Influence of percolation pattern on growth and yields of rice plants and uptake of cadmium with soil dressing models

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Abstract
A greenhouse experiment was conducted to evaluate the effect of open system percolation and close system percolation on accumulation of Cadmium in various parts of the rice plant using cadmium polluted paddy field model with soil dressing. Low groundwater level in an open system percolation model caused oxidation of soil, on the other hand, the closed system percolation model with a high ground water level resulted in grayish reduced soil. The concentration of cadmium in polluted soil was 3.39 mg/kg. Cadmium accumulation in all parts of rice plants (roots, stems, leaves and grains) was higher for open system percolation in the paddy field model than for the closed system percolation. Cadmium uptake by rice plants was enhanced in the open system percolation model due to the interactions of oxidation and reduction. Finally it can be concluded that the low redox potential (Eh) value in a closed system percolation model was effective in reducing cadmium accumulation in rice plant.

Key Words
Percolation pattern, cadmium concentration of rice plant, growth and yields, soil dressing.

Introduction
Heavy metal pollution in soil has an adverse effect on plant growth. Cadmium is one of heavy metals for soil pollution. WHO set the cadmium concentration for edible rice grain <0.001 mg/ kg. Eating of high cadmium content rice may cause Itai-Itai disease, which was documented in Toyama prefecture of Japan. Many technologies have been studied for reduction of cadmium in rice grain. Water management in paddy fields may be used as a method to reduce cadmium uptake in rice plants as the Ministry of Agriculture, Forestry and Fisheries and National Institute for Agro-Environmental Sciences, Japan (2002) recommended the flooding water of paddy before and after the heading, and soil improvement using fertilizers for minimizing cadmium uptake in rice plants. The percolation pattern is related to hydraulic conductivities of the soil layers and hydraulic conditions such as groundwater level (Adachi *et al.* 1992), which may acts as controllers of soil redox potentials, consequently the uptake of cadmium in the rice plants. In paddy field, water is needed for saturating soil, surface ponding, percolation seepage (bund percolation) and evapo-transpiration (Adachi *et al.* 1992). Sasaki *et al.* (2009) studied a polluted paddy field model but did not include soil dressing treatment, therefore the purpose of this study is to clarify the influence of percolation pattern on growth and yields of rice plants and uptake of cadmium with soil dressing polluted paddy fields models.

Experimental design and method
The experiment was conducted in a green house of Hirosaki University, Japan. Using stratified paddy field model consisting of 50cm×30cm×70cm in size steel box filled with four layers of soil materials. Plow layer (I layer; 0-12.5cm), plow sole (II layer; 12.5-22.5cm), upper subsoil (III layer; 22.5-57.5cm), and lower subsoil (IV layer; 57.5-65.0cm) were constructed with Andosol (I layer), cadmium polluted soil (II layer) ,gravel (III layer) and gravel with sand (IV layer). Stratified paddy field models were subjected to two kinds of percolation pattern as an open system percolation and a closed system percolation. These two percolation systems were imposed in paddy field models by controlling water level at 52.5cm and 7.5cm, respectively using a subsurface drainage pipe. The ground water level in an open and a closed percolation pattern was 52.5 and 7.5 cm, respectively. Platinum electrodes were placed in each soil layer to measure the value of oxidation reduction potential in soil.

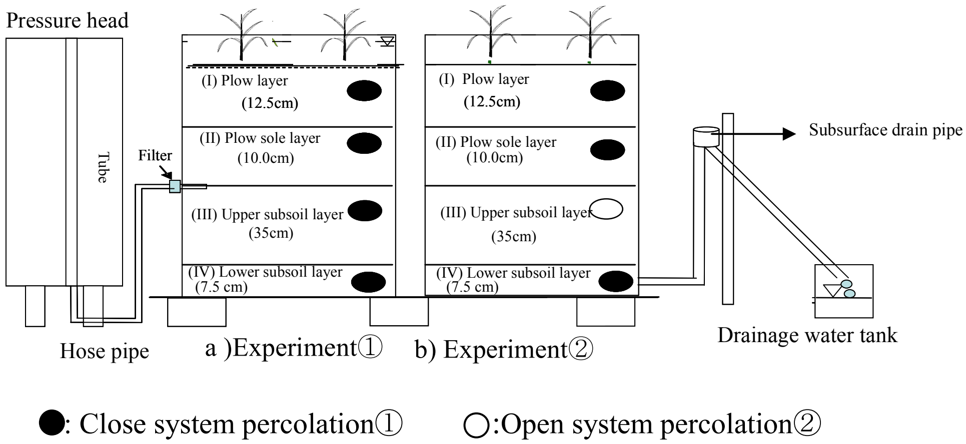

Figure 1. Experimental design of stratified paddy field models

Table 1. Physical and chemical properties of sample soil.

Measurement items	Density (g/cm^3)	Soil texture	Total iron *	Cd *	T-N (%)	T-P (%)	Organic matter content (%)
Andosol	2.592	SCL	5,683	0.19	0.44	0.60	10.0
Polluted soil	2.453	L	2,820	3.39	0.40	0.15	9.4
Gravel	2.680	-	600	0.13	0.00	0.35	0.00

Soil texture is based on the International Soil Society classification; explain SCL and L stands for: L = Loamy; SCL = Silt Clay Loam *represents mg/kg dry soil.

