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# Effects of Cadmium on Mineral Nutrient Concentrations in Plants Differing in Tolerance for Cadmium

**H. Obata and M. Umebayashi**

*Faculty of Bioresources, Mie University, Tsu Mie 514, Japan*

## ABSTRACT

The effects of 3 d treatments with 0.3 and 1.0 $mg \cdot L^{-1}$ of cadmium (Cd) on selected mineral nutrient composition in plants differing in tolerance for Cd were studied. The concentrations of potassium (K) decreased in Cd-sensitive kidney bean and pea and that of manganese (Mn) decreased in the semi-resistant rice and maize plants with increasing application of Cd in the culture solution. Copper (Cu) content increased in the roots of the plants above, but no changes in Cu contents were observed in the Cd resistant cucumber and pumpkin plants. Calcium (Ca), magnesium (Mg), and zinc (Zn) did not show any clear tendency with Cd applications in any of the plants examined. Water absorption by kidney bean was reduced by Cd, but that of rice and cucumber was not. Permeability of the plasma membrane of root cells may be affected by Cd, whereas absorption of some of the elements and water may be prevented.

## INTRODUCTION

Cadmium (Cd) is a very hazardous element to human beings. In Japan, Cd in rice grains is a major problem of heavy metal pollution. Means have been sought to prevent the accumulation of Cd in brown rice (Kitagishi and Yamane, 1982). However, the phytotoxicity of Cd remains to be clarified.

The yield of rice grains was reduced remarkably by treatment with heavy metals, especially with the soft metal, $Cu^{2+}$, compared to the harder metal, $Mn^{2+}$ (Chino, 1968). Chino showed that soft metals interfere with the water absorption of rice plant. Heavy metals may also interfere with the uptake of nutrients and/or induce leakage of nutrients by damaging the plasma membrane. Cadmium is one of the soft metals which reduces rice yields. Cadmium may interfere with nutrient uptake by affecting the permeability of plasma membranes (De Filippis, 1979; Strickland, 1979). The present authors show that Cd tolerance of plasma membrane ATPase, extracted and partially purified from roots, appears to be positively correlated with Cd tolerance in undisturbed plants (Obata et al., 1996).

In this study, an investigation was conducted on the effects of Cd on water absorption and mineral element concentrations in tops and roots of plants differing in tolerance for Cd.

## MATERIALS AND METHODS

### Materials and Treatment

Six plant species of three families with different Cd tolerance were used: leguminosae (sensitive to Cd), kidney bean, *Phaseolus vulgaris* L. cv. Hatsumidori; pea, *Pisum sativum* L. cv. Kinusaya; gramineae (semi-resistant), rice, *Oryza sativa* L. cv. Yamahikari; maize, *Zea mays* L. cv. Honey bantum; cucurbitaceae (resistant), cucumber, *Cucumis sativus* L. cv. Suzunari suyo; and pumpkin, *Cucurbita Pepo* L. cv. Kuriebisu.

The seeds of rice plants were germinated on a plastic net. After 14 d, the plants were transferred to styrene foam square holders. Four plants per holder were grown in Kimura B solution for rice culture containing $(NH_4)_2SO_4$ 48.2, $K_2SO_4$ 15.9, $MgSO_4$ 65.9, $KNO_3$ 18.5, $Ca(NO_3)_2$ 59.9, $KH_2PO_4$ 24.8, Fe-citrate 5 as $Fe_2O_3$, $MnCl_24H_2O$ 0.9, $ZnSO_47H_2O$ 0.11, $CuSO_45H_2O$ 0.04, $H_3BO_3$ 2.9, $H_2MoO_4$ 0.01 $mg{\cdot}L^{-1}$. The initial pH was 5.4. Each solution was renewed once a week and not aerated.

The seeds of the other plants were germinated in vermiculite. After 10 to 20 d, the plants were transferred to styrene foam square holders as above and grown in Kimura A solution for upland plants containing $(NH_4)_2SO_4$ 24.1, $K_2SO_4$ 63.6, $MgSO_4$ 43.9, $KNO_3$ 55.4, $Ca(NO_3)_2$ 29.9, $KH_2PO_4$ 24.8, Fe-citrate 5 as $Fe_2O_3$, $MnCl_24H_2O$ 0.9, $ZnSO_47H_2O$ 0.11, $CuSO_45H_2O$ 0.04, $H_3BO_3$ 2.9, $H_2MoO_4$ 0.01 $mg{\cdot}L^{-1}$. The initial pH was 5.4. Each solution was aerated and renewed once a week.

