Research article

Effect of Groundwater Level on Cadmium Uptake and Yield of Soybean from Cadmium Polluted Soils

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Abstract Human uptake of Cadmium (Cd), a toxic heavy metal that can cause kidney damage and other physiological disorder, takes place mainly through food. In some regions of Japan, the agricultural land area was polluted with heavy metals especially Cd. Management of groundwater level can be effective method for minimization of Cd uptake in plant at large scale agricultural field. In this greenhouse experiment, we investigated two constant groundwater levels; 10cm groundwater level model (M-10) and 40cm groundwater level model (M-40) on Cd uptake in Soybean plant in Cd polluted soils (3.39 $mgkg^{-1}$). The redox potential of soil layer was measured from seed sowing to harvesting. Thickness of gravel layer, non-polluted soil and polluted soil was 14, 15 and 25cm respectively. The soil layer (10-40 cm) of M-10 was always measured in reduction condition and 0-40cm layer of M-40 was always in oxidation condition. Cd concentration of Soybean seed was significantly lower in M-10 (0.92 ± 0.1 $mgkg^{-1}$) than that of M-40 (1.31 ± 0.2 $mgkg^{-1}$). Cd concentration of stem was also found significantly lower in M-10 (0.82 ± 0.1 $mgkg^{-1}$) than that of M-40 (2.34 ± 0.2 $mgkg^{-1}$). In the other hand, main stem height of soybean plant of M-40 (111.6 ± 5.1 cm) was significantly higher than that of M-10 (100.5 ± 3.6 cm). In vegetative stage (first 50 days) the SPAD-value was observed higher in M-40 (about 46.5) and lower in M-10 (about 31.3). Branch number, 100 seed weight and seed yield were also found significantly higher in M-40 than those of M-10. The result revealed that, reduction condition was effective for minimization of Cd uptake in Soybean plant whereas, oxidation condition was favorable for seed yield.

Keywords cadmium uptake, groundwater level, soybean yield

INTRODUCTION

Many heavy metals exist in minute amounts in natural agricultural soil. However, when the amounts exceed a certain level due to pollutants brought from outside, soil contamination occurs and agricultural products become contaminated. It poses a great threat to the environment and human health worldwide due to the persistent nature and toxicity and their accumulation in the food chain (Bahadir et al., 2007). Cadmium (Cd) is one of the most harmful heavy metals. Cd occurs naturally in the environment in its inorganic form as a result of volcanic emissions and weathering of rocks. In addition, mining, modern industrialization, use of fertilizers and Cd containing sludge has led to an increase in levels of Cd in soil, water and living organisms.

Several possible methods of minimizing absorption of Cd by agricultural crops exist mainly, 1) soil dressing, 2) water management (paddy field), 3) chemical cleaning of soil, 4) phytoremediation and 5) use of different varieties and rootstock. But most of these methods are very costly and time consuming for effective minimization. A further possible mechanism of reducing Cd uptake may be via groundwater level management. In this process, oxidation-reduction condition of root zone is controlled by groundwater level management. In oxidation conditions, Cd converts to a soluble form that plants can uptake easily. On the other hand, in reduction condition it is not in available form for the plant. Furthermore, the environmental and economic benefits of groundwater level management through reduced pollution and increased yields have been documented (Kalita and Kanwar, 1993).

Soybean is one of the world's major and fastest expanding crops in terms of both calorie and protein intake. Soybean is an important traditional food, and sauce and paste made from it are intrinsic to the Japanese gastronomic culture. A large-scale domestic agricultural products survey in Japan showed that the Cd concentration in one-sixth of the total soybean seed exceeded 0.2 $mgkg^{-1}$, the international allowable limit proposed by the Codex Alimentarius Commission (MAFF, 2002). It is important to increase the yield as well as minimization of Cd from polluted soils. The objective of the study is to find out the relation between groundwater level on cadmium uptake and soybean yield. This will help to minimize uptake of heavy metals especially Cd in different grain crops.

MATERIALS AND METHODS

Soil Properties

In this study, we used polluted soil from Eastern Japan (we kept the place secret) and non-polluted soil from Kanagi, Aomori prefecture. The physio-chemical properties of the soil were measured by the standard methods of analysis (Table 1).