After construction of paddy field model, 15 lines of rice plants (Cultivar: Tsugaru-Roman) were transplanted in each paddy field model with 10 cm planting distance. Fertilizers were applied as recommended dose for Tsugaru-Roman cultivar. Oxidation-reduction potential (ORP) is referred to as redox potential (Eh) was measured electrometrically in each soil layer using a ORP meter (Central Science Co., Ltd., Model UC-203). Analysis of Cd in grains, roots, stems and leaves of rice plant by atomic absorption spectrometrys analysis (Hitachi High –technologies. Co., Model Z2000). Growth of rice plants was investigated by measurement of plant height, number of stem, dry matter weight, per plant grain yield and filled grain ratio.

Results and discussion

In an open system percolation model, the pressure head distribution was under positive pressure in the plow layer but changed to negative pressure in the plowsole layer and upper subsoil layer. However in a closed system percolation system, the pressure head distribution had positive pressure in all layers. Positive and negative pressure was controlled by ground water level. We postulated that Cd in rice plants for the negative hydraulic pressure model was higher than that with positive hydraulic pressure model. According to Sukthai P. *et al.* (2005) Cd uptake was higher by rice plants with positive hydraulic pressure than those with negative hydraulic pressure.

The ORP value in plow layer and plowsole layer was lower than 300 mV in both the open percolation and closed percolation models. However, the ORP value in subsoil was more than 300 mV in the open percolation system, whereas it was lower than 300 mV in the closed percolation system. The ORP value of more than 300 mV is indicative of oxidising conditionsa and lower than 300 mV indicates reductive conditions. In principle, soil layers with oxidising conditions promote the accumulation of cadmium in plant.

Rice plants in the closed system percolation with paddy field model showed better vegetative growth and grain yield than those in the open system percolation. In experiment ①, plant height, number of stems and dry matter weight of rice plants were higher than for experiment ② but no difference was found for heading time. The weight of grains and filled grain ratio were also higher in experiment ① than experiment ② (Table 2). High cadmium uptake in rice plant might have an adverse effect on growth and yield of the rice plant as Zhou *et al.* (2003) found that rice plant height and grain yield were decreased by about 4 to 5 cm and 20 to 30 %, respectively due to the effect of Cd.

Table 2. Growth and yield of rice plant in different percolation system.

Treatment	Plant height(cm)	Stem no.	Leaf no.	Dry matter weight (g/stump)	Weight of grains (g/stump)	Filled grain ratio (%)
Experiment ①	103.8±4.14	12.7±1.95	14.80±0.4	814	40.6	89.0
Experiment ②	102.6±2.97	12.0±2.10	15.0±00	731	36.5	86.8

Cadmium concentrations in rice plants followed: root> stem > grain in both paddy field models. Percolation pattern also influences uptake of Cd by rice plants. In experiment ② Cd concentrations were higher in all parts of rice plants than for experiment ① (Figure 2 and 3). Cadmium concentration in stem and leaf and grain were 0.23 and 0.01 mg/ kg in experiment ① whereas in experiment ② values were 0.75 and 0.29 mg/kg, respectively. With an open system percolation, atmospheric air entered through air flow path at the subsoil layer. In the presence of oxygen, cadmium forms cadmium sulphate ($CdSO_4$), which is more available for uptake by rice plants but in close system percolation, air could not enter into soil profile in absence of air flow path. Moreover, high groundwater level in the closed system percolation model favored the reduced condition of soil layers. Cadmium concentrations of roots in each layer were relatively higher for experiment ②than experiment ① (Figure 3).

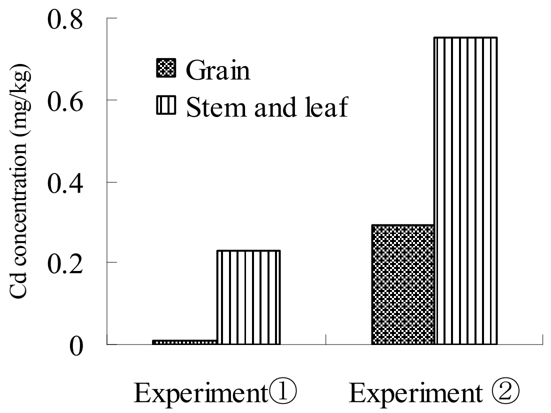

Figure 2. Cadmium concentration in brown rice grain and stem plus leaf

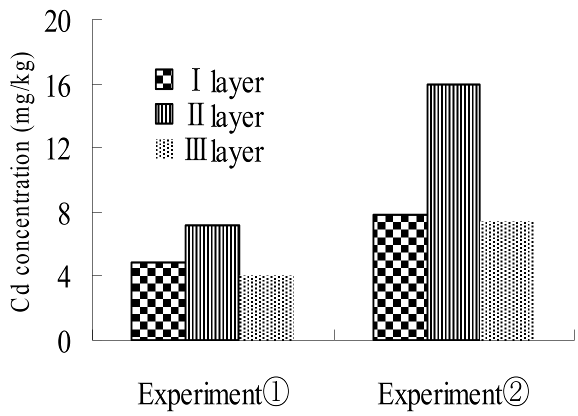

Figure 3. Cadmium concentration in roots

Conclusion

Percolation pattern is one of the important factors together with soil pH, temperature, anaerobic bacteria, heavy metal concentration, gravel size and soil fertility for the growth and development of rice plants. Percolation pattern controls the oxidation- reduction status of soil, consequently the uptake of cadmium by rice plants. A closed system percolation pattern can be considered a tool to reduce cadmium uptake by rice plants, growing in cadmium polluted paddy fields.

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