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Effect of Organic Fertilizer on Cadmium Uptake by Rice Growing in Contaminated Soil

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Abstract

The effects of organic fertilizer on the cadmium uptake by rice growing in contaminated soil were studied in a nursery experiment. The types of soil used were uncontaminated and fertilizer free, contaminated and fertilizer free, contaminated and organically fertilized at 3.25 ton/ha, contaminated and organically fertilized at 6.25 ton/ha and contaminated and organically fertilized at 12.5 ton/ha. Four varieties of Thai rice, Khao Dawk Mali 105 (KDML105), RD6, Phitsanulok3 and Niaw San-Pa-Tong, were planted in each container. Samples of the soil and plants, consisting of the above-soil growth, below-soil growth, husk and grain, were taken every 30, 60, 90 and 120 days to determine the amount of cadmium uptake in each part. After 120 days, the results showed that the Niaw San-Pa-Tong variety grown in the contaminated soil with organic fertilizer at 12.5 ton/ha displayed the lowest accumulated cadmium uptake in the above-soil parts, at 4.1 mg/kg, whereas Phitsanulok3 grown in the contaminated soil and fertilized at 6.25 ton/ha showed the lowest cadmium uptake in below-soil parts, at 9.19 mg/kg. The lowest level of cadmium deposited in the grain, at 0.06 mg/kg, was found in the Phitsanulok3 cultivar growing in the contaminated soil fertilized at 12.5 ton/ha. With regard to the accumulative cadmium uptake, we propose that a concentration of organic fertilizer ranging between 6.25-12.5 ton/ha produces the best results.

Keywords: organic fertilizer; cadmium; uptake; rice; soil

1. Introduction

The current environmental problems in Thailand are at a critical point and will have a negative effect on both humans and all living creatures. Particularly serious are the problems caused by the introduction of heavy metal hazardous waste entering the soil and water resources, the sources of which are primarily mining and agricultural practices that disturb the soil. In these practices, heavy metals leach into the water-holding layers of the soil, both on the surface and underground, and are eventually retained in the soil.

A report by the International Water Management Institute demonstrated cadmium contamination both in the soil and agricultural products from Northern Thailand (Department of Fundamental Industries and Mining, 2006). For this reason, a promotional campaign was instituted to encourage the rice farmers to cultivate sugarcane, instead of rice, to be used in ethanol production (not as a food product). In addition, it was thought that the sugarcane would help to remove the cadmium from the soil. Some rice farmers were reluctant to follow this transition and insisted on growing their rice for survival; others whose land plots were not fit for sugarcane cultivation continued growing their rice crops, with the cadmium presumably persisting in these crops. The present study, therefore, evaluated the cadmium uptake by rice grown under greenhouse conditions using four varieties, Khao Dawk Mali 105 (KDML105), RD6, Phitsanulok3 and Niaw San-Pa-Tong, and soil taken from the actual area of contamination described above. Although cow manure was applied as the organic fertilizer material in this study, we anticipated that the cadmium conversion would occur in a similar fashion when using commercial organic fertilizer. Hence, this study produced a better understanding of how organic fertilizer usage relates to the cadmium-retention ability of the soil and uptake by rice roots. The results presented here should be helpful in determining the appropriate amounts of organic fertilizer that rice farmers should use to return the farm land to food crop production.

2. Materials and Methods

2.1. Cadmium uptake experiment

1) Soil preparation: We surveyed the soil from the area that was contaminated with cadmium using

guidance data from the Geographic Information System (GIS), National Research Center for Environmental and Hazardous Waste Management, Chulalongkorn University (2005), which identifies the area locations and the degree of cadmium contamination. At the contaminated site, we collected soil samples at depths of 0-30 cm, and we also randomly collected soil samples for further cumulative cadmium uptake analysis. The soil samples were analyzed for the following parameters: soil texture, pH, cation exchange capacity (CEC), electrical conductivity (EC), organic matter in the soil (OM), nitrogen (N), phosphorous (P), potassium (K) and the total amount of cadmium (Total Cd).

