Pertanika J. Sci. & Technol. 27 (1): 443 - 458 (2019)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Response of Cadmium Accumulation in Rice (*Oryza sativa* L. cv. SPR1) Grown with Different Organic Soil Amendments

Chitsanuphong Pratum

Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom 73170, Thailand

ABSTRACT

Rice (*Oryza sativa* L.) is one of the food crops, which is found to have the great capacity of cadmium (Cd) accumulation. This research was done to investigate the response to Cd accumulation in rice grown with different organic soil amendments (OA), namely soil supplemented with swine manure (SM), cow manure (CM), mixed chicken manure and rice husk (CR), vermicompost (VC), and greensward compost (GC), respectively. Each OA (4% w/w basis) was applied in each treatment with 3 Cd levels at 20, 40, and 60 mg/kg, respectively. The results showed that rice plants were not able to grow in 4% w/w of SM and CM, respectively and wither following 70 d of planting. It was found in the other treatment results that CR, VC, and GC increased harvest index (HI) as well as soil pH while decreasing soil Eh and Cd-HI, compared with the control treatment. All the Cd concentrations did not affect the height, but the wet weight of plants, decreased with increase in Cd concentrations. Regarding the Cd accumulation, it was found that CR is most effective in absorbing Cd in the paddy soils. In terms of Cd uptake, it was found that GC was the only OA that could reduce the Cd uptake in the rice plant parts. The result is consistent with reduction observed in the accumulation of cadmium in stems, leaves, and especially rice grain. Therefore, based on the current finding, both CR and GC soil amendments can be considered for immobilizing Cd in the contaminated fields.

Keywords: Cadmium accumulation, organic soil amendments, paddy soil, rice plants

ARTICLE INFO

Article history:
Received: 30 March 2018
Accepted: 27 June 2018
Published: 24 January 2019

E-mail address:
chitsanuphong.pra@mahidol.ac.th, enchitsanu@gmail.com

INTRODUCTION

Heavy metal soil contamination is a serious and globally widespread problem that limits crop yields. Heavy metal pollutants do not easily biodegrade and remain almost indefinitely in the environment. When

ISSN: 0128-7680
e-ISSN: 2231-8526

it comes to heavy metal types, cadmium (Cd) is one of the highly toxic heavy metals which has a negative impact on the living cell at a very low concentration. From a health perspective, WHO (2003) agreed to maintain the Provisional Tolerable Weekly Intake of Cd at 7 µg/kg of body weight. Nowadays, the main sources of Cd entry into the environment come from anthropogenic sources. The most significant anthropogenic sources are fuel combustion, base-metal mining, sludge from paint and plastic stabilizer industries, and phosphate fertilizers as well as bio-solids in agriculture.

Rice (*Oryza sativa* L.) is one of the staple foodstuffs for many countries in Asia, especially Thailand, where contamination with Cd has been detected (Liu et al., 2007; Tang et al., 2016). The range of Cd concentration from 7.15 to 14.24 mg/kg was found in the rice grains from Mae Tao floodplains of Tak Province, Thailand (Pluemphuak et al., 2014). Meanwhile, CAC (2006) proposed a draft provisional maximum level for Cd content in polished rice of 0.4 mg/kg, used for the safety of both consumption and international trade. Simmons et al. (2003) revealed that rice grains accumulate higher Cd than stems and leaves, which significantly increases the risks to human health. Hence, the accumulation of Cd in the rice plants, especially rice grains, has been a major concern.

Therefore, reducing Cd bioavailability would be an urgent demand for safe rice production. A large number of methods have been employed to reduce Cd mobility such as a control in pH and increase in additional binding sites in the paddy soil (Zhou et al., 2014). Li et al. (2008) showed that the several soil amendments (namely; calcium magnesium phosphate, calcium silicate, pig manure, and peat) were able to increase the rice yield by 0.3-15.3 fold, and effectively decreased the Cu and Cd concentrations in rice grain by 23.0%-50.4%. This research demonstrated the effectiveness of organic soil amendments (OA) to reduce Cd bioavailability in a paddy soil and reduce Cd uptake by rice plants under continuous flooding conditions.

