

Influence of Cadmium on Growth of Root Vegetable and Accumulation of Cadmium in the Edible Root

Shu-Fen Cheng^{a*} and Chin-Yuan Huang^b

^a*Department of Environmental Engineering and Management, Chaoyang University of Technology, 168 Gifeng E. Rd., Wufeng, Taichung County, Taiwan, R.O.C.*

^b*Ordnance Readiness Development Center,
Nantou County, Taiwan, R.O.C.*

Abstract: The problem of farmland contaminated by heavy metals raises serious concerns because the contaminants accumulated in the plant not only affect the growth and quality of crops but also threaten the health of consumers. In this research, three root vegetables, i.e., sweet potato (*Ipomoea batatas* L.), carrot (*Daucus carota* L.) and radish (*Raphanus sativus* L.), were planted in soil collected from cadmium-contaminated and uncontaminated farmland. The plant growth rate were used to investigate the influence of cadmium on the growth of these plants. The accumulation of cadmium in the edible root is also studied in order to understand the safety of these edible vegetables. The results indicate that during the initial growth period, cadmium does not show obvious influence on the growth of all three plants. When the edible root started to develop, the growth rate for plants growing in the contaminated soil is obviously affected. Their average mass is reduced by about 50%. The cadmium contents in the edible root of all three plants exceed the allowable quantities stipulated by various nations. Thus, the plants grown in cadmium-contaminated should be banned as foodstuff.

Keywords: plant; heavy metal; accumulation; edible root.

Introduction

Improper treatment and disposal of industrial wastewaters and solid wastes are major causes of soil contamination by heavy metals. In recent years, a large quantity of farmland suffers contamination of heavy metals in Taiwan. Results of tracing the sources indicate that the contamination is caused by the discharge of industrial wastewater into irrigation canal. The problem of farmland heavy metal contamination has raised serious concerns. Heavy metals are absorbed and accumulated by plants thus are absorbed directly or indirectly by human bodies through the food

chain.

Cadmium is a common ingredient in plastic stabilizer, paint and lacquer, is a common farmland contaminant. It is not metabolized once digested and not easily excreted that it affects kidney and the bone system. Results of recent research indicate that cadmium is capable of highly disrupting the endocrine system and is often considered as an “environmental hormone”. The literature information also shows that cadmium is the most absorbed among 8 heavy metals and that it is easily transferred within the plant [1, 2]. When ab-

* Corresponding author; e-mail: shufen@mail.cyut.edu.tw

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sorbed by the root, cadmium can be easily transferred to other parts such as stem and leaves. If excess quantity is accumulated in the plant body, cadmium will adversely affect the plant growth and metabolism [3]. Since cadmium has some similar chemical characteristics as zinc and manganese, it sometimes replaces the latter at the reactive site resulting in inhibited enzymatic activities thus leading to plant withering, yellowing and retarding growth [4].

Results of some research indicate that leave vegetables have high absorption and accumulation of cadmium [5, 6] while grains have relatively low accumulation of cadmium [5, 7]. Heavy metals in the soil either form chelating substances, through ion exchange or are attached to other substances. When plants absorb water and nutrient from soil, heavy metals are carried into the plant body via the root tissue [4, 8]. The plant root tissue may release low-molecular organic acids, e.g. acetic, oxalic, fumaric, citric and tartaric acid, which facilitate metal absorption by forming more soluble compounds or chelates with heavy metals [4, 9-11] or changing the metal mobility. In literature, the root is reported to contain much higher concentrations of heavy metals than stem and leaves. Roots of *Silene vulgaris* and *Elsholtzia splendens* contain 11 times and 30 times, respectively, copper concentration than their shoot [12]. Further, the concentration of accumulated copper in the root of *Phragmites australis* is 5 or 65 times that in the shoot [13].