Table 1 Soil physical and chemical properties (Paul et al., 2011)

Sample	Density (g/cm^3)	Soil texture	MgO	Na_2O	CaO	K_2O	Total Fe	Cd	T-N (%)	T-P (%)	OM (%)
			*	*	*	*	*	*			
Polluted soil	2.453	L	496	114	2909	311	2820	3.39	0.40	0.15	4.80
Non Polluted soil	2.592	SCL	918	84	1530	159	5683	0.14	0.44	0.60	6.00
Gravel	2.680		147	18	539	58	600	0.13	0.00	0.35	0.05

Note: Soil texture is based on the International Soil Society classification. L: Loamy; SCL: Silty Clay loam. $mgkg^{-1}$ dry soil. Gravel diameter size 2-4mm*

Experimental Design

The experiment was conducted in green house of Hirosaki University at Aomori prefecture. Two plastic containers were used for two groundwater level treatment model; 10 cm (M-10) and 40 cm (M-40). Both containers were filled with gravel (small stone; 14 cm), non-polluted soil (15 cm) and polluted soil (25 cm) shown in Fig. 1. After filling soil, Eh sensor and temperature sensor was set up for every soil layer of the box.

Cultivation Procedure

Before seeding the groundwater level was set up as 10cm for both treatments for 12 hours to moist the soil. After 12 hours of seeding the groundwater level was set up as per treatment. Groundwater level was maintained by Mariotte bottle arrangement which supplied water through the bottom of the plastic box. Fertilizer (N,P,K) was applied as per recommended rate for Rhyho variety. The seeds of soybean plants (*Glycine max* (L.) Merr.cv. Rhyho) were sown in four points of every box at 4 seeds/point at 1st June 2012 about 2-3 cm depth of soil. After emergence, (15 days after sowing) soybean plants were thinned to 2/point as well as 8/box. In every 4 days, 2000 ml water was supplied in every box that is equal to rainfall of 4 days in this location. The plants were periodically sprayed with insecticide.

Measurement Procedure

Oxidation-reduction potential (ORP) of each soil layer was measured by electrometrically using ORP meter (Central Science Co., Ltd., model UC-203) from vegetative to harvesting period. Leaf color measured using chlorophyll meter (Minolta Co. Model SPAD-502) from first trifoliate leaf stage. The latest fully developed trifoliate leaf was used for leaf color measurement. Cd content of seed, stem and root was measured after harvesting and drying and then extracted by nitric acid and sulfuric acid and the analyzed by Atomic Absorption Spectrophotometer (Model Z-2000, Hitachi Corporation) as described by the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF ,1979).