MATERIALS AND METHODS

Paddy Soil and Organic Wastes Characterization

A clean soil sample was collected from a paddy field in the topsoil layer at a depth of 0 to 20 cm in Nakhon Pathom Province, Thailand. Then, plant detritus and adulterated things were removed. Meanwhile, five OA: swine manure (SM), cow manure (CM), mixed chicken manure and rice husk (CR), vermicompost (VC), and greensward compost (GC) were prepared in the same way as the paddy soil samples. The selected physicochemical properties of paddy soil and OAs were listed in Table 1.

Cd-contaminated Soil Preparation

The preparation of Cd-contaminated soil consisted of 3 Cd levels; 20, 40, and 60 mg/kg, respectively. The Cd stock solution needed for mixing into the paddy soil sample was prepared using cadmium chloride pentahydrate, $CdCl_2 \cdot 2.5H_2O$, dissolved in 500 ml distilled water (Liu et al., 2003). The Cd solution was slowly poured into and thoroughly mixed with the paddy soil sample. The initial concentrations of Cd in the spiked soil were 19.60±0.20, 40.22±0.62, and 62.87±0.37 mg/kg, respectively. The soil was air dried and stored at room temperature.

Table 1

Selected physicochemical properties of paddy soil and organic soil amendments

Characterization	Paddy soil	Organic soil amendments				
		SM	CM	CR	VC	GC
pH	6.9	7.4	8.1	7.5	6.7	7.2
Electric Conductivity (dS/m)	0.1	4.6	9.1	8.8	2.6	1.5
Organic Matter (%)	1.1	48.8	61.8	46.4	28.2	28.9
Available Phosphorus (mg/kg)	6.0	2,055.0	282.0	2,574.0	173.0	157.0
Available Potassium (mg/kg)	186.0	7,419.0	22,853.0	13,206.0	2,454.0	1,634.0
Total Nitrogen (%)	0.1	3.1	1.5	1.8	1.4	1.5
Total Organic Carbon (mg/kg)	8.6	127.4	67.4	125.2	112	112.3
Cadmium (mg/kg)	nd	nd	nd	nd	nd	nd
Cation Exchange Capacity (cmol/kg)	62.6	1,110.0	1,450.0	98.0	39.0	65.0
C/N ratio	-	15.7	41.2	25.8	20.1	19.3
Particle size distribution (%)						
Sand	28	-	-	-	-	-
Silt	31	-	-	-	-	-
Clay	41	-	-	-	-	-

Note: nd = not detected

Rice Variety

The breeder seed, Suphan Buri 1 (SPR1) rice, was obtained from the Thai Rice Science Institution (TESI), Suphan Buri Province, Thailand. For the preparation of seedlings, rice seeds were soaked in tap water without chlorine for about 2 day (d) at room temperature and the germinated seeds were grown in the Cd-contaminated soil sample. After 30 d, the seedlings with 2 - 3 tillers or height of tillers about 10 cm were transplanted into plastic pots (Liu et al., 2007).

Experimental Design

A completely randomized experimental design was used and, in addition, greenhouse experiments were also carried out at the Faculty of Environment and Resource Studies, Mahidol University, Thailand. Each 4% w/w basis of OAs was thoroughly mixed with Cd-contaminated soil and then, stored in the plastic pot (10-L cylindrical plastic container). Furthermore, the pot experiments were submerged with 2 - 3 cm tap water without chlorine above the soil surface for 14 d before transplanting rice (Liu et al., 2005). The pot treatment was arranged in the six treatments according to the addition of OA: control treatment without any OA (T1), added SM (T2), added CM (T3), added CR (T4), added VC (T5), and added GC (T6), respectively. All the pot treatments received macronutrient (N-P-K) thrice; i.e. the 3^{rd} day before the seedling transplant, the 20^{th} day after the transplant, and the 5^{th} day before the panicles heading, respectively. One gram of urea and 1 g of $K_2HPO_4 \cdot 3H_2O$ were applied to each pot experiment on each occasion (Liu et al., 2007; Liu et al., 2003). The total growth periods in the pot experiments were maintained under the flooded conditions. The experiments were carried out in triplicates.