Edible roots of root vegetables such as sweet potato (*Ipomoea batatas* L.), carrot (*Daucas carota* L.) and radish (*Raphanus sativus* L.) belong to root tissues; they have a direct contact with soil. Thus, heavy metals may enter the edible root directly through the root tissue. On the other hand, the edible root is an important nutrient storing tissue, thus heavy metals may also be transported along with other photosynthetic nutrients from the leaves. Therefore, whether the root vegetables and other leave vegetables have different influ-

ence of cadmium on the plant growth as well as cadmium accumulation in the plant tissue is the main objective of this research.

2. Materials and Methods

2.1. Materials and culture conditions

Three common edible root vegetables, i.e. sweet potato (*Ipomoea batatas* L.), carrot (*Daucas carota* L.) and radish (*Raphanus sativus* L.) were selected to investigate the difference in the absorption capacity and pathway of metal accumulation between their root and edible root tissues. The selected plants are planted in cadmium-contaminated soil and uncontaminated soil under similar growing conditions including fertilizing and watering. The contaminated soil, collected from a cadmium-contaminated farmland in Hu-Wei Township located in Central Taiwan, contains 247.4 mg kg⁻¹ cadmium. It is a sandy loam according to the USDA texture triangle classification [14]. The cadmium-free control soil was collected from un-contaminated farmland at the same location. After crushing, removing debris and mixing, triplicate samples were collected for analyses of particle size, pH, water content, organic matter content and cationic ion exchange capacity.

A 40-m² plot was used for carrying out the study. The top 30-cm soil was removed and replaced with the contaminated soil and uncontaminated soils, respectively. All soils are conditioned by adding organic fertilizer, which consists of nitrogen, phosphorus, potassium and organic substance prior to planting. The sweet potato, Taoyuan #1, was planted in the fall using the sapling method. Fifty strong seedlings with 30-cm length, short knot spacing and big stem are planted around 25 cm apart each in the plots containing contaminated and normal soils, respectively. In addition to watering and weeding, organic supplementary fertilizer was applied 30 days after planting. Additionally, both carrot and radish were also grown from seeds.

About 600 seeds each were seeded a 3-m² plot of in September. Twenty days after germination, organic supplementary fertilizer was applied. Some plants were occasionally removed to maintain adequate spacing between two adjacent plants. After 40 days when the second sampling was completed, each plot contained 200 well-grown plants at 10 cm apart.

The first sampling of sweet potato was carried out on the 60th day of planting, and every 20 days thereafter, after sweet potato had been planted. Before the 120th day, the sweet potato plant biomass was smaller thus two plants were collected as one sample for analysis; after the 120th day, one plant was collected as one sample. For carrot and radish, samples were collected every 20 days after germination. During the initial sampling period, the plants were smaller thus more plants were collected for each sample with 50 plants collected on the 20th days, 25 plants collected on the 25th day and 15 plants collected on the 60th day. After the 60th day, 10 plants were collected as one sample. Triplicate samples were collected using the average random sampling method such that the samples collected were evenly distributed over the entire growing plot.

Each sampled plant is separated into root, stem, leave and underground edible root for analyses of respective weight, water content and cadmium content. For cadmium analysis, 3 g of the dry sample is burnt at 300 °C for 1 hour. The resulting ash is digested with 3:1 aqua regia under room temperature for 16 hours. The mixture is filtered and the filtrate is subject to the flame atomic absorption spectrometry analyses for cadmium.

3. Results and Discussion

3.1. Characteristics of the Soil for Cultivating the Plants

Table 1 lists the characteristics of the cadmium-contaminated soil and un-contaminated control soil used in this study. Except water and cadmium contents, all other characteristics including pH, organic matter content and CEC, etc., do not show obvious differences based on statistical t-test result ($P < 0.05$). Adjusting the watering process during the experiment can eliminate the difference in water content. Thus, the only difference in the characteristic of these two soils is the cadmium content.

