INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 10, No. 5, p. 232-238, 2017

RESEARCH PAPER OPEN ACCESS

Determination of cadmium accumulation potential and toxicity threshold level of rice in Alfisol

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Key words: Cadmium, Phytotoxicity, Toxic level, Bioconcentration, Human food chain

http://dx.doi.org/10.12692/ijb/10.5.232-238 Article published on May 29, 2017

Abstract

Cadmium (Cd) is responsible for limiting the crop yield and contaminating the food chain. Therefore, an experiment was carried out in net-house, department of soil science, Bangladesh Agricultural University, Mymensingh during 2010-2011 to assess the role of Cd on yield and bioaccumulation of Cd in rice as well as food chain contamination. The experiment was conducted in pot with rice (*Oryza Sativa* L.) as a test crop on acidic soil (Alfisol). The soils were contaminated with increasing concentrations of Cd (i.e 0, 3, 6, 9, 12, 18 and 24 mg kg^{-1} soil). The concentrations of Cd in rice at different levels of soil contamination were compared with the threshold concentrations of Cd in cereals as established by the Codex Alimentarius Commission (CAC). A bioaccumulation factor was calculated to estimate the potential transfer of Cd to the food chain. According to the results, Cd showed phytotoxic effect on rice growth and Cd contaminated soil was of great potential risk of Cd transfer to the human food chain. The pre-established maximum acceptable concentration of Cd in soil of 1-20 mg kg^{-1} was not safe to prevent the contamination of food chain for acidic soil.

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Introduction

Rice is the staple food of Bangladesh and the world's third largest crop, which has significant uses of human nutrition. People, especially those who take rice as main food for daily energy are exposed to significant amount of heavy metals via rice (Watanabe *et al.*, 1996). Among the major staple crops, rice is the particular one with high Cd uptake and accumulation (Chaney *et al.*, 2004). Cadmium is one of the main pollutants in rice paddy soil near industrial areas and highly toxic to rice growth and development (Chien and Kao, 2000). It can be absorbed and transported effectively by rice plants, and thus it could easily enter the food chain. Cadmium is a potentially toxic metal that can accumulate in the human body with a half-life exceeding 10 years (Salt *et al.*, 1995). Cadmium cannot be chemically degraded or destroyed. Therefore, Cd tends to bioaccumulate once entered the organisms (Zhuang *et al.*, 2009).

Warnings and critical limits are often based on total soil Cd content. Few countries have established guidelines for threshold concentrations of Cd to regulate metal levels in soils. However, it is widely accepted that the total soil Cd concentrations are poor indicators of their potential effects and their toxicity to terrestrial organisms (Abollino *et al.*, 2005; Finžgar *et al.*, 2007). Therefore, to determine the potential for Cd to confer health problems to consumers of crops grown on contaminated soils, bioavailability and food chain transfer need to be considered. There is a great disparity between countries as to the maximum acceptable levels of metals established by them for agricultural soils receiving anthropogenic inputs of metals (McLaughlin *et al.*, 2000). The maximum acceptable concentration of Cd, among different countries, is in the ranges of 1-20 mg kg^{-1} (Council Directive 86/278/EEC, 1986; McLaughlin *et al.*, 2000). Few countries have also established guidelines for allowable concentrations of metals in such foods as cereals. According to these guidelines, allowable concentrations of Cd in cereals are 0.4 mg Cd kg^{-1} fresh weight (Hamon and McLaughlin, 2003).

Cadmium has been identified as the major heavy metal of health concern in contaminated lands. It is relatively more available to plants and is found in concentrations in harvestable parts of the crops that could be harmful to humans but are not toxic to the plant (Stevens and McLaughlin, 2006). Therefore, the aims of this study were (i) to assess the effect soil Cd contamination on the yield reduction of rice, and (ii) to determine the bioconcentration of Cd by rice and the risk of food chain contamination.

Materials and methods

Location and soils

An experiment was conducted in pot with rice (*Oryza Sativa* L.) as a test crop on acid soil collected from Banbladesh Agricultural Development Corporation (BADC) farm Madhupur, Bangladesh (24.09°N-90.26°E). The soil was in Kalma series with soil order Alfisol. The important properties of these soils are presented in table 1. The collected soils were air dried and ground to pass through a 2-mm sieve.