Analytical Methods

Rice Plant Growth. The rice plants from each pot were harvested at 45, 90, and 120 d after planting for the rice plant growth analysis. The wet weights of the shoots and roots of the rice plant samples were measured. The stem height was measured from the aboveground portion to the top of the stem. Any symptoms of Cd-induced toxicity exhibited by rice plant samples were visually noted throughout the experimental period. In addition, the harvest index (HI) was also measured by the total weight of harvested rice plants at the final of the experimental period (120 d) in each pot. Then, HI was calculated according to Eqn. 1 (Liu et al., 2005).

$$\text{Harvest index} = \frac{W_{grains}}{W_{grains} + W_{shoots}} \qquad \text{[Eqn.1]}$$

where W_{grains} and W_{shoots} represent the dry weight content in rice grains and shoots, respectively.

Selected Soil Chemical Properties. The selected soil chemical properties were divided into 2 parameters namely, soil pH and soil redox potential (Eh). The electrode was placed 5 cm below the submerged paddy soil in each pot for measurements, which were repeated at intervals of 7 d (Pluemphuak et al., 2014).

Cd Concentration in Rice Plants and Paddy Soils. The rice plants from each pot were harvested 120 d after planting for Cd accumulation analysis. After harvesting, the rice plants were washed thoroughly 3 times with tap water and 3 times with distilled water (Liu et al., 2003), and then separated into rice grains (pedicel, husk, bran, and polished rice), leaves, stems, and roots and finally oven-dried at 60 – 65 °C until constant weight was obtained.

The dried rice plants were ground into powder and sieved through 2-mm mesh sieve. Then, the rice plants (1.0 g) were digested in concentrated HNO_3 and 30% H_2O_2, 4:1 (v/v). In the case of paddy soil, plant detritus and any visible fragments were separated and the soil air-dried at room temperature till constant weight. The dried paddy soils were ground into powder and sieved through 2-mm mesh sieve. Further, the soils (0.5 g) were digested in 37% HCl and concentrated HNO_3, 3:1 (v/v). The total Cd in these solutions was determined with Atomic Absorption Spectrophotometer (Hseu, 2004; Siswanto et al., 2013).

Cd Accumulation Potential in Rice Plants. The Cd accumulation potential in rice plants was divided into 2 parameters namely, the Cd-harvest index (Cd-HI) and the correlation coefficient of Cd in paddy soil and rice plant parts. The Cd-HI was estimated using Eqn. 2 (adapted from ur Rehman et al., 2017).

$$\text{Cd -Harvest index} = \frac{Cd_{grains} + Cd_{straw}}{Cd_{grains} + Cd_{straw} + Cd_{soil}} \qquad \text{[Eqn.2]}$$

where Cd_{grains}, Cd_{straw}, and Cd_{soil} represent the Cd content in rice grains, straw, and paddy soil, respectively.

In addition, the rice plant parts (namely; rice grains, shoots, and roots) were used for the correlations coefficient of Cd. The linear correlation coefficient studies were made to evaluate the relationships among Cd concentrations in the paddy soil and the Cd concentrations and accumulation in various parts of rice plants.

Statistical Analysis

All data were analyzed by the SPSS Program for Windows. One-way ANOVA at confidence intervals of 95% ($P<0.05$) was used for statistical analysis. Where significant, the multiple comparisons of means were made using Duncan's new multiple range tests (DMR test). In addition, Pearson's correlation coefficient (r) was used for a statistical measure of the strength of a linear relationship between paired data: Cd concentrations in the paddy soil and the Cd concentrations and accumulation in various parts of rice plants at confidence intervals of 95% ($P<0.05$) and 99% ($P<0.01$).

RESULTS AND DISCUSSION

Rice Plant Growth

The rice plants in T2 and T3 were not able to grow at 70 d after planting. The rice roots showed symptoms of black root rotting with a characteristic rotten egg odor, stunted growth, lack of tillering, yellowish rice foliage, and wilting. Therefore, T2 and T3 rice plant growth cannot be measured. This might be due to hydrogen sulfide (H_2S) toxicity in rice roots as shown in Figure 1. One of the main gases related to pig manure and cow manure is H_2S, which oxidizes rapidly to sulfuric acid (H_2SO_4) in the presence of water (Koelsch et al., 2004; Ni et al., 2000). The formation of H_2S often results from the microbial breakdown of organic matter in anaerobic digestion (Joshi et al., 1975). As H_2S toxicity progresses, rice plants suffer reductions in the absorption of nutrients and its metabolic system (Lamers et al., 2013).