Table 1. Properties of polluted and unpolluted soils

soil	Contaminated	Uncontaminated
pH	6.45a (0.30)	6.8a (0.38)
Organic matter content (weight)%	1.7a (0.25)	1.3a (0.21)
Water content (weight)%	1.5a (0.15)	2.2b (0.41)
CEC (meq per 100 g)	12.7a (0.98)	10.5a (1.02)
Cd conc. (mg kg ⁻¹)	247.4a (6.75)	3.8b (0.65)
Sand (by weight)%	78.1a (1.84)	74.8a (2.48)
Silt (by weight)%	7.1a (0.90)	9.3a (1.25)
Clay (by weight)%	14.8a (1.15)	15.9a (1.22)

Values in parentheses denote standard deviations (n=3). Different letters in the same horizontal row indicate a significant difference at $p < 0.05$.

3.2. Influence of Cadmium on the Growth of Root Vegetable Plants

The influence of cadmium on the growth of sweet potato, carrot and radish is studied in this research by recording the weight variations of the whole plant and the edible root growing in cadmium-contaminated soil and the un-contaminated control soil. Figure 1 shows the average weights of the whole plant (including leaf, stem, root and edible root) and edible root for sweet potato plants sampled between the 60th and the 180th day after planting. The error bar represents the standard deviation. The influence of cadmium on the growth rate of sweet potato plant growth is analyzed using the t-test on samples collected from the same part at the same growth time. Similar letters shown on top of the error bar indicate that the plants growing in cadmium-contaminated soil exhibit no difference in their growth rate as the control set growing in un-contaminated soil ($p < 0.05$). Figure 1 also shows that during the initial 120 days of growth, the average sizes of plants growing in cadmium-contaminated soil and uncontaminated soils are similar. After the 120th day, weights of the plants in the contaminated soil apparently are smaller than those of the control set. The growth period for sweet potato is about 5 to 6 months. When harvested on the 180th day, the weight difference between these two plant sets can reach 130.1 g per plant; the weight of plants growing in the contaminated soil is only 50% of that growing in un-contaminated soil. The edible root starts to appear on the 120th day in sweet potato plants growing in both contaminated and un-contaminated soils. The Figure displays that the edible sweet potato root develops rapid after the 120th day, however, the sweet potato growing in cadmium-contaminated soil has apparently a lower yield than that growing in un-contaminated soil. After 180 days of growth, the average edible root weight of the contaminated plants is only 63% of that for

the un-contaminated control plants.

Figure 2 shows the results obtained on carrot. The samples collected on the 20th and 40th day show no obvious weight difference between the contaminated and un-contaminated plants. This indicates that during the initial growth period, cadmium does not affect the carrot growth. After the 60th day, obvious weight difference started to appear. Collected on the 120th day, the average weight for the contaminated plant is only 53% of the average weight for the un-contaminated plant. The carrot edible root starts to form on the 60th day for plants growing in both contaminated and un-contaminated soils. The average weights for samples collected on the 60th day are 2.8 g and 4.6 g for plants growing in contaminated and un-contaminated soils, respectively. Although the yield is smaller for plants growing in contaminated soil, the difference is not obvious. After the 80th day, obvious weight difference starts to show; the growth rate of carrot growing in contaminated soil becomes apparently slower. Carrot has a growth period of about 100 to 120 days. The weight of edible root for carrot samples collected on the 120th day from the contaminated soil is only 47% of that for the control growing in un-contaminated soil.

Results obtained with radish are similar to those obtained with carrot as shown in Figure 3. During the initial 40 days of growth, the average weights of plants growing in contaminated soil and un-contaminated soil show no obvious difference. After the 60th day, the weight difference becomes noticeable. Between the 60th and the 80th day, radish plants grow rapidly and the weight difference becomes very obvious. Radish plants have a growth period of 70 to 80 days. As seen in Figure 3, whether growing in the contaminated or un-contaminated soils, radish plants show retarded mass increase after the 80th day. The mass of plants growing in contaminated soil gradually decreases because they start to show withering. On the 80th day, the average weight of the contaminated plants is only 54%

of that of the un-contaminated control plants. The edible root of radish, appearing on the 60th day, weighs 4.5 g per plant for the contaminated radish and 10.6 g per plant for the un-contaminated radish collected on the 60th day; the weight difference is obvious. Between the 60th and the 80th days, the radish

plant weight increases rapidly but mostly due to increase of weight in the edible root. The yield of edible root for radish growing in contaminated soil is only 45% of that growing in un-contaminated soil on the 80th day and only 40% on the 100th day.