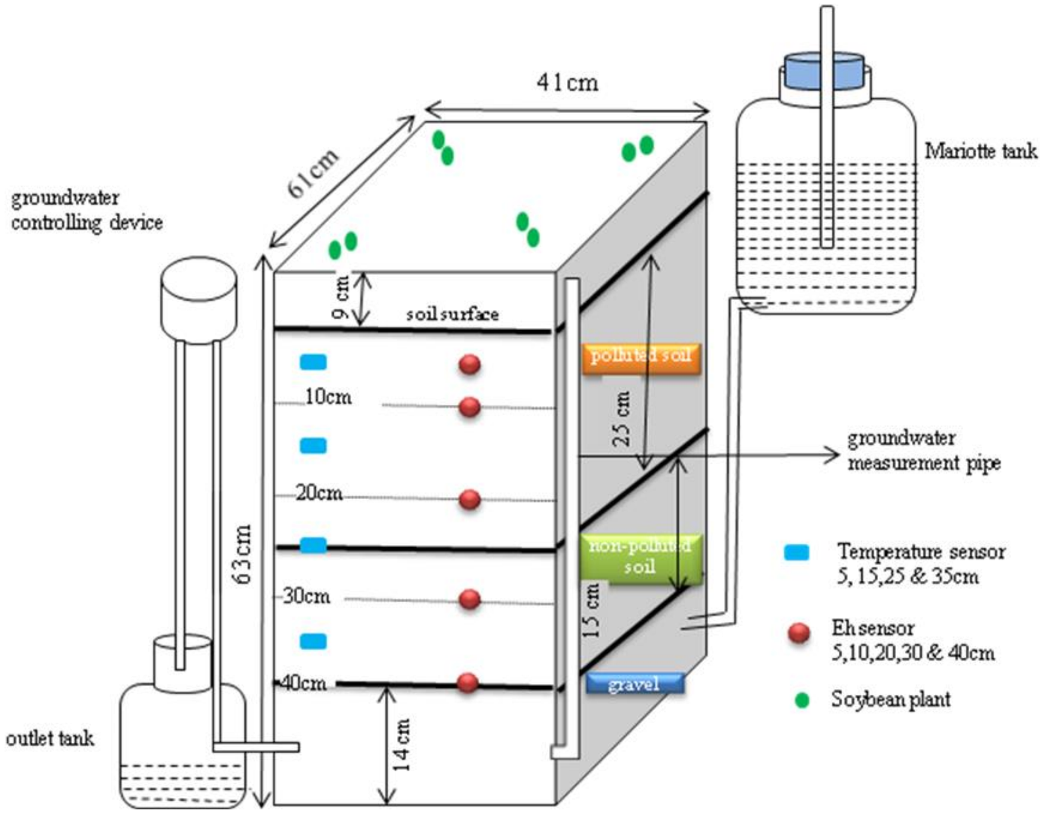

Fig. 1 Layout of plastic container used in the experiment

RESULTS AND DISCUSSION

Redox Potential of Soil Layers (Eh)

Oxidation-Reduction potential (ORP) condition is known as a redox potential (Eh). The Eh value in soil more than 300 mV is an indicator of oxidation condition and lower than 300 mV indicates reduction condition (Iimura, 1981). Eh value varied in two boxes for two different groundwater level treatment model. Eh value is less than 300 mV in below 10cm (from soil surface) in M-10 for saturated condition by groundwater level (Fig. 2). In case of M-40, soil layer (0-40 cm) was remaining in oxidation condition at about 700 mV Eh value (Fig. 3).

So it means reduction condition remained through crop life time of M-10 and oxidation condition occurred in M-40. The proportion of soluble cadmium decreases abruptly with the decrease of soil redox potential (Iimura, 1981). So, Cd dissolute decreased comparatively in M-10 than M-40.