In other treatments, the study of the rice plants height revealed that all Cd level (20, 40, and 60 mg/kg) did not affect the rice plants height and neither did it show any abnormalities in stems and leaves of rice plant. However, Cd level at 100 mg/kg was found to directly affect and reduce the height of the rice plants (Herath et al., 2014). On the part of the rice plants wet weight, all Cd level did affect the rice plants wet weight. Wet weight was found to decrease as the Cd concentrations increased. The reduction of wet weight might be due to inhibition of Cd on the physiological processes, namely, photosynthesis, cell division, plant metabolism and cellular respiration. (Li et al., 2017).

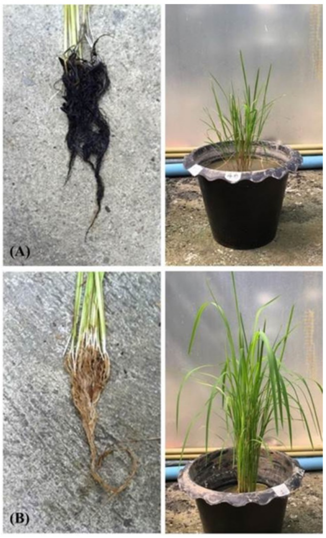

Figure 1. Symptoms of hydrogen sulfide toxicity on rice roots; (A) the black root rotting in T2 and T3 and (B) the normal root in T1 (control treatment)

Harvest Index (HI)

The HI was used as an indicator of plant efficiency in dry weight accumulation. In general, the harvest index of rice is 0.17 - 0.56 (Ju et al., 2009). As shown in Table 2, Cd level at 20 and 40 mg/kg did not affect the HI, which was not significantly different ($P>0.05$). In addition, Cd level at 60 mg/kg has the highest HI with significant differences ($P<0.05$) at T6. The low Cd concentration (at 20 and 40 mg/kg) did not affect the harvest index of SPR1 rice. This might be attributed to its tolerance mechanism to Cd toxicity (Juang et al., 2012; Tang et al., 2016). The glutathione (GSH) of rice plants played an important role in keeping the cellular redox balance under Cd stress (Sebastian & Prasad, 2014). In

Table 2

HI of rice plants grown in Cd-contaminated soil at different Cd levels

Treatment	Cd levels (mg/kg)		
	20	40	60
T4	0.36±0.06 a, A	0.31±0.04 a, A	0.28±0.01 ab, A
T5	0.34±0.02 a, A	0.32±0.05 a, A	0.31±0.02 ab, A
T6	0.41±0.09 a, A	0.40±0.04 a, A	0.35±0.09 b, A
T1 (control treatment)	0.43±0.05 a, C	0.34±0.05 a, B	0.23±0.09 a, A

Note: Data with the small letters (a, b) showed differences between Cd contents (rows) and the capital letters (A, B, C) showed differences between treatment (columns) at P<0.05 according to the DMR test

addition, phytochelatin is also produced to enhance the tolerance of rice plants to Cd stress (Tiryakioglu et al., 2006) The Cd is trapped in the vacuole of the roots and leaves in rice plants (Li et al., 2017). A decrease of HI was observed with increase in Cd concentrations. Khampuang et al. (2016) reported a similar observation.

Selected Soil Chemical Properties

Soil pH. Results regarding average soil pH (throughout planting at 120 d) are presented in Figure 2. Cd level 20 at mg/kg, the soil pH increased due to the OAs in the following order: T5 > T6 > T4 > T1 (control treatment). Cd level at 40 and 60 mg/kg, the soil pH increased due to the OAs in the following order T6 > T4 > T5 > T1 (control treatment). The soil pH was significantly (P<0.05) increased, which may be due to alkaline properties of the OAs. The soil pH has been shown to be one of the key factors which govern the availability of heavy metals in acidic soil (Hooda & Alloway, 1998). Lower pH levels in soil have resulted in rice plants absorbing high amounts of Cd and accumulations in various parts, especially the rice grains. Therefore, increasing the pH of the soil can reduce the Cd absorption by rice, which can be used both in highland and lowland areas (Kikuchi et al., 2008).