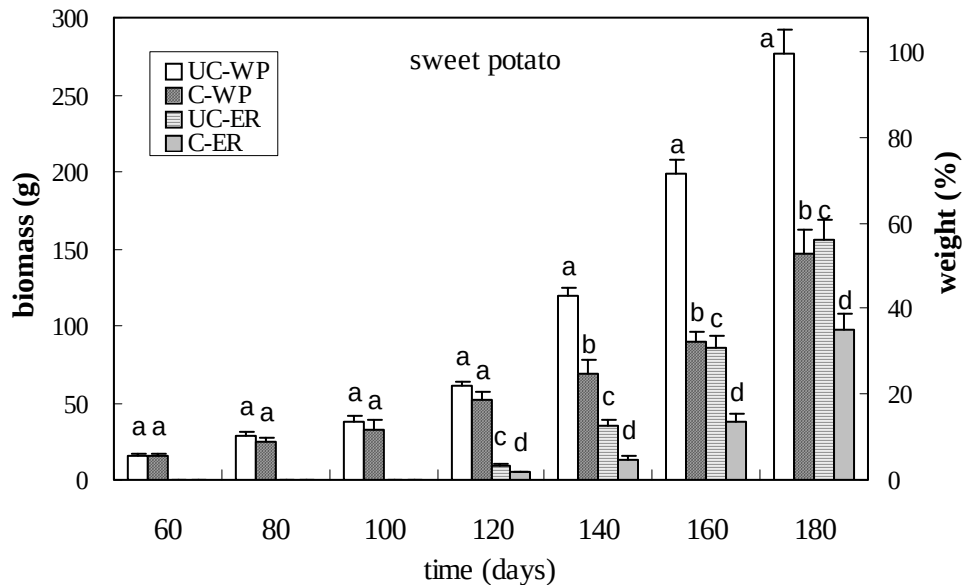


Figure 1. The average weights of the whole plant and edible root for sweet potato plants. UC-WP: whole plant in un-contaminated soil; C-WP: whole plant in contaminated soil; UC-ER: edible root in un-contaminated soil; C-ER: edible root in contaminated soil. The weight percentages base on the weight of whole plant in un-contaminated soil.

The comparative results on the growth of sweet potato, carrot and radish grown in cadmium- contaminated and un-contaminated soils show many similarities on the influence of cadmium on these three root vegetables. During the initial growth period, the edible root has not yet developed and there is no difference in the growth rate (based on mass) between the plants growing in contaminated and un-contaminated soils. This indicates that concentrations of the cadmium accumulated in the plant tissue are within the tolerable limits. During the later growth period when the edible root begins to develop, the growth rate

of the contaminated plants becomes adversely affected. The root tissue is an important gate for heavy metals to enter the plant body from soil. Most heavy metals enter the plant body through cellular ion exchange and absorption, and then transported to the various plant tissues [4]. In this research, the cadmiums content is analyzed on samples collected at the various growth phases for all three root vegetable plants. As shown in Figure 4, carrot and radish show rapid increase of cadmium in their root tissues between the 60th and the 80th day. The period between the 60th and the 80th day is also the time when carrot and radish

have rapid growth in the edible root as evidenced by the comparison of Figure 2 and Figure 3. This is also observed in sweet potato as seen in Figure 4 that the cadmium content

in sweet potato reaches the highest level on the 120th day, the time when sweet potato starts to develop the edible root.