2) Preparation of the containers: We used plastic buckets with a 30-cm diameter top, 20-cm diameter bottom and 30-cm height as the planting containers. A total of 16 containers were filled with 10 kg dry weight of the soil.

3) Preparation of the plants: The rice varieties, Khao Dawk Mali 105 (KDML105), RD6, Phitsanulok3 and Niaw San-Pa-Tong, were obtained from the Department of Rice, Ministry of Agriculture and Co-operation. The criterion of the grain selection included those of similar size and weight and a percentage of germination above 90%.

4) Preparation of the organic fertilizer: Cow manure was obtained from an uncontaminated area and analyzed to confirm that it was cadmium-free. It was desiccated until dried and then applied at ratios of 0, 3.25, 6.25 and 12.5 ton/ha and triplication of experiments.

5) Plant growth and care: Each rice varieties were surfaced sterilized and germinated in DI-water for 2-3 days and transplanted into the containers with a density of 5 plantlets per container and the observe their hardiness was selected after 2 weeks so that a density of 3 plants per container per rice varieties was obtained and the plants received regular watering; the water level was controlled within the flood limits throughout the duration of the trial. As soon as the grain reached maturity, it was left to dry until it was ready for harvesting. No chemical fertilizer or any other functional chemicals were used during the experiment.

6) Soil sampling: The soil and plants were sampled at intervals of 30, 60, 90 and 120 days, corresponding to the stages of initial, vegetative, panicle formation and maturation, respectively, and the cadmium uptake from the soil was determined. The plant material was washed with distilled water and sorted into two groups: the above-soil parts (i.e., the stems and leaves) and the below-soil parts (i.e., the roots). The material was dried in a hot-air oven at 105 °C for 24-48 hours until reaching a constant weight, ground into a fine powder and analyzed for the total cadmium content. At the final time interval of 120 days, the material consisted of the grain seed and husks, which were processed by trampling and analyzed for the cadmium uptake.

7) Water sampling: Samples of the water in the containers were collected 4 times, at intervals of 30, 60, 90 and 120 days. The samples collected were stored in 200-ml glass bottles to which 2-3 drops of 65% nitric acid was added before refrigeration. These samples were also analyzed for the total Cd.

2.2. Analytical methods

The analysis of cadmium in the soil and the 4 different tissues of the rice plants (above-soil parts, below-soil parts, grain and husk, was conducted using USEPA method 3052 (USEPA, 1996). The cadmium determination in the water was performed using USEPA method 3051A (USEPA, 1998) by an acid digestion technique with a microwave digestion, followed by the measurement of total cadmium with atomic absorption spectrometry (AAS).

2.3. Statistical Analyses

The statistical variance of the cumulative cadmium uptake from the soil and the total cadmium uptake by the rice was analyzed using Analysis of Variance (ANOVA) statistical models at the 95% confidence level. The data variances were compared with those of the means using Duncan's New Multiple Range Test (DMRT), and we utilized the Statistical Package for Social Science (SPSS) to analyze the data into operational solutions.

3. Results and Discussion

3.1. Soil properties

The soil used in this experiment was of a clay loam texture class; additional properties are provided in Table 1. We found that the experimental soil demonstrated a cadmium accumulation of 68.9 mg/kg, which exceeds the safety standards for the cultivation of food crops.

3.2. Soil pH

For the organic fertilizer concentrations of 3.25, 6.25 and 12.5 ton/ha, the pH in the soil with Khao Dawk Mali 105 ranged from 7.80 to 7.86, 7.75 to 8.01 and 7.67 to 7.81, respectively, whereas that with the RD6 cultivar ranged from 7.81 to 7.87, 7.81 to 7.96 and 7.88 to 8.01, that with Phitsanulok3 ranged from 7.40 to 7.77, 7.82 to 7.94 and 7.84 to 7.94, and that with Niaw San-Pa-Tong ranged from 7.74 to 8.02, 7.27 to 7.83 and 7.83 to 7.96, respectively. The variations in the pH were minor because the organic fertilizers applied interacted with

Table 1. Fundamental properties of the experimental soil

Parameters	Properties
Sandy Clay (%)	33.2
Silty Clay (%)	32.0
Clay (%)	34.8
Texture Class	Clay Loam
pH	7.4
CEC (c $mol_{(+)}$/kg)	15.5
EC (ds/m)	0.125
Organic Matters (%)	2.18
Nitrogen (%)	0.109
Phosphorous (ppm)	21
Potassium (ppm)	150
Cadmium (mg/kg)	68.9

the cadmium and formed metal complexes that caused gradual changes in the soil pH (Adriano, 2001).