Thirty to sixty d following germination, Cd was applied at 3 concentrations, 1.0 $mg{\cdot}L^{-1}$, 0.3 $mg{\cdot}L^{-1}$, and nil, in duplicate and allowed to grow for 3 d. After two additional days of growth in a culture solution without Cd, the plants were harvested, separated into roots and tops by scissors, dried at 70°C, weighed and ground to pass a 3-mm sieve.



### Mineral Element Analysis

One g of each sample was ashed by the $HNO_3$-$HClO_4$ method. Potassium, Ca, Mg, Mn, Zn, and Cu were determined using a PE-370 Perkin Elmer atomic absorption spectrophotometer.

### Determination of Water Absorption

Kidney bean, rice, and cucumber were cultured as above. Forty d after germination, the plants were removed briefly from the pots at 10 AM and each pot was weighed. The pots were weighed as above once a day for 4 d. Cadmium was then applied at 1.0, 0.3 $mg{\cdot}L^{-1}$, and nil in duplicate and plants were grown for three more days. The pots were weighed as above. Daily decrease in pot weight was regarded as weight of water absorbed by the plants. On the final day of the experiment, the fresh weight of each plant was determined and water absorption was corrected based on the results.

## RESULTS

The data in Figure 1 show that the dry weights of kidney bean and pea were decreased by increased Cd treatments. Cadmium had no significant effect on the dry matter of other plants. Figure 2 shows the results of water absorption of each pot relative to the control plot. Water absorption by kidney beans was decreased the following day due to 1.0 $mg{\cdot}L^{-1}$ Cd treatment and two days later by 0.3 $mg{\cdot}L^{-1}$ Cd treatment. Cadmium resistant cucumber and Cd semi-resistant rice showed no effect of Cd treatments on water absorption.

Figure 3 (A to D) shows the concentrations of each element in the tops and roots of plants. Potassium content in the roots of kidney bean and pea treated with 1 $mg{\cdot}L^{-1}$ Cd was less than that at 0.3 $mg{\cdot}L^{-1}$ Cd and that in the control (Figure 3A). Potassium content was unaffected by Cd treatment in other plants. No change in Ca or Mg content was also observed by any of the Cd treatment in the roots of any plant (data not shown).

Manganese content in the tops of rice and in roots of maize decreased markedly with an increase of Cd application in the culture solution (Figure 3B). Most of the Mn is accumulated in the tops of rice and in the roots of maize. Manganese content was unaffected in the tops and roots of the other plants as a result of Cd treatment. Zinc showed no clear response to Cd treatment (data not shown). Copper accumulated in the roots of all plants and increased somewhat in the roots of leguminosae and gramineae, but decreased in the tops of all plants except in pea with Cd application in the culture solution (Figure 3C). Cadmium may promote Cu absorption and reduce translocation of this element from the roots to the tops in these plants. Absorption and accumulation of Cd were restricted to the roots of all plants (Figure 3D).

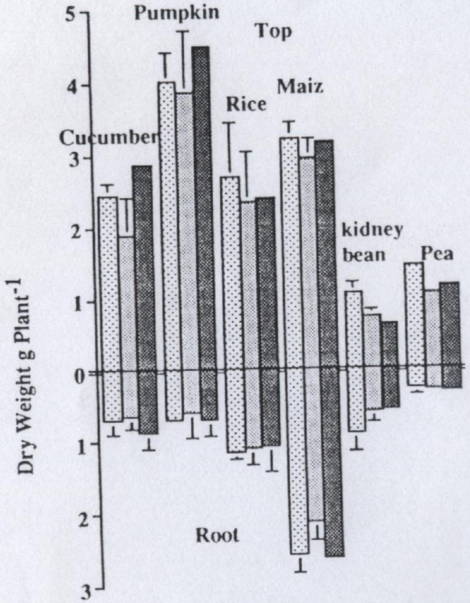


FIGURE 1. Dry weight of tops and roots of each plant treated with nil (control)(□), or 0.3 mg·L$^{-1}$ Cd (■), or 1.0 mg·L$^{-1}$ Cd (■). Vertical bars are S.D.