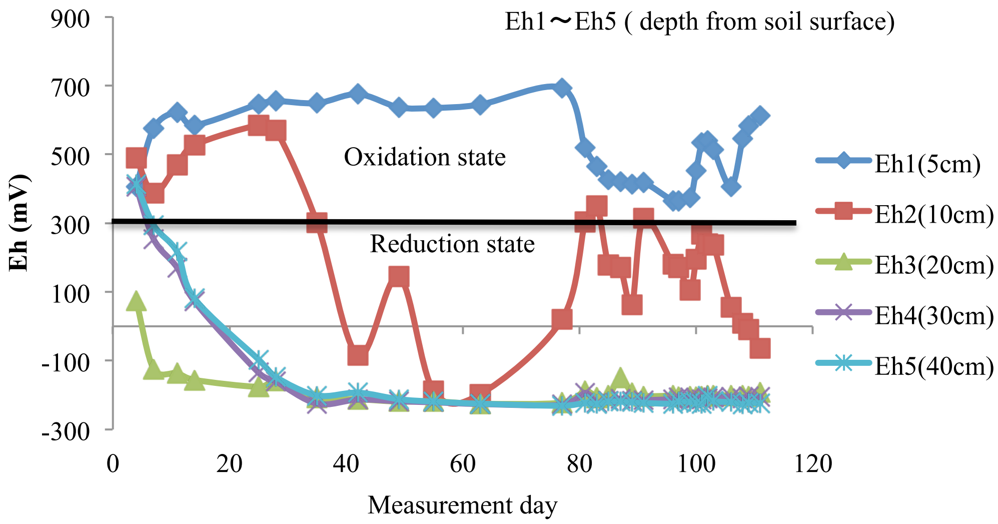

Fig. 2 Eh value of soil layer of 10 cm groundwater level model

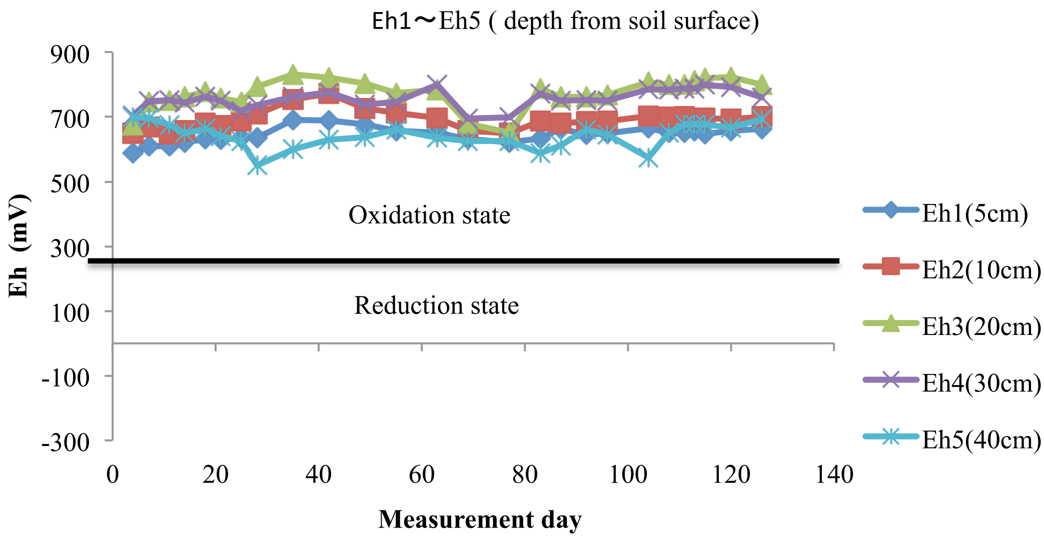

Fig. 3 Eh value of soil layer of 40 cm groundwater level model

Cadmium Concentration in Soybean Plants

Cadmium concentration of different parts of soybean plant was found higher in M-40 than M-10. Accumulation of Cd uptake in seed by soybean plants was significantly higher in case of M-40 (1.31 ± 0.2 mgkg^{-1}) than M-10 (0.92 ± 0.1 mgkg^{-1}) at $p > 0.001$ (Fig. 4).

The reason was that, reduction condition occurred in M-10 for high groundwater level and M-40 caused oxidation condition for lower groundwater level. Absorption and accumulation of Cd was significantly reduced with diminishing Eh in reductive conditions formed by flooding rice fields (Lu et al., 1992). Previous researchers showed that in soil reduction condition, the presence of sulphate ion can be converted to sulfide ion which reacts with Cd and produce relatively insoluble Cadmium sulfide (Ono et al., 2003). This mechanism supported to the M-10 and that is why the Cd uptake by soybean plants was low. Cd uptake of soybean stem was also significantly higher in M-40 than M-10 (Fig. 5). The average value of stem Cd uptake of M-40 and M-10 were (2.34 ± 0.2 $mgkg^{-1}$) and (0.82 ± 0.1 $mgkg^{-1}$) respectively. It showed that Cd concentration was found 3 times higher in M-40 than M-10. This result revealed that redox condition of soil influences the uptake of Cd and mobilization in soybean plants. Accumulation of Cd in roots of soybean plants in M-10 (5.92 ± 0.5 $mgkg^{-1}$) had no significant difference ($p = 0.875$) with that of M-40 (6.08 ± 2.2 $mgkg^{-1}$) shown in Fig. 6. The Cd Concentration of soybean root was found higher than that of stem and seed.

These happened due to the apparent free space (it represents the intercellular space freely accessible to ions) of plant tissues were much greater in root tissue than other parts. In M-10, the Cd concentration of root found about 7 times higher than that of stem and seed; and in M-40, the Cd concentration of root found about 3 times higher than that of stem and seed. Accumulation of Cd in root was the highest of the total Cd in the plant (Jarvis and Jones, 1976; Cui et al., 2008) which is similar to this study.

