of rice plants was increased by combined application of rice straw residue with chemical fertilizer practices. We suggest that it is an effective approach to mitigate Cd exposure associate with rice consumption. The total and available Cd contents in soil were closely related to soil physicochemical properties, that is, the soil physicochemical properties (i.e., soil pH, total N, and total P contents) can be considered as important evaluation factors affecting Cd concentration in soil and plant of rice among different fertilization treatments.

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