## DISCUSSION

The growth of kidney bean and pea was inhibited remarkably by Cd, but the growth of the other plants was not. Kuboi et al. (1986, 1987) noted the Cd tolerance of higher plants to be family dependent in the order, cucurbitaceae > gramineae > leguminosae. In this study, the growth of the Cd sensitive leguminosae was decreased by Cd. At 1.0 mg·L$^{-1}$ Cd, leaf burn and severe wilting were noted on kidney bean, whereas wilting was observed in peas and secretion of sap from leaf tips of rice ceased. On the other hand, the Cd tolerant cucurbitaceae did not show any effect at all. Water absorption by roots of sensitive plants appeared to be inhibited by Cd. As discussed previously, water absorption decreased by Cd application in Cd sensitive kidney bean, but not in rice or cucumber. Chino (1968) showed that water absorption by rice was decreased by Cu, soft metal as Cd, indicating a possible damage of the plasma membrane by Cu treatment.



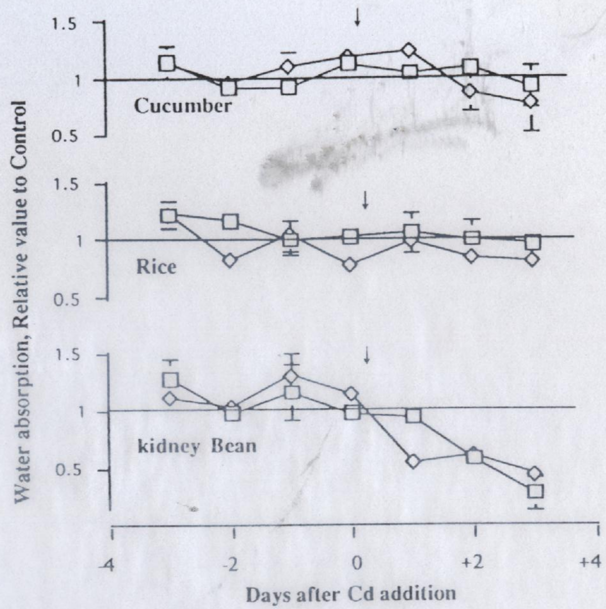


FIGURE 2. Water absorption of each plant with 0.3 mg·L$^{-1}$ (□) and 1.0 mg·L$^{-1}$ (◇) Cd treatment relative to control. Arrows show Cd addition. Vertical bars are S.D.

Potassium content in the Cd sensitive leguminosae roots was decreased, but not in the Cd tolerant cucurbitaceae or semi-tolerant gramineae roots. Potassium content decreased remarkably with increase in Cd application in the callus of maize and kidney bean, but not in the callus of rice or cucumber plants (Obata et al., 1994). Cadmium may thus be considered harmful to the plasma membrane of root cells of Cd sensitive plants, causing water and K absorption to be inhibited, or K to leak out from root cells. The present authors (Obata et al.,1996) noted the plasma membrane $H^+$-ATPase activity of Cd sensitive leguminosae roots to be reduced significantly compared to the Cd tolerant cucurbitaceae by Cd treatment. The $H^+$-ATPase activity is essential to the proton motive force for the active transport of many solutes (Serrano, 1989). The reduction of ATPase activity by Cd may be a determining factor for the absorption or exclusion of many nutrient elements. Cadmium may also react with membrane proteins other than ATPase, e.g., $K^+$-channel and may also react with phosphate in phospholipid in the membrane. These reactions of Cd with the plasma membrane components is believed to contribute to Cd toxicity in plant roots.