Soil Eh. The Eh, an index to relatively quantity the oxidizing and reducing substances, is also an important factor that can control the Cd bioavailability. In paddy soil, continuous flooding, and the OAs had impacts on soil Eh. Cd level at 20 and 40 mg/kg, soil Eh was decreased by the OAs in the following order: T4 > T5 > T6 > T1 (control treatment). While for the Cd level at 60 mg/kg, soil Eh was decreased by the OAs in the following order: T4 > T6 > T5 > T1 (control treatment). The results showed that the OAs could significantly (P<0.05) decrease Eh, which are presented in Figure 3. The soil Eh decreased after applying the OAs probably from increasing the amount of reducing matters (e.g., ferrous ion (Fe^{2+}), humic acids, and fulvic acids) in paddy soil during the interaction between the OAs and paddy soil components (Ji et al., 2007; Liu et al., 2010). Therefrom, Cd in paddy soil was in the form of insoluble compounds, combined with the reducing matters. In addition, root exudates include both organic ligands and inorganic ligands (e.g., Cl^-, SO_4^{2-}, NH^{4+}, CO_3^{2-}, PO_4^{3-}, etc.). These substances function not only as the energy source of microorganisms but also as ligands to chelate with Cd^{2+} and then influence the pH and Eh conditions as well as chemical characteristics in the rhizosphere (Dong et al., 2007).

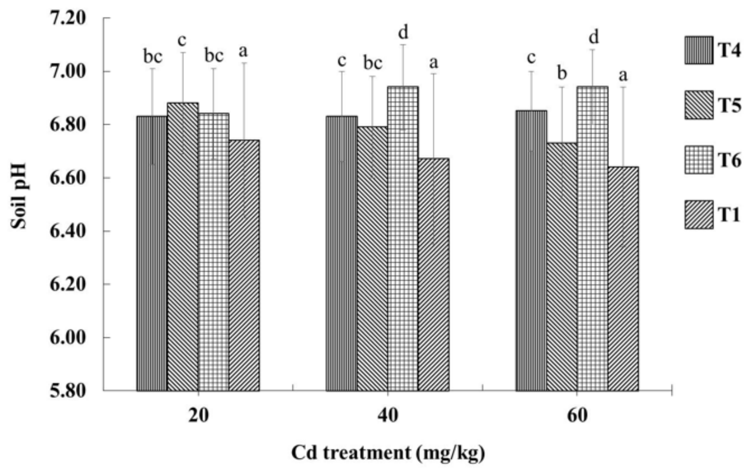

Figure 2. Average soil pH (throughout planting at 120 d) in Cd-contaminated soil and the small letters (a, b,.. d) showed differences each bar diagram at $P<0.05$ according to the DMR test

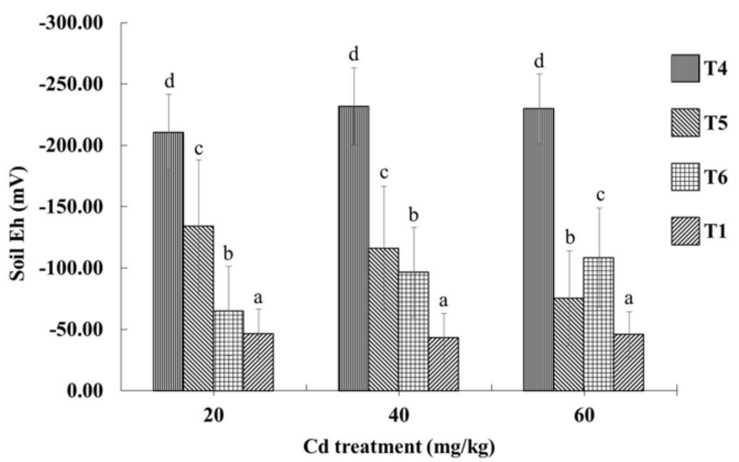

Figure 3. Average soil Eh (throughout planting at 120 d) in Cd-contaminated soil and the small letters (a, b,.. d) showed differences each bar diagram at $P<0.05$ according to the DMR test