Pot experiment

Ten kilogram of soil (dry weight basis) was taken in a series of non-porous and plastic pots. A blanket dose of 115 mg kg^{-1} N, 25 mg kg^{-1} P, 50 mg kg^{-1} K and 10 mg kg^{-1} S was applied to each pot. Full doses of P, K, S and Cd (treatment wise), and 1/3 N dose were mixed with soil. The soil was submerged with distilled water for 24 hour. The remaining N was applied in two equal splits at 20 and 45 days after transplanting. Different levels of Cd were added as $Cd(NO_3)_2$ @ 0, 3, 6, 9, 12, 18 and 24 mg kg^{-1} soil. Three rice seedlings (BRRI dhan 31) of 30 day old were transplanted in a pot. The crop was harvested at the maturity stage.

Analysis of grain and straw sample

The grain and straw were air-dried and then oven-dried at 70°C. Dried plant tissues and grains were digested with di-acid mixture (HNO_3:$HClO_4$ = 4:1) and analysed for Cd (Yoshida *et al.*, 1976) by Atomic Absorbtion Spectrophotometer (UNICAM, 969). The total amount of Cd in plants was extracted and analyzed to ensure that the Cd is not transferred to the food chain.

The concentrations of Cd in rice at any level of soil Cd was compared with the threshold concentrations of Cd in creals as established by the Codex Alimentarius Commission (CAC) (Hamon and McLaughlin, 2003). From this comparison the maximum allowable concentrations of this metal in the soil (i.e. the total Cd in soil which lead to Cd threshold concentrations in plants) was defined. This way, the utility of using the pre-established soil threshold concentrations for Cd (Hamon and McLaughlin, 2003) as a substitute for plant metal thresholds to control food chain exposure to metals was tested. To test the phytotoxicity of the metals, the plants yield reduction was also determined at the applied soil Cd concentrations. The toxic level of Cd has been determined by graphical method. A method proposed by Bingham *et al.* (1975) was employed to calculate the critical toxic concentration of Cd in soil and plants. Percent relative dry matter yields (Cate and Nelson, 1965) were plotted against extractable content of Cd in soil or content of Cd in plant tissues.

Critical toxic limits of Cd in soil and plants were determined for 10 percent reduction in dry matter yield (Lagriffoul *et al.*, 1998; Deepali-Joshi *et al.*, 2010). To estimate the potential transfer of Cd to the food chain the bioconcentration of soil metal by plant is also calculated as follow:

$$BCF = \frac{\text{Total metal in plant fresh matter (mg/kg)}}{\text{Total metal in soil (mg/kg)}} \times 100$$

Where, BCF (-) is biconcentration factor.

Results and discussion

Grain and straw yield of rice

The concentration of different levels of cadmium significantly decreased the grain and straw yield over control (Table 2).

The highest grain (25.14 g pot^{-1}) and straw (32.76 g pot^{-1}) yield of rice was recorded for control. It was almost identical to 3 mg Cd kg^{-1} soil but significantly higher than any other treatments).

Table 1. Characteristics of the experimental soils.

Physical Parameter	Value
Sand	37.27
Silt	36.30
Clay (%)	26.46
Texture	Loam
Chemical characteristics	
pH	5.46
OM (%)	1.51
CEC (cmol kg^{-1})	12.5
Total N (%)	0.075
Available P (mg kg^{-1})	5.85
Available S (mg kg^{-1})	15.32
Exchangeable K (cmol kg^{-1})	0.11
Exchangeable Ca (cmol kg^{-1})	2.26
Exchangeable Mg (cmol kg^{-1})	0.78
Total Cd (mg kg^{-1})	0.38

The lowest yields of grain (14.24 g pot^{-1}) and straw (22.36 g pot^{-1}) were recorded from 24 mg Cd kg^{-1} soil treated pot. The grain yield decreased with increasing level of Cd. Reductions in the dry matter yields of Cd sensitive plants with increasing rates of added Cd, were also recorded by Sarkunan *et al.* (1991) and Gajdos *et al.* (2009).

Decline in relative yield in rice grain ranged from 0.48% to 42.88%. On the other hand, relative straw yield reduction was ranged from 0.76% to 32.30% (Fig. 1). Adverse effects of Cd on crops have been reported by Selvam and Woon Chung (2009).