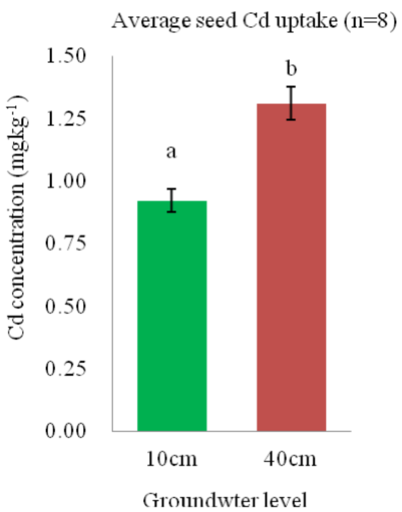

Fig. 4 Cadmium concentration in seed

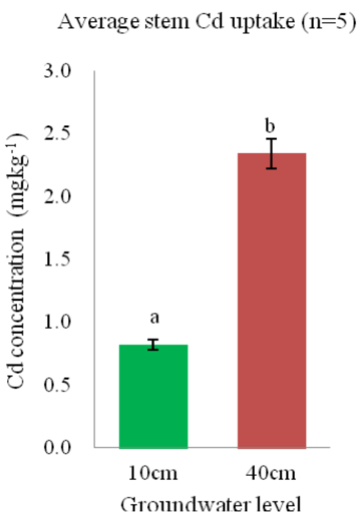

Fig. 5 Cadmium concentration in stem

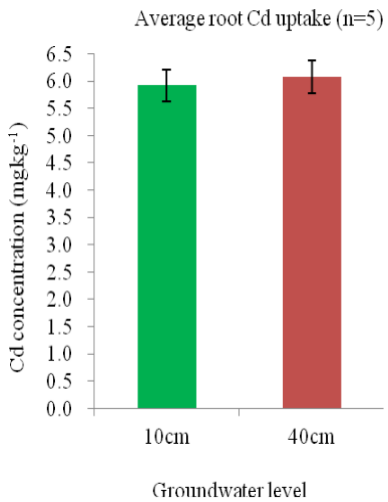

Fig.6 Cadmium concentration in root

Soybean Yield Components

The average main stem height in M-40 (111.6 ± 5.1 cm) was significantly higher than that of M-10 (100.5 ± 3.6 cm) shown in Table 2. This result might be occurred due to high groundwater level effect in M-10. In M-10, first 30 days vegetative growth was affected due to the excessive moisture in the soil which was clearly visible in our experiment. Vegetative growth was inhibited following shorter stem (Garside et al., 1992a) by the effect of excess moisture which is supported to the present study. Main stem length was found higher with lower water table treatment (Shimada et al., 1995) which is also similar to M-40.

There was a significant difference happened in case of soybean yield due to groundwater level difference in this experiment. The average good seed weight per plant was 68.1 ± 14.6 g in M-40 and 35.1 ± 13.8 g, in M-10 (Table 2). Effects of groundwater level on soybean yield have been observed by many researchers. The optimum groundwater table depth for getting highest yield little differs from researcher to researcher; that is 20cm (Abe et al., 1981), 40cm (Ishibashi et al., 1982), 30cm to 50cm (Ueno, 1979) and 50cm (Shibata and Endo, 1976). In our experiment, we found higher yield in M-40 than M-10. Another researches showed that, soybean gave high yield when grown at around 10cm depth groundwater table in the saturated soil culture at the semi-arid tropical region in Australia (Garside et al., 1992b). In Japan most of the high yielded records were obtained on a drained paddy field where the water table maintained at around 50cm from the soil surface.

100 seed weight and branch number plant^{-1} were found significantly higher for M-40 than M-10. In M-40, 100 seed weight was found 39.2 ± 2.8 g and in M-10 was 30.9 ±1.7 g (Table 2). It showed that Soybean seed of M-40 was good quality. In M-40 showed higher (7.9 ± 0.9) branch number than M-10 (5.9 ± 1.6) (Table 2). Previous researches found 100 seed yield decreases for excess moisture in the soil at the ripening stage (Sugimoto et al., 2000). The average stem diameter and seed/pod were not significantly differing in M-40 to M-10.