3.3. Cadmium accumulation in the water and soil

1) The accumulation of cadmium in the water: The levels of cadmium in the water of the experimental containers are given in Table 2. The amount of cadmium detected in the water was insignificant in comparison with that in the soil. This indicates that the leaching of cadmium into the water was minimal.

2) The accumulation of cadmium taken up from the soil: At 120 days, the cumulative amounts of cadmium taken up from the soil amended with organic fertilizer at 0, 3.25, 6.25 and 12.5 ton/ha by Khao Dawk Mali 105 were 55.06, 67.18, 76.73 and 68.62 mg/kg, respectively, whereas the amounts for RD6 were 39.20, 56.96, 85.49 and 75.54 mg/kg, respectively; those for Phitsanulok3 were 36.42, 67.17, 71.18 and 70.21 mg/kg, respectively; and those for Niaw San-Pa-Tong were 40.76, 67.22, 77.18 and 77.52 mg/kg, respectively.

For each variable, the cumulative amount of cadmium taken up from the soil (Fig. 1) without organic fertilizer was less than that from the soil with organic fertilizer. This suggests that the cadmium uptake from the soil with organic fertilizer would be highest due to the fact that the application of organic fertilizer would enhance heavy metals retention in the soil because the organic matter possesses many negative ions that could attract positive ions 2-30 times better than other colloids. For this reason, the application of organic fertilizer into the soil will help prevent heavy metal uptake (Pinto *et al*., 2004; National Research Center for Environmental and Hazardous Waste Management, 2005).

3.4. Cadmium uptake by rice

At 120 days, the amount of cadmium accumulated in the above-soil tissues (stems and leaves) grown in the soil with organic fertilizer at concentrations of 0, 3.25, 6.25 and 12.5 ton/ha were as follows: 8.00, 7.17, 5.84 and 5.61 mg/kg, respectively, for Khao Dawk Mali 105; 8.67, 8.09, 5.04 and 4.67 mg/kg, respectively, for

Table 2. Cadmium amount in water

Rice varieties	Organic fertilizer (ton/ha)	Cd Accumulative at time intervals (mg/L)			
		30 days	60 days	90 days	120 days
Khao Dawk Mali 105	0	0.072	0.123	0.056	0.379
	3.25	0.062	0.082	0.123	0.354
	6.25	0.085	0.092	0.066	0.261
	12.5	0.077	0.026	0.082	0.397
RD6	0	0.058	0.054	0.113	0.392
	3.25	0.02	0.089	0.122	0.131
	6.25	0.071	0.035	0.131	0.283
	12.5	0.082	0.057	0.036	0.275
Phitsanulok3	0	0.087	0.012	0.114	0.254
	3.25	0.057	0.074	0.28	0.198
	6.25	0.064	0.103	0.17	0.216
	12.5	0.097	0.053	0.11	0.17
Niaw San-Pa-Tong	0	0.041	0.109	0.174	0.105
	3.25	0.105	0.077	0.147	0.301
	6.25	0.106	0.053	0.142	0.198
	12.5	0.111	0.116	0.122	0.368