Among the levels of Cd concentration, percent yield loss was more in higher level and less in lower level (Fig.2). Therefore, due to Cd toxicity, percent yield loss was more in higher level and less in lower level of Cd. More yield loss in higher Cd level is in agreement with the findings of Lokhande and Kalkar (1999). Reductions in the dry matter yields of Cd sensitive plants with increasing rates of added Cd, were also recorded by Gajdos *et al.* (2009). Soil pH is the main factor of this phenomenon, because soil-Cd is easily mobile in a pH range of 4.5-5.5 while at higher pH values it turns into insoluble carbonate and phosphate forms (Kabata-Pendias, 2000). In a soil solution, Cd often occurs as the Cd^{2+} ion, but it can also create complex ions. When soil pH increases, $CdOH^+$ ions are bound more strongly by organic colloids, aluminum, and iron oxide. This process lowers Cd availability to plants (Patorczyk-Pytlik and Spiak, 2000).

Table 2. Effects of cadmium on the grain and straw yields of rice.

Treatment	Grain	Straw	Above ground biomass
		g pot^{-1}	
Cd_0 (Control)	25.14a	33.03a	58.17a
Cd_3 (3 mg kg^{-1} soil)	25.02a	32.78a	57.80a
Cd_6 (6 mg kg^{-1} soil)	23.28b	31.12b	54.40b
Cd_9 (9 mg kg^{-1} soil)	20.24c	28.24c	48.48c
Cd_{12} (12 mg kg^{-1} soil)	19.36d	27.27c	46.63c
Cd_{18} (18 mg kg^{-1} soil)	17.45e	25.68d	43.13d
Cd_{24} (24 mg kg^{-1} soil)	14.36f	22.36e	36.72e
CV (%)	2.31	1.67	1.99

Values within columns followed by same letters do not differ significantly at 5% level by DMRT.

The maximum accumulation of Cd was 1.32 mg kg^{-1} dry rice grain at 24 mg kg^{-1} Cd in soil. On the other hand, maximum accumulation of Cd in rice straw was 23.25 mg kg^{-1} at 24 mg kg^{-1} Cd in soils (Fig. 2). It indicates that rice straw is tending to take up more Cd than rice grain. In higher Cd concentration levels, plants Cd concentrations were more i.e. plants uptook and accumulated more Cd.

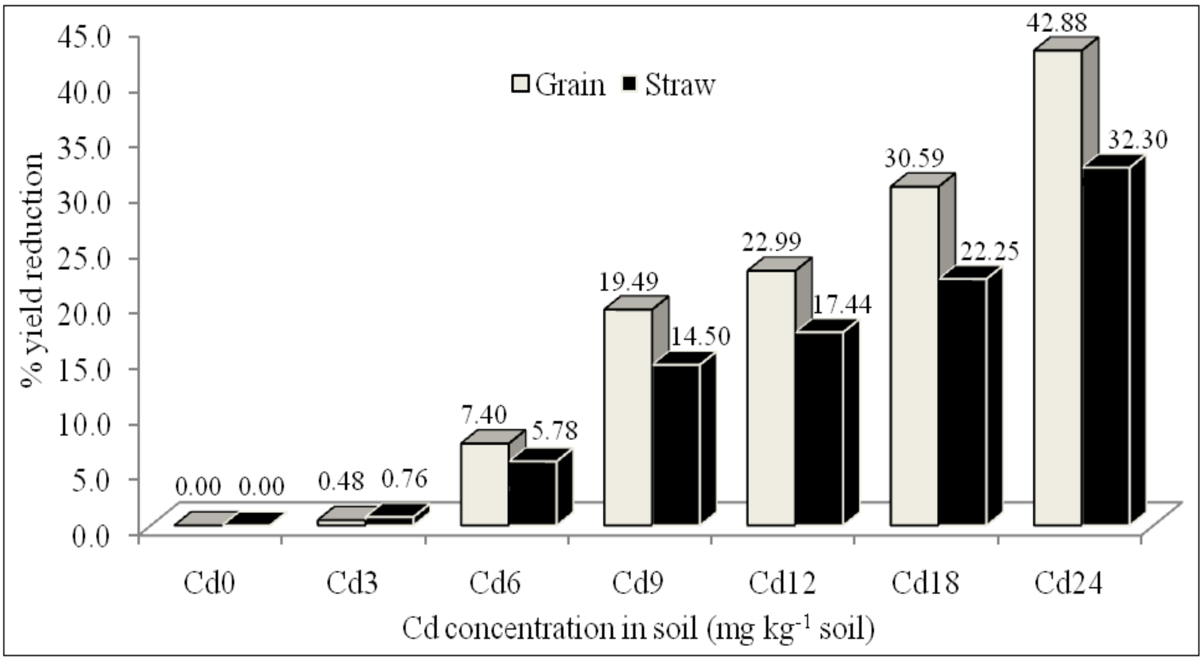

Fig. 1. Effects of soil Cd concentration on the % yield reduction.