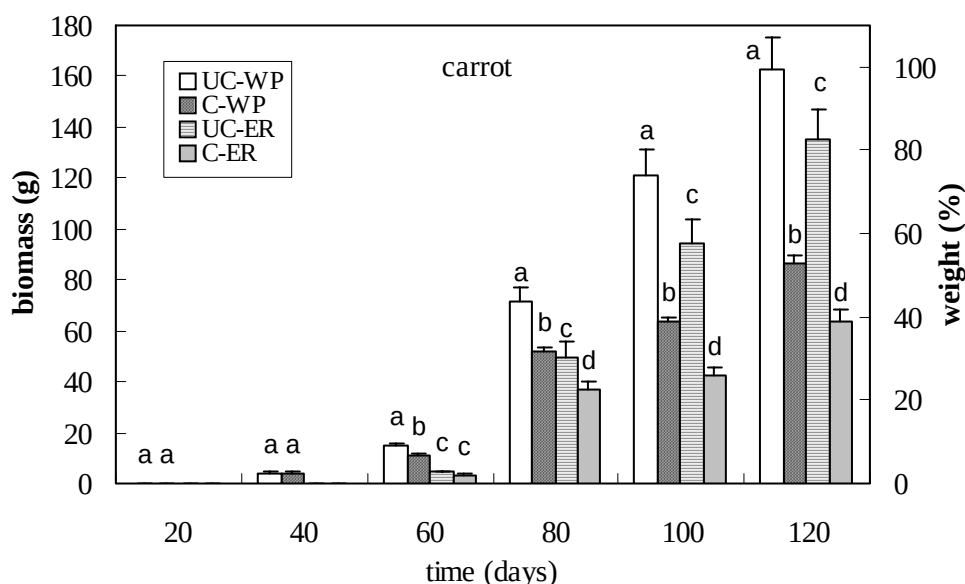


Figure 2. The average weights of the whole plant and edible root for carrot plants. UC-WP: whole plant in un-contaminated soil; C-WP: whole plant in contaminated soil; UC-ER: edible root in un-contaminated soil; C-ER: edible root in contaminated soil. The weight percentages base on the weight of whole plant in un-contaminated soil.

3.3. Accumulation of Cadmium in Edible Root and the Consumption Safety

Figure 5 shows the absorption and accumulation of cadmium in the edible roots of sweet potato, carrot and radish during their growth in the contaminated soil. The accumulation of cadmium in the edible root of all root vegetables rises with increasing growth time. Radish can be harvested on the 80th day of growth; its cadmium concentration averages 57.5 mg kg⁻¹ on the 80th day and 89.5 mg kg⁻¹ on the 120th day. Among the three plants studies, the edible root of carrot accumulates the lowest cadmium concentration of 60.1 mg kg⁻¹ on the 120th day when it is harvested. Sweet potato has the

highest cadmium adsorption capacity; the cadmium concentration in the sample collected on the 120th day is as high as 53.7 mg kg⁻¹. Thereafter, cadmium accumulation accelerates with growth time to reach the highest level of 137.6 mg kg⁻¹ on the 160th day; it reduces slight to average 118.3mg kg⁻¹ on the 180th day.

The reason for the reduction of cadmium accumulation on the 180th day is that root, stem and leaves of the contaminated sweet potato plant start to wither thus the average mass reduces from 52.0 g on the 160th day to 48.7 g on the 180th day. According to literature information, the plant will no longer absorb large quantities of water and nutrients including cadmium in the later growth period.

Figure 1 shows the edible root of sweet potato is still growing between the 160th and the 180th day. Since the adsorption rate for

cadmium by the root is decreasing, the average cadmium concentration in the edible root on the 180th day declines.