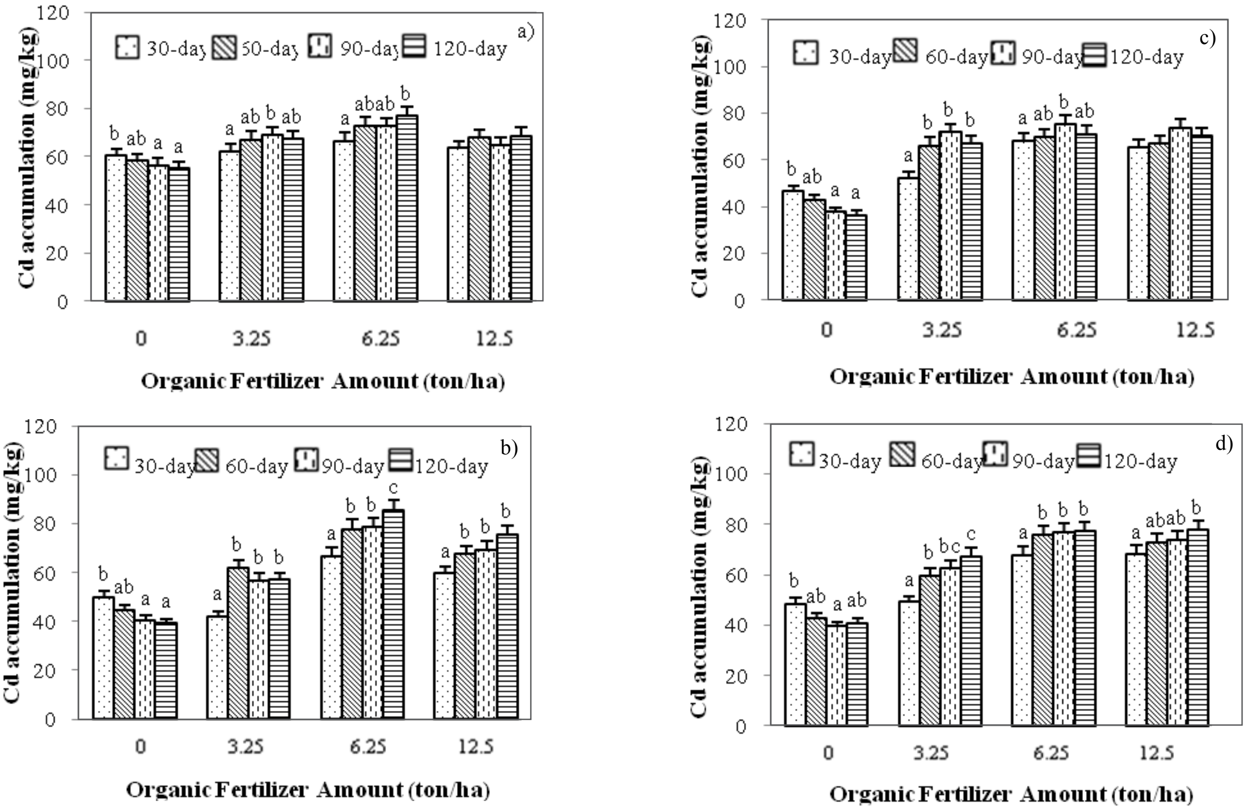

Figure 1. Cadmium accumulation in the soil a) Khao Dawk Mali 105, b) RD6, c) Phitsanulok3 and d) Niaw San-Pa-To. Mean ± SEM, *n=3*. Numbers followed by the same letter in each bars are not significantly different at $p<0.05$ by DMRT.