These results are similar to the findings of Mahler *et al.* (1978). Differential Cd uptake by the plants grown on acid soils has been attributed to the reduction in the solubility of Cd associated with high pH.

Adsorption of metals almost invariably decreases with increasing soil acidity (Basta and Tabatabai, 1992; Bolan *et al.*, 1999a; Naidu *et al.*, 1994). The Cd content in rice was increased with the increased of soil Cd contamination.

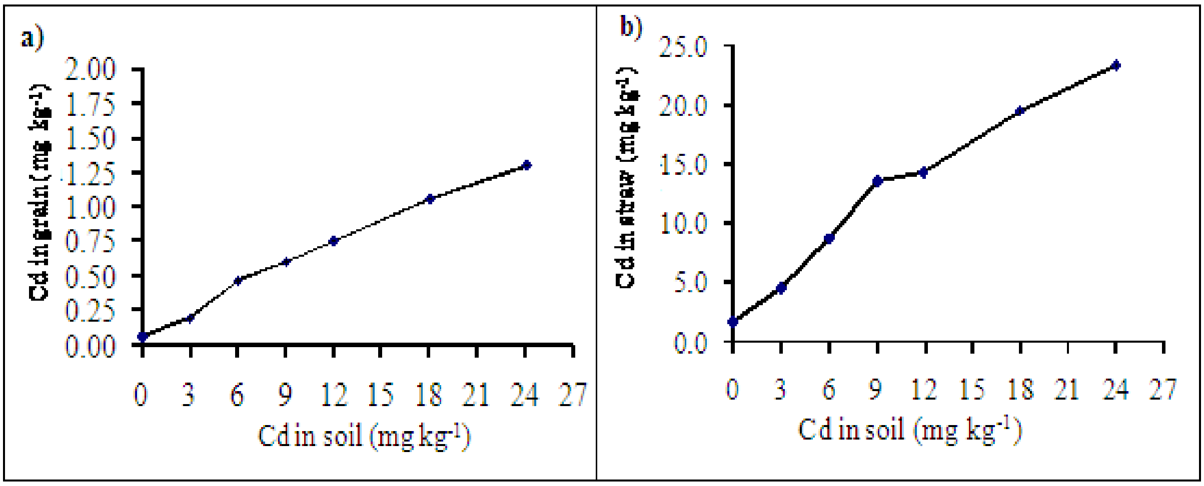

Fig. 2. Concentration of Ca in rice (a) grain and (b) straw for the different levels of Ca contamination in soil.

To test the metal phytotoxicity the reductions in plant yield were assessed at the upper and lower limits of pre-established maximum acceptable concentration of the metal in soil (1-20 mg kg^{-1} siol for Cd). The yield reductions, as an indication of metal phytotoxicity was between ≈ 0 to 35.85% for rice grain and ≈ 0 to 26.63% for rice straw , when soil total Cd was in the range of pre-established maximum acceptable concentration (1-20 mg Cd kg^{-1} soil) (Fig. 3). In case of rice straw, yield reduction was lower than rice grain i.e. phytotoxicity was higher in rice grain.