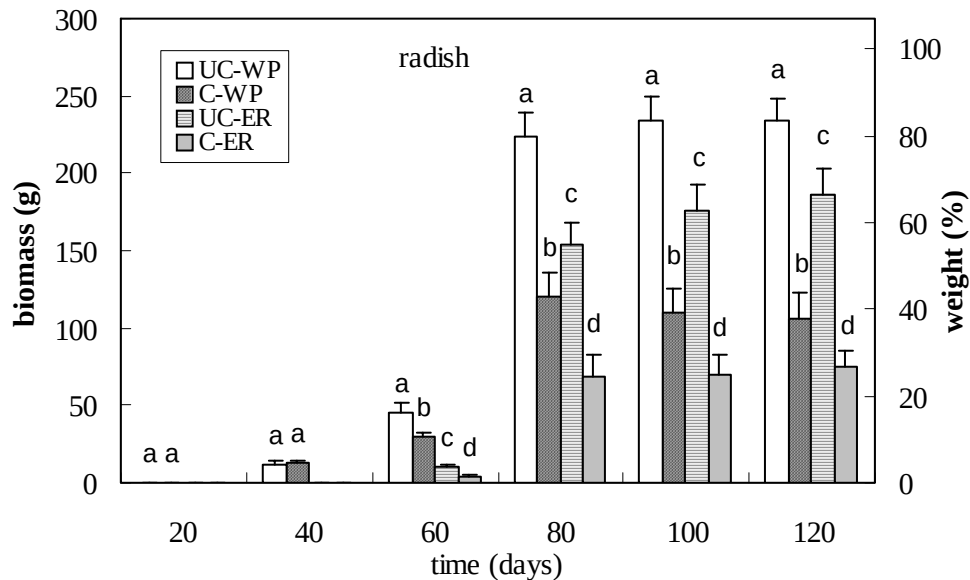


Figure 3. The average weights of the whole plant and edible root for radish plants. UC-WP: whole plant in un-contaminated soil; C-WP: whole plant in contaminated soil; UC-ER: edible root in un-contaminated soil; C-ER: edible root in contaminated soil. The weight percentages base on the weight of whole plant in un-contaminated soil.

The allowable cadmium concentration in crops as stipulated by the various nations generally falls between 0.05 to 1.0 mg kg⁻¹. For example, the German limit is 0.05 mg kg⁻¹ in vegetables and 0.1 mg kg⁻¹ in grains [5]; Japan sets the maximum allowable cadmium concentration of 1.0 mg kg⁻¹ in rice [15] while Switzerland has the 0.1 mg kg⁻¹ limit for both vegetables and grains [16]. Concentrations of the accumulated cadmium in the edible roots of all three vegetables obtained in this research much exceed the above allowable limitations. Additionally, based on the daily allowable cadmium uptake of 1 µg kg⁻¹ as recommended by Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO) [4], the allowable cadmium uptake by an adult

with an average weight of 60 kg is 60 µg that is equivalent to less than 1 g of sweet potato, carrot or radish as grown in this research. This result indicates that the vegetables grown in the contaminated soil as obtained in this study is not suitable for human consumption.

This research reveals that the control vegetable plants growing in un-contaminated soil show increasing cadmium accumulation in the edible root with growing time. On the 120th day, the average cadmium concentration in the carrot edible root reaches 0.067 mg kg⁻¹, which has already exceeded the German limit. For radish, the average cadmium concentration in the edible root is 0.085 mg kg⁻¹ on the 80th day; it reaches 0.25 mg kg⁻¹ on the 120th day that has already gone above the allowable limits of many nations such as

Switzerland, Finland and China [5, 17]. Among all three vegetable plants, the sweet potato edible root has the highest cadmium accumulation. In the control set, the average cadmium concentration in the edible root is

1.26 mg kg⁻¹ that is higher than the allowable limit currently enforced in most nations. According to FAO and WHO suggestion that the average daily consumption of sweet potato should not exceed 47.6 g.