Table 3

Cd accumulation in rice plants and paddy soils at different Cd levels

Cd levels (mg/kg)	Treatment	Cd concentration (mg/kg)								[1] Capacity to absorb Cd (%)
		Paddy soil	Roots	Shoots						
				Stems	Leaves	Rice grain				
						Pedicel	Husk	Bran	Polished rice	
20	T4	17.63±0.31 ^{a}	1.06±0.06 ^{a}	0.07±0.01 ^{a}	0.36±0.04 ^{a}	0.19±0.01 ^{b}	0.02±0.00 ^{a}	0.12±0.03 ^{a}	0.12±0.00 ^{a}	13.70±4.65 ^{c}
	T5	14.39±1.37 ^{a}	4.20±0.15 ^{c}	0.09±0.01 ^{a}	0.43±0.06 ^{a}	0.05±0.01 ^{a}	0.05±0.01 ^{a}	0.11±0.02 ^{a}	0.11±0.01 ^{a}	0.00±0.00 ^{b}
	T6	12.60±1.09 ^{a}	4.95±0.02 ^{d}	0.15±0.02 ^{b}	0.90±0.05 ^{c}	0.33±0.00 ^{c}	0.09±0.03 ^{b}	0.21±0.01 ^{b}	0.19±0.01 ^{b}	0.00±0.00 ^{a}
	T1	14.89±1.24 ^{a}	3.35±0.05 ^{b}	0.22±0.01 ^{c}	0.71±0.02 ^{b}	0.18±0.04 ^{b}	0.05±0.01 ^{ab}	0.13±0.02 ^{a}	0.11±0.00 ^{a}	0.00±0.00 ^{b}
40	T4	35.67±1.22 ^{b}	2.42±0.04 ^{a}	0.18±0.01 ^{a}	1.18±0.02 ^{a}	0.29±0.04 ^{a}	0.04±0.00 ^{a}	0.04±0.02 ^{a}	0.20±0.00 ^{a}	27.83±7.80 ^{c}
	T5	29.85±1.78 ^{a}	8.11±0.07 ^{b}	0.17±0.00 ^{a}	1.21±0.13 ^{a}	0.25±0.03 ^{a}	0.13±0.03 ^{c}	0.21±0.00 ^{b}	0.27±0.01 ^{b}	13.28±6.40 ^{b}
	T6	27.53±1.85 ^{a}	10.76±0.41 ^{c}	0.27±0.02 ^{b}	1.01±0.02 ^{b}	0.31±0.07 ^{a}	0.09±0.02 ^{b}	0.19±0.01 ^{b}	0.21±0.00 ^{a}	7.48±6.22 ^{ab}
	T1	24.54±4.34 ^{a}	9.85±0.09 ^{b}	1.06±0.02 ^{c}	3.01±0.02 ^{c}	0.49±0.04 ^{b}	0.26±0.02 ^{d}	0.44±0.01 ^{c}	0.36±0.01 ^{c}	0.00±0.00 ^{a}
60	T4	54.50±3.55 ^{c}	5.92±0.07 ^{a}	0.13±0.01 ^{a}	1.12±0.05 ^{b}	0.17±0.00 ^{a}	0.08±0.01 ^{a}	0.27±0.02 ^{b}	0.27±0.00 ^{b}	16.75±0.62 ^{d}
	T5	51.06±2.39 ^{bc}	8.76±0.10 ^{c}	0.37±0.03 ^{c}	1.23±0.03 ^{c}	0.33±0.01 ^{b}	0.16±0.04 ^{b}	0.32±0.00 ^{c}	0.34±0.00 ^{c}	11.02±2.55 ^{c}
	T6	47.56±6.45 ^{ab}	13.22±0.34 ^{d}	0.23±0.01 ^{b}	0.83±0.04 ^{a}	0.19±0.04 ^{a}	0.07±0.01 ^{a}	0.18±0.02 ^{a}	0.19±0.01 ^{a}	5.18±4.22 ^{b}
	T1	44.45±3.92 ^{a}	8.54±0.07 ^{b}	1.31±0.04 ^{d}	3.98±0.04 ^{d}	1.30±0.05 ^{c}	0.37±0.03 ^{c}	0.81±0.02 ^{d}	0.48±0.00 ^{d}	0.00±0.00 ^{a}

Note: Data with the small letters (a, b,…d) showed differences between columns at $P<0.05$ according to the DMR test.