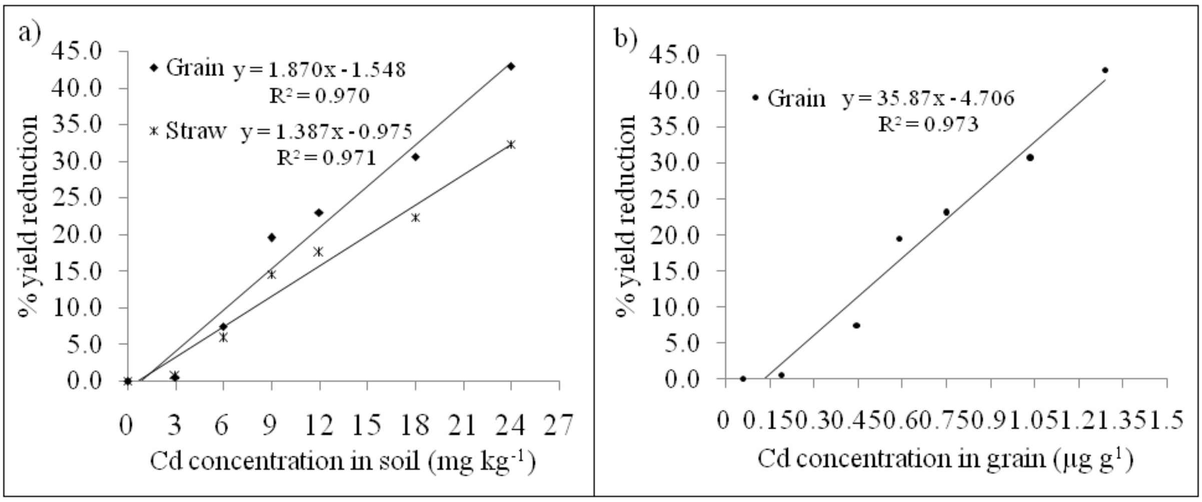

Fig. 3. Relationship between % yield reductions with a) soil Cd concentration and b) grain Cd concentration.

The threshold values for Cd phytotoxicity were defined as the concentration in the plant tissue above which growth was reduced or metabolism changed ± 10% (Lagriffoul *et al.*, 1998; Deepali-Joshi *et al.*, 2010).

In the graphical method, according to Lagriffoul *et al.* (1998) and Deepali-Joshi *et al.* (2010), the toxic level of total soil Cd for rice grain was found 6.18 mg kg^{-1} soil but in case of straw, it was 7.91 mg kg^{-1} soil (Fig. 3).

On the other hand, the toxic level of Cd concentration in plant tissue of rice grain was 0.41 mg kg^{-1} at 10% yield reduction. Sarkunan *et al.* (1991) also found significant reduction in grain and straw yields of rice at 10 mg Cd kg^{-1}.

To assess the risk of human food chain contamination, the metal concentration of plant's fresh matter, when grown on a soil which the Cd concentrations were in the range of upper and lower limits of pre-established maximum acceptable concentration of the metal in soil (1-20 mg kg^{-1} soil), was compared with the allowable concentration of this metal in cereals (0.4 mg kg^{-1}).

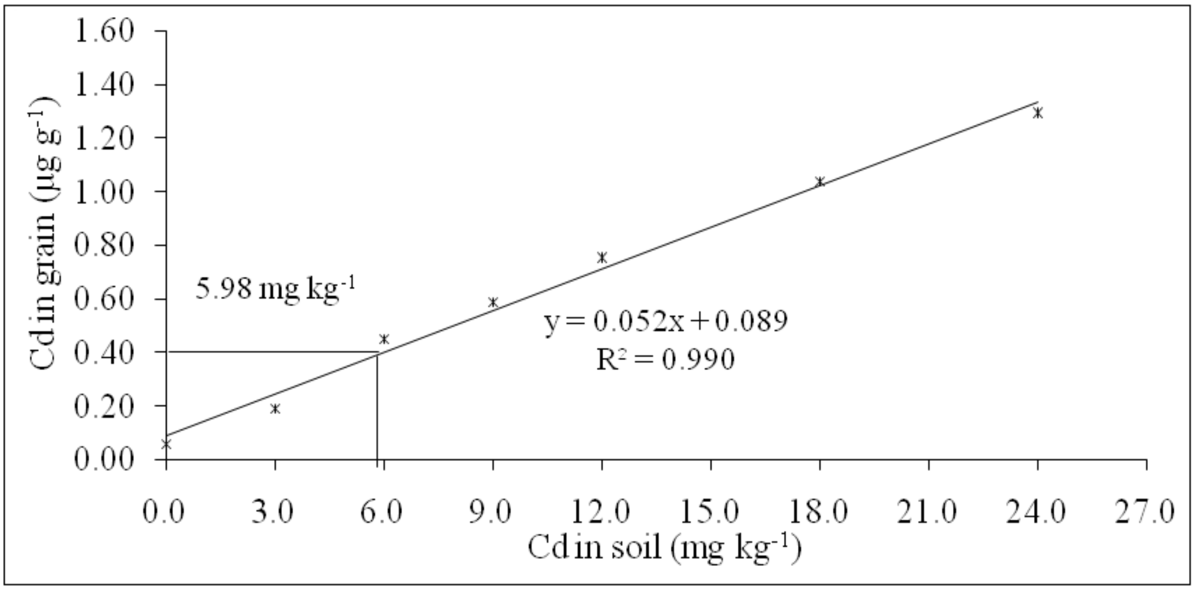

Fig. 4. Relationship between soil Cd concentration with grain Cd concentration.