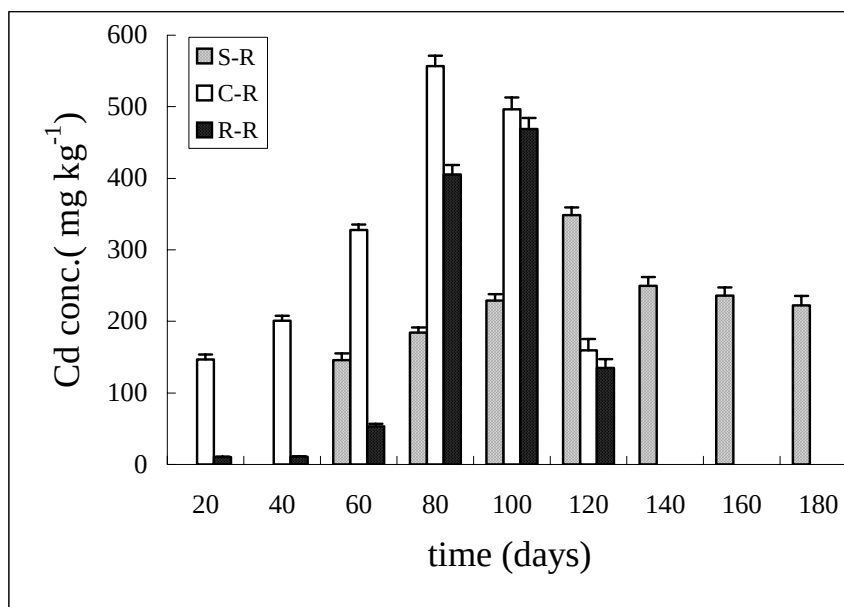


Figure 4. The concentration of Cd in the roots of sweet potato, carrot and radish. S-R: for sweet potato; C-R: for carrot; R-R: for radish

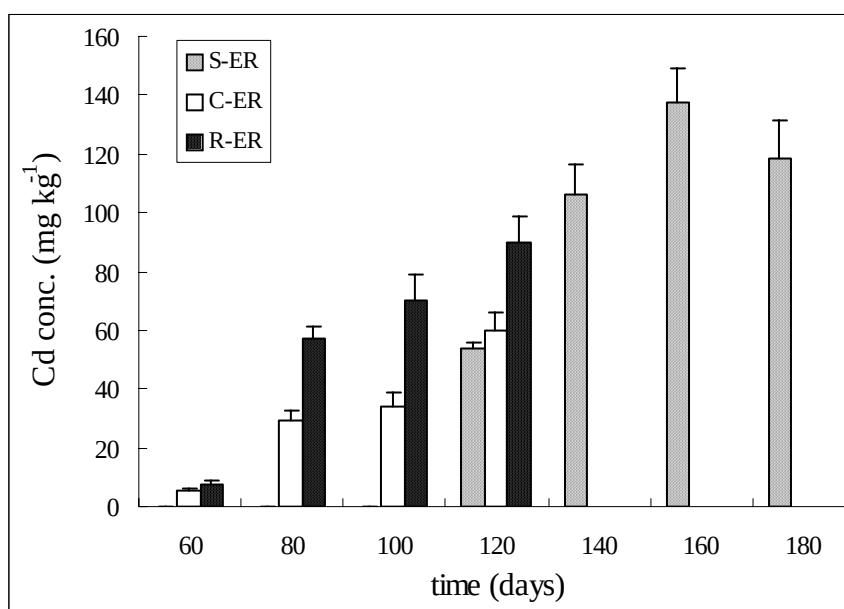


Figure 5. The concentration of Cd in the edible roots of sweet potato, carrot and radish. S-ER: for sweet potato; C-ER: for carrot; R-ER: for radish

Results obtained in this research indicate that the edible root of three root vegetables has somewhat high capacity of absorbing and accumulating cadmium. The control un-contaminated soil contains 3.8 mg kg^{-1} cadmium that is below the 5 mg kg^{-1} level stipulated by laws and regulations currently implemented in Taiwan. However, the edible roots of sweet potato, carrot and radish growing in such un-contaminated soil have accumulated cadmium to such levels that have already exceeded the limits of allowable cadmium concentration enforced in many nations. Therefore, soils with slight cadmium contamination should not be used for growing sweet potato, carrot and radish, etc. root vegetable crops.