[1] the capacity to adsorb Cd of T4, T5, and T6 when compared with T1 (control treatment)

Table 4

Cd-HI of rice plants grown in Cd-contaminated soil

Treatment	Cd levels (mg kg^{-1})		
	20	40	60
T4	0.48±0.08 $^{b, A}$	0.51±0.02 $^{b, A}$	0.36±0.03 $^{a, A}$
T5	0.57±0.11 $^{ab, A}$	0.70±0.03 $^{b, A}$	0.51±0.03 $^{a, B}$
T6	1.30±0.10 $^{c, C}$	0.70±0.03 $^{b, A}$	0.35±0.04 $^{a, A}$
T1 (control treatment)	0.86±0.07 $^{a, B}$	1.89±0.26 $^{b, B}$	1.57±0.11 $^{b, C}$

Note: Data with the small letters (a, b,c) showed differences between Cd contents (rows) and the capital letters (A, B, C) showed differences between treatment (columns) at P<0.05 according to the DMR test

Table 5

Pearson's correlation coefficient between Cd in paddy soil, rice grains, shoots, and roots

		Paddy soil	Rice grains	Shoots	Roots
T4	Paddy soil	-	0.877**	0.728*	0.964**
	Rice grains	-	-	0.341	0.965**
	Shoots	-	-	-	0.561
	Roots	-	-	-	-
T5	Paddy soil	-	0.961**	0.914**	0.879**
	Rice grains	-	-	0.978**	0.955**
	Shoots	-	-	-	0.990**
	Roots	-	-	-	-
T6	Paddy soil	-	-0.598	-0.406	0.920**
	Rice grains	-	-	0.572	-0.504
	Shoots	-	-	-	-0.132
	Roots	-	-	-	-
T1	Paddy soil	-	0.934**	0.916**	0.595
	Rice grains	-	-	0.997**	0.805**
	Shoots	-	-	-	0.844**
	Roots	-	-	-	-

Note: *, ** Correlation is significant at P<0.05 and P<0.01, respectively.

Cd Concentration in Rice Plants and Paddy Soils

As shown in Table 3, an increase of Cd was observed in both rice plants and paddy soils of all treatments when Cd concentration was increased in soils. Meanwhile, the polished rice Cd concentration in T4, T5, T6, and T1 (control treatment) increased when Cd concentration in soil increased and reached a maximum value of 0.48 mg/kg cadmium in T1 (Cd level at 60 mg/kg). The influence of the OAs on Cd adsorption in the paddy soils revealed that CR (at 4% w/w basis) was most effective for Cd adsorption. On the average, the capacity to adsorb Cd when compared with T1 was 13.70±4.65%, 27.83±7.80%, and 16.75±0.62% with 20, 40, and 60 mg/kg applied paddy soil, respectively. These results agree with those of Shokalu et al. (2017), in which a high capacity adsorb Cd of 99.7% was observed when poultry manure was applied at 4% w/w basis. In addition, the results also reported that the addition of poultry manure (4% w/w) caused the significant reduction in the bioavailable Cd concentration.