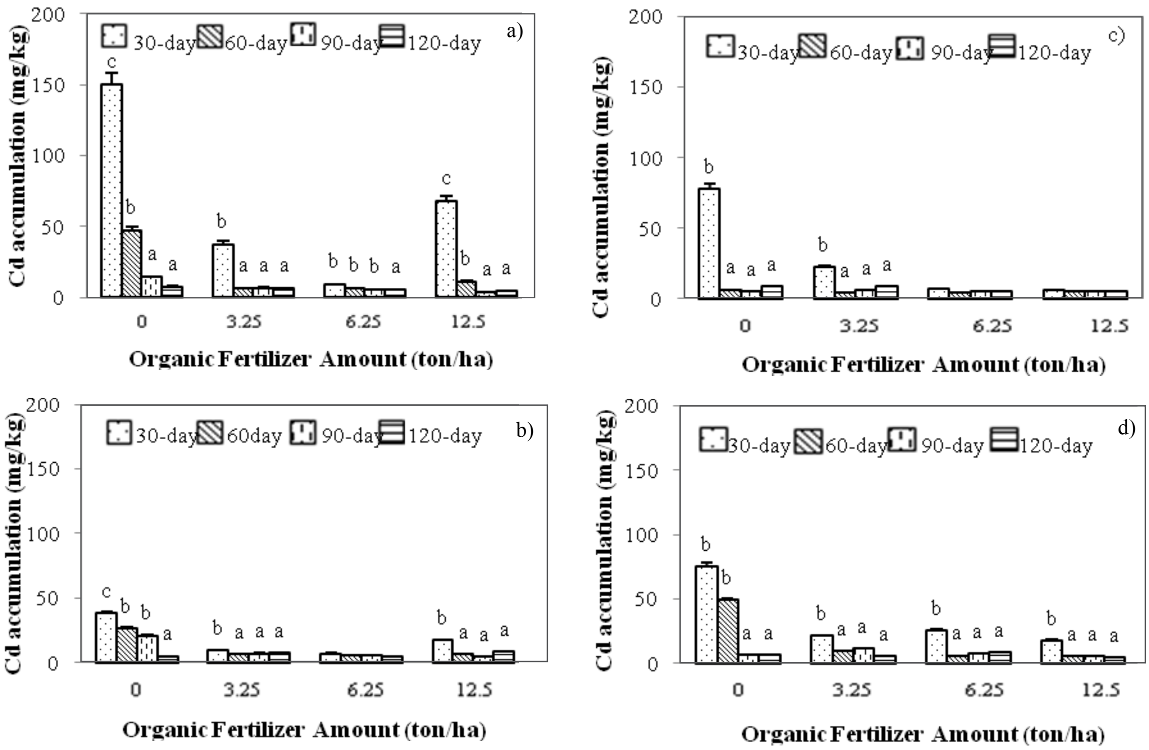

Figure 2. Cadmium accumulation in the above soil tissues (stems and leaves) a) Khao Dawk Mali 105, b) RD6, c) Phitsanulok3 and d) Niaw San-Pa-Tong.
Mean ± SE M, *n=3*. Numbers followed by the same letter in each bars are not significantly different at $p<0.05$ by DMRT.