Table 2 Soybean yield components of two different groundwater levels

	Yield components					
Ground-water level	Stem height (cm)*	Stem diameter (mm)	Branch No.*	Seed/pod	100 seed wt.[1] (g)*	Good seed wt.[1] (g)*
10 cm	100.5 ± 3.6	7.3 ± 1.9	5.9 ± 1.6	1.94 ± 0.08	30.9 ± 1.7	35.1 ± 13.8
40 cm	111.6 ± 5.1	9.0 ± 0.9	7.9 ± 0.9	1.92 ± 0.05	39.2 ± 2.8	68.1 ± 14.6

*Note: * means significant according to ANOVA at 0.05 level. 1- Seed weight at 15% moisture. In all cases (n=8)*

Leaf Color (SPAD-Value)

The chlorophyll meter provides a simple, quick, portable and non-destructive method for estimating leaf chlorophyll content. In SPAD-value graph (Fig. 7) we can clearly see the effect of groundwater level on leaf chlorophyll content. In M-10 model, vegetative state (up to 50 days after sowing) the leaf chlorophyll content was lower (about 31.3) whereas M-40 model was higher (about 46.5). It happened in M-10 model because of high groundwater level. But, after 50 days it recovers by its adaptation quality. We know that, soybean plant has high range of adaptation quality in high range of groundwater level. In previous study, (Garside et al., 1992a) reported that temporary chlorosis occurred when saturated-soil-water culture was given to soybean plants and that caused a reduction of leaf nitrogen content (Sugimoto et al., 1988). So it is clear that groundwater level has an effect on leaf chlorophyll content. Chlorophyll contents decrease as well as decrease seed yield in lower water table treatment (Shimada et al., 1995) that is similar to this experiment.

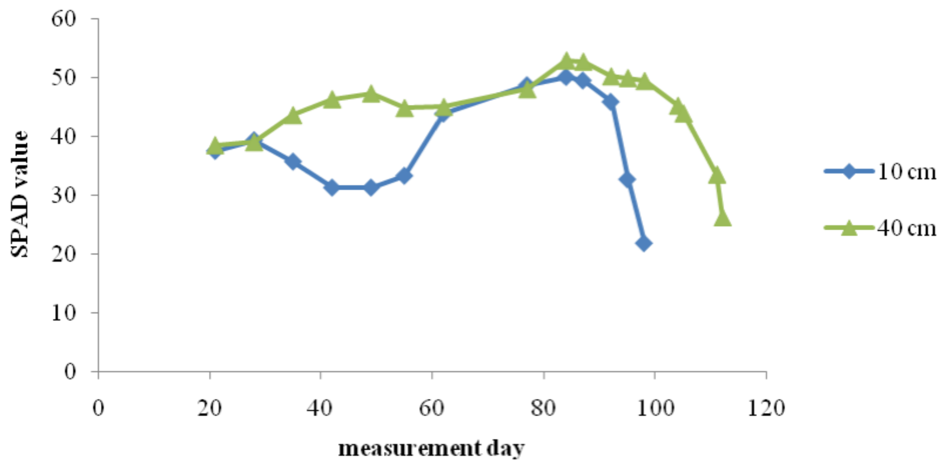

Fig. 7 SPAD value of soybean plant grown in two different groundwater level

CONCLUSION

The accumulation of Cd in soybean plants was significantly affected by groundwater level. Groundwater level controls the oxidation-reduction status of soil, consequently uptake of heavy metal by soybean plants. In oxidation condition of soil, plants uptake more Cd than reduction condition of soil due to increase of soluble Cd. This result suggested that low groundwater level as well as oxidation condition promotes Cd uptake in soybean plant and high groundwater level as well as reduction condition inhibits the Cd uptake. This could be an effective technique for minimization of Cd and other heavy metal uptake from polluted soils and it can be improve the management of polluted soil in many countries. We need more research about various ranges of groundwater level and various stage of soybean to develop agronomic management of soybean cultivation in polluted soil.

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