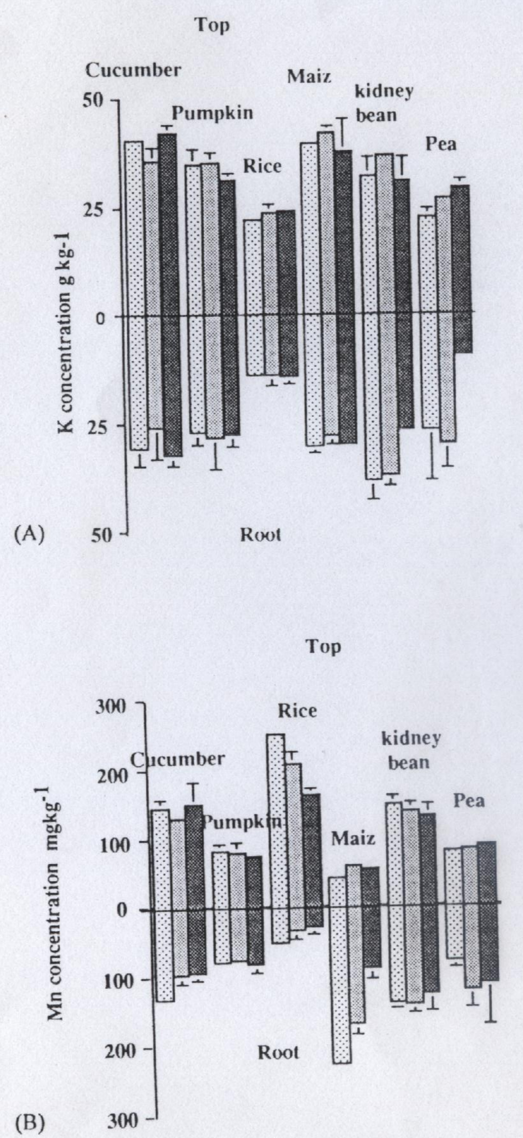


FIGURE 3. (A) Potassium, (B) manganese, (C) copper, and (D) cadmium concentration of tops and roots of each plant treated with nil (control)( ▒ ), or 0.3 mg·L⁻¹ Cd ( ▓ ), or 1.0 mg·L⁻¹ Cd ( █ ). Vertical bars are S.D.



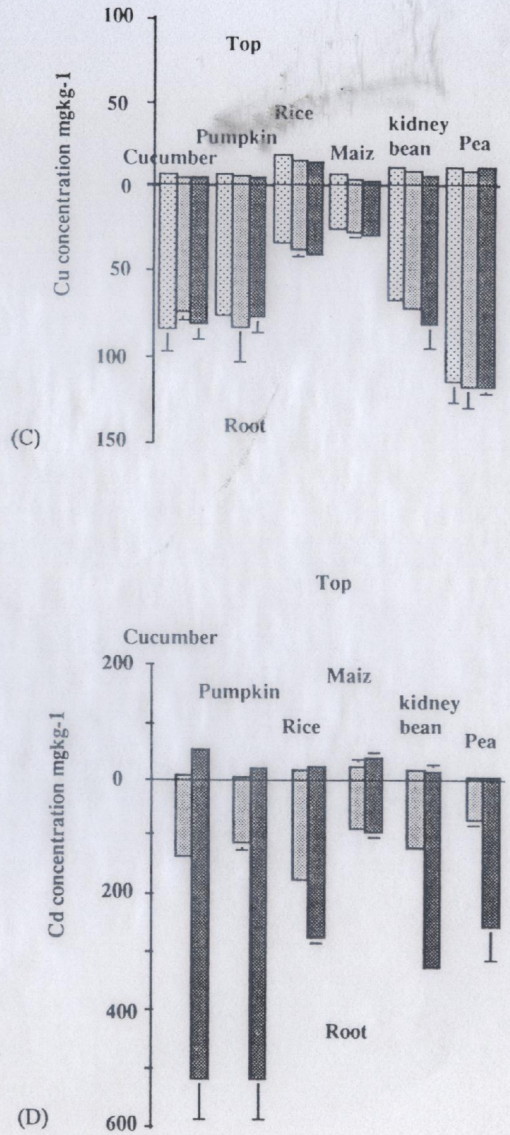


FIGURE 3. Continued

Copper in the roots of gramineae and leguminosae increased with Cd application. Cadmium and Cu were previously shown to form complexes with the SH compound produced by Cd in rice roots. Copper contents in Cd treated rice roots were higher than those in control roots (Obata and Umebayashi, 1986). The SH compound produced by Cd appeared to bind Cu, hence could compensate for Cu deficiency since large amounts of Cu were absorbed. However, this did not explain why cucurbitaceae, with the highest production of SH compound, did not show high Cu accumulation by Cd treatment. Kuboi (1988) observed increased Cu, Zn, and Fe in roots after Cd treatment. The remarkable reduction in Mn absorption by gramineae as a result of Cd treatment was of interest since it was observed a few days after Cd treatment. Horiguchi and Fukumoto (1987) noted Mn to accumulate in the tops of rice plant and roots of maize. In this study, the effect of Cd on Mn absorption was more pronounced in rice and maize plants. Gussarsson (1994) showed that K, Ca, Mg, and Mn contents in the roots of birch seedlings were reduced, whereas Cu and Mo contents increased by Cd treatment. In this experiment, the same tendencies were observed with respect to the decreasing concentrations of K and Mn and increasing Cu content in the Cd sensitive leguminosae and/or semi-resistant gramineae, but not in the resistant cucurbitaceae.

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