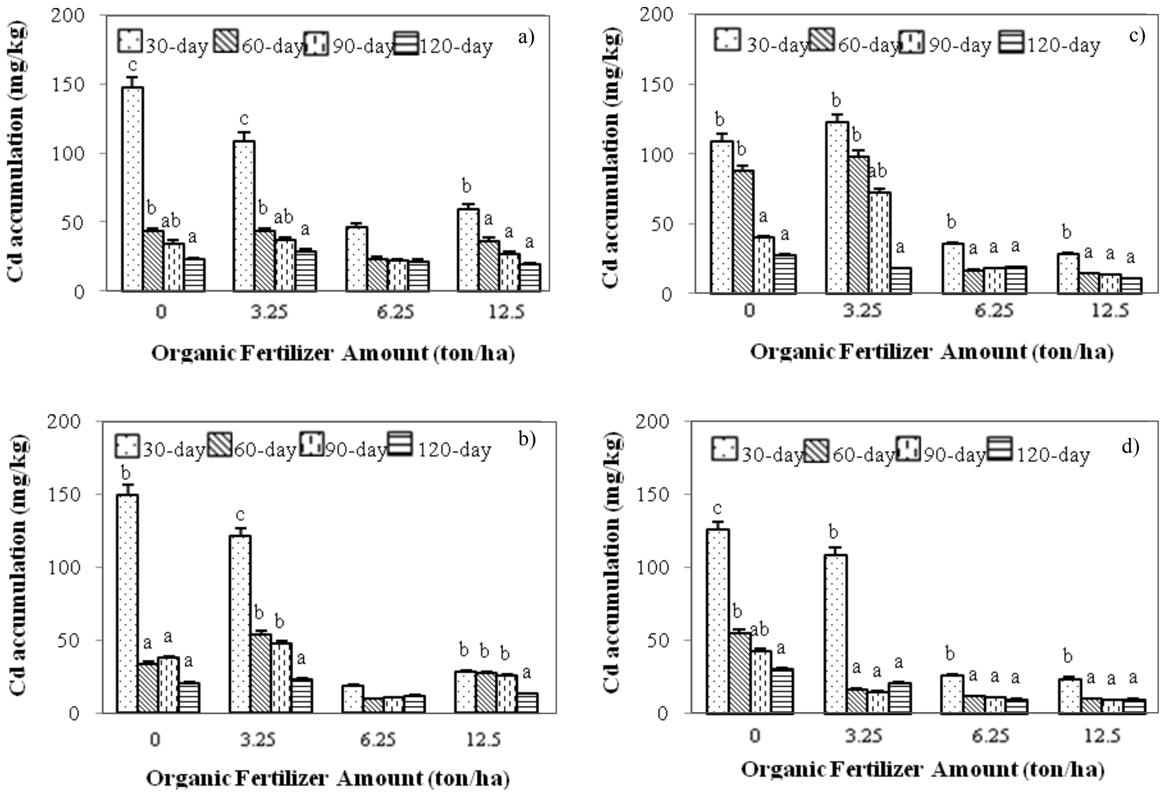

Figure 3. Cadmium accumulation in the below soil tissues (roots) a) Khao Dawk Mali 105, b) RD6, c) Phitsanulok3 and d) Niaw San-Pa-Tong Mean ± SEM, $n=3$. Numbers followed by the same letter in each bars are not significantly different at $p<0.05$ by DMRT.

RD6; 4.84, 7.24, 4.57 and 8.21 mg/kg, respectively, for Phitsanulok3 and 6.29, 5.42, 8.27 and 4.10 mg/kg, respectively, for Niaw San-Pa-Tong. At 120 days, the amount of cadmium accumulated in the below-soil tissues (roots) grown in the soil with organic fertilizer at concentrations of 0, 3.25, 6.25 and 12.5 ton/ha were as follows: 23.05, 28.98, 21.63 and 19.43 mg/kg, respectively, for Khao Dawk Mali 105; 20.52, 22.61, 11.72 and 13.08 mg/kg, respectively, for RD6; 29.63, 20.06, 9.12 and 9.42 mg/kg, respectively, for Phitsanulok3 and 26.76, 17.65, 18.63 and 10.73 mg/kg, respectively, for Niaw San-Pa-Tong.

Figs 2 and 3 demonstrate that the accumulated cadmium uptake by both the above- and below-soil tissues tended to decrease over time. We also found that, in all of the experimental rice varieties, the overall amounts of cadmium accumulated were lower in the plants grown with organic fertilizer than without fertilizer. This result was in accordance with a previous report that using organic compounds mixed with sediment and rice straw resulted in a slow rate of cadmium uptake from the soil (Chen and Chen, 2002). In our study, the cadmium accumulation for each of the varieties was higher in the roots than in the stems. This was also consistent with a previous report on the accumulated cadmium by rice, soybean and maize that were grown in soil contaminated with cadmium (Murakami and Ishikawa, 2007). Kim *et al*. (2002) illustrated that a little portion of cadmium is translocation to the shoot and that about 82% is accumulation in the roots of rice seedlings. From the analysis of the accumulated cadmium in the rice husk (Fig. 4), we determined that Khao Dawk Mali 105 and RD6 showed the lowest values, at 8.16 and 9.16 mg/kg, respectively, while growing in the soil with organic fertilizer applied at 12.5 ton/ha. The cadmium accumulation was the lowest in Phitsanulok3, at 9.38 mg/kg, under the soil with organic fertilizer at 6.25 ton/ha, and for Niaw San-Pa-Tong, its cadmium uptake was the lowest while growing in the soil with organic fertilizer at 3.25 ton/ha, at 4.78 mg/kg. For the grain, the cadmium accumulation in Khao Dawk Mali 105, RD6, Phitsanulok3 and Niaw San-Pa-Tong were consistently the lowest while growing in the soil with organic fertilizer at 12.5 ton/ha, with values of 0.11, 0.09, 0.06 and 0.07 mg/kg, respectively. Liu *et al*. (2007) found that the cadmium accumulated in different part of the rice plant were as follows: root > stem > leave > grain; over 98% of cadmium was found in the root and stems. However, Kashiwagi *et al*. (2009) concluded that the cadmium concentration in grain is determined by the cadmium already accumulated in the leaves and stem before the panicle formula stage.