The analysis of the efficiency of the OAs to increase Cd accumulation in the rice plants revealed that the GC (at 4% w/w basis) was most effective in stimulating Cd accumulation, especially the roots. As a result, the Cd accumulation in roots increased, while Cd in polished rice significantly decreased ($P<0.05$). This reduces the accumulation of cadmium in stems, leaves, and especially rice grain. In addition, the accumulation of cadmium in various parts of the rice plants found that the Cd accumulation is greater than stems followed by leaves and then rice grain, respectively. The paddy soil properties can be improved by the binding between organic matter in the GC and clay particles via cation bridges because it increases soil porosity and stimulates root growth (Gao et al., 2010; Leroy et al., 2008). Organic matter can also indirectly improve soil structure by increasing microbial activity and thus the production of microbial slimes, fungal hyphae and/or roots to bind aggregates together (Tisdall & Oades, 1982). In addition, the chemical fertility (e.g., soil pH electric conductivity (EC) and CEC), was also increased by compost application (Bulluck et al., 2002; Ouédraogo et al., 2011). On the average, Cd concentration (mg/kg) in polished rice was 0.19±0.01, 0.21±0.00 and 0.19±0.01 with 20, 40 and 60 mg/kg applied paddy soil, respectively. The Cd content was lower than 0.4 mg/kg, which is the highest acceptable Cd concentration in polished rice (CAC, 2006). Hence, applying the OAs to paddy soil can reduce Cd accumulation in rice plants (Wang et al., 2012).

Cd-harvest Index (Cd-HI)

The Cd-HI calculation is a proximal approach (Qayyum et al., 2017). It has been described for the Cd absorption from soil by the use of plants such as rice plants in the present study. For Cd level at 20 mg/kg, the T6 showed that the Cd-HI significantly increased ($P>0.05$). For Cd level at 40 and 60 mg/kg, the T1 showed that the Cd-HI significantly increased ($P>0.05$). The higher Cd-HI in T6 might be due to the GC stimulating root growth, resulting in an increase in the Cd absorption. Plant root growth can increase greatly when using organic compost (Gao et al., 2010). Whereas, all types of the OAs (CR, VC, and GC) were effective in decreasing the Cd absorption from paddy soil by rice plants. However, the decreasing Cd-HI in each treatment might be due to a decrease in available Cd concentration in the soil with the application of the OAs, as shown in Table 4.

The Trend of Cd Uptake

Pearson's correlation coefficient was used to study the trend of Cd uptake of rice plants. As shown in Table 5, the increase of Cd concentration in the paddy soils has an influence on the increase of Cd accumulation in the rice parts, especially rice grains, at T4, T5, and T1 (control treatment). It has increased significantly ($P<0.01$). These results agree with those of Tang et al. (2016), Sebastian and Prasad (2014), Hanč et al. (2008), and Rizk et al. (2014) found that Cd accumulation in rice plant parts increased when Cd concentration in the paddy soil increased. In Cd translocation, the xylem is the major physiological process determining the Cd accumulation level in shoots and rice grains of rice plants (Uraguchi et al., 2009).

At T6, the Cd concentration in paddy soil was negatively correlated with the Cd concentrations in rice grains and shoots. This showed that the increase in Cd concentration in paddy soil did not increase the Cd concentrations in rice grains and shoots. However, the Cd concentrations in paddy soil were positively correlated with the Cd concentrations in roots. This showed that the increase in Cd concentration in paddy soil increased the Cd concentrations in roots. This result showed that Cd accumulation decreased in rice plant parts with the GC applied compared with other OAs. The Cd in paddy soil did not tend to accumulate in rice plants because it was mostly absorbed by the roots (see data section; Cd concentration in rice plants and paddy soils). Abe et al. (1995) also reported GC stimulated root growth (particularly nodal roots), which helped in absorbing nutrients or heavy metals. In addition, the application of the GC combined with the chemical fertilizer can increase the length and weight of roots from 30 to 40 % (Rizk et al., 2014; Yang et al., 2004).

CONCLUSIONS

In this research, OAs had a positive effect on reducing Cd uptake by rice. All OAs increased HI and soil pH while decreasing soil Eh and Cd-HI, compared with the control treatment. Among the OAs, CR was highly effective in absorbing and retaining Cd in the paddy soil. Whereas, GC was the only OA that could reduce the Cd uptake into the rice plant parts, especially polished rice. The studied indicated that Cd in paddy soil do not tend to accumulate in rice plants because it is mostly absorbed by the rice roots. Therefore, it can be suggested that both CR and GC might be used to immobilize Cd in the Cd-contaminated fields. Future work should evaluate on the combination of CR and GC organic soil amendments and its application to immobilize Cd.

ACKNOWLEDGMENT

The financial support (No. 004/2016) from Asia Research Center, Chulalongkorn University, Thailand, is gratefully acknowledged.

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