Rice grain was used as dry basis, therefore risk assessment was measured by dry weight basis. Result show that rice grain concentrations of Cd was fairly greater than the allowable concentration of Cd in cereals of 0.4 mg kg^{-1}, when they were grown on a soil with 5.98 mg Cd kg^{-1} acid soil (Fig. 4).

These results showed that, for the soil in this study, the pre-established maximum acceptable concentration of Cd in soil of 1-20 mg kg^{-1} is not safe to prevent the contamination of food chain. These results also showed that the Cd is of a greater potential of entering the human as well as animal food chain in acidic soil.

Conclusion

Increasing levels of Cd significantly reduced the yield of rice. Yield reduction was higher due to higher phytotoxicity caused by higher accumulation of Cd at higher level of Cd.

Results also showed that, the pre-established maximum acceptable concentration of Cd in soil (1-20 mg kg^{-1}) is not safe to prevent the contamination of food chain for acidic soil. So, it is necessary to set up new maximum acceptable concentration of Cd for acidic soil.

References

Basta NT, Tabatabai MA. 1992. Effect of cropping systems on adsorption of metals by soils. II. Effect of pH. Soil Science **153**, 195–204.

Bolan NS, Naidu R, Khan MAR, Tillman RW. 1999. Syers J.K. The effects of anion sorption on sorption and leaching of cadmium. Australian Journal of Soil Research **37,** 445-460. http://dx.doi.org/10.1071/S97046

Cate RB, Nelson LA. 1965. International Soil Testing Series Technical Bulletin 1, North Carolina, USA, p. 32.

Deepali-Jushi, Srivastava PC, Srivastava P. 2010. Toxicity threshold limits of cadmium for leafy vegetables raised on mollisol amended with varying levels of farmyard manure. Pedologist **54,** 249-256.

Gajdos E, Bakonyi N, Levai L, Veres S, Marozsan M, Toth B. 2009. Physiological examination of cadmium contamination on corn and sunflower seedlings. Zbornik-Radova-44-Hrvatski-i-4-Medunarodni-Simpozij-Agronoma,-Opatija,-Hrvatska,-16-20-Veljace, 510-512 P.

Lagriffoul A, Mocquot B, Mench M, Vangronsveld J. 1998. Cadmium toxicity effects on growth, mineral and chlorophyll contents, and activityes of stress related enzymes in young maize plants (*Zea mays* L.). Plant and Soil **200,** 241-250. http://dx.doi.org/10.1023/A:1004346905592

Lokhande RS, Kelkar N. 1999. Studies on heavy metals in water of Vasai Creek Maharashtra. Indian Journal Environment Protect **19,** 664-668.

Mahler RJ, Bingham FT, Page AL.1978. Cadmium-enriched sewage sludge application to acid and calcareous soils – effect on yield and cadmium uptake by lettuce and chard. Journal of Environmental Quality **7,** 274–281.

Mclaughlin MJ, Parker DR, Clarke JM. 1999. Metals and micronutrients: Food safety issues. Field Crops Research **60,** 143–163. https://doi.org/10.1016/S0378-4290(98)00137-3

Naidu R, Bolan NS, Kookana RS. 1994. Tiller K.G. Ionic-strength and pH effects on the adsorption of cadmium and the surface charge of soils. European Journal of Soil Science **45,** 419-429.

Sarkunan V, Misra AK, Nayar PK. 1991. Effect of compost, lime and P on cadmium toxicity in rice. Journal of Indian Society of Soil Science **39,** 595-597.

Selvam A, Woonchung W. 2009. Cadmium uptake potential of *Brasssica napus* cocropped with *Brassica parachinensis* and *Zea mays*. Journal of Hazardous Materials **167,** 170-178. http://dx.doi.org/10.1016/j.jhazmat.2008.12.103

Tiller KG. 1988. Heavy metals in soils and their environmental significance. Advances in Soil Science **9,** 113–142.

Watanabe T, Shimbo S, Moon CS, Zhang ZW. 1996. Cadmium contents in rice samples from various areas in the world. Science of the Total Environment **84,** 191-196. https://doi.org/10.1016/0048-9697(96)05100-5

Zhuang P, Zou B, Li Ny, Li Z.A. 2009. Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: implication for human health. Environment Geochemical Health **31,** 707-715. http://dx.doi.org/10.1007/s10653-009-9248-3