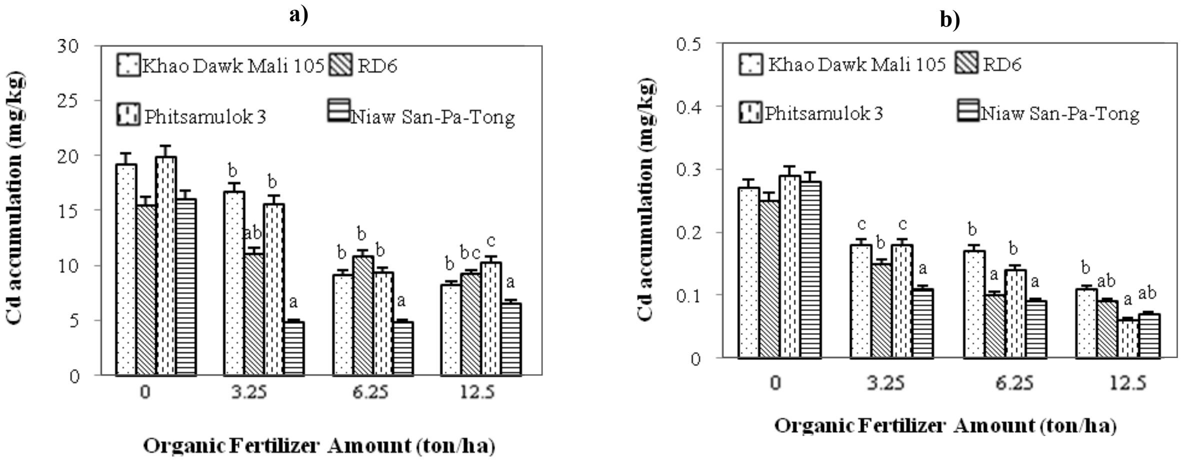

Figure 4. Cadmium accumulation in the varieties of rice a) Husk and b) Grain Mean ± SEM, *n=3*. Numbers followed by the same letter in each bars are not significantly different at *p<0.05* by DMRT.

Fig. 4 shows that, for each of the varieties of rice, the cadmium uptake by the husk and grain of the plants growing in the soil without organic fertilizer was higher than the plants growing in soil with organic fertilizer at all of the tested concentrations. This suggests that the husk and grain accumulated less cadmium when grown in soil with organic fertilizer. This result was consistent with the study of the effects of organic fertilizer on heavy metals adsorption from the soil (Kashem and Singh, 2001; Pinto *et al*., 2004; Mahara *et al*., 2007).

4. Conclusions

The results show that the addition of organic fertilizer to the soil correlated with a higher accumulation of cadmium. Thus, we conclude that organic fertilizer can help the soil retain cadmium and that 6.25 ton/ha of organic fertilizer would produce optimum results. Specifically, after 120 days, the cadmium accumulation in both the above- and below-soil tissues were the lowest under the condition of 6.25 ton/ha organically fertilized soil. The cadmium accumulation by Phitsanulok3 was less than that by Khao Dawk Mali 105. At 120 days, the cadmium accumulation by Niaw San-Pa-Tong was the lowest under the condition of 12.5 ton/ha organically fertilized soil. The cadmium uptake of RD6 was lower than that of Niaw San-Pa-Tong and was the lowest under the condition of 12.5 ton/ha organically fertilized soil. Phitsanulok3 demonstrated the least Cd accumulation in the grain. In our study, the cadmium accumulation under organic fertilizer conditions in the grain did not exceed the standard set by the EU of a maximum of 0.2 mg/kg (Commission Regulation, 2006).

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