4. Conclusions

Results of this research show that the heavy metal cadmium does not have obvious influence on the growth of sweet potato, carrot and radish during their initial growth. When the plants start to develop the edible root, the absorption and accumulation of cadmium in the root tissue will increase leading to rising cadmium concentrations in the various tissues. Additionally, the accumulated cadmium will show obvious effect to retard the plant growth. This research also discovers that the adverse influence of cadmium on the growth of root vegetables usually appears when the edible root begins to develop. The weight of the harvested contaminated plants has only 50% of the weight of the control plant grown in un-contaminated soil. Therefore, when the crop yield of a farmland becomes obvious lower than that expected for normal conditions, one must pay attention to a possible cadmium contamination of the farmland.

The edible root of sweet potato, carrot and radish is nutrient-storing organs. Thus, heavy metals such as cadmium may accumulate in the edible root along with the stored nutrients.

In this research, the cadmium concentration in the edible root of all three plants far exceeds the allowable concentrations of most nations. Being the worst case of cadmium accumulation in the sweet potato edible root that is 2000 times the German allowable cadmium limitations, sweet potato is not suitable for consumption. Additionally, the research also discovers that the root vegetable plants growing in the control un-contaminated soil also show increasing accumulation of cadmium in the edible root with growth time. The edible root of the harvested carrot and radish contain cadmium much higher than the allowable limits set by many nations; sweet potato has even higher cadmium concentration in the edible root. It is recommended that soils with slight cadmium contamination should not be used for growing root vegetables such as sweet potato, carrot and radish, especially sweet potato.

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References

- [1] Kabata-pendias, A., Pendias, H. 2001. *"Trace elements in soil and plants"*. C.R.C. Press. Boca Raton. Florida. U.S.A.
- [2] Lin, H. C. and Chiou, C. K. 1990. Response of lettuce, mustard, rice and corn crops to cadmium treatment. *Proceeding of the 2nd workshop of Soil Pollution Prevention*, 257-272.
- [3] Barber, A. and Brennan, E. 1974. Phytotoxic effects of cadmium. *Phytopathology*, 64: 578-586.
- [4] Taiz, L. and Zeiger, E. 2002. *"Plant Physiology"*. Sinauer Associates. Massachusetts.
- [5] Chen, Z. S., Lai, H. Y., Tsai, C. C. and Lee, C. H. 2004. Heavy metal concentra-

- tions affect crop quality and phytoremediation of heavy metal-contaminated rural soils. In: Ho, C. C., Tzeng, C. C., Yang, J. T. and Wang, S. C. (Eds.). *Proceedings of the Symposium of Innovative Strategy on Plant Protection- Agricultural Productivity, Product Safety and Environmental Protection*: 157-182.
- [6] Kovacs, M., Turcsanyi, G., Penksza, K., Kaszab, L. and Szoke, P. 1993. Heavy metal accumulation by ruderal and cultivated plants in a heavily polluted district of Budapest. In: Markert, B. (Eds) *Plants as Biomonitors: Indicators for Heavy Metal in the Terrestrial environment*. VCH Verlagsgesellschaft mbH, Weinheim, Germany, 495-505.
- [7] Kim, J. Y., Kim, K. W., Lee, J. U., Lee, J. S. and Cook, J. 2002. Assessment of As and heavy metal contamination in the vicinity of Duckum Au-Ag mine, Korea. *Environmental. Geochemical. Health*, 24: 215-227.
- [8] Evanko, C. R. and Dzombak, D. A. 1997. Remediation of Metals-Contaminated Soils and Groundwater. "Technology Evaluation Report", TE-97-01, Ground-Water Remediation Technologies Analysis Center.
- [9] Chen, Y. X., Lin, Q., Luo, Y. M., He, Y. F., Zhen, S. J., Yu, Y. L., Tian, G. M. and Wong, M. H. 2003. The role of citric acid on the phytoremediation of heavy metal contaminated soil. *Chemosphere*, 50: 807-811.
- [10] Lin, Q., Chen, Y. X., Chen, H. M., Yu, Y. L., Luo, Y. M. and Wong, M. H. 2003. Chemical behavior of Cd in rice rhizosphere. *Chemosphere*, 50: 755-761.
- [11] Mench, M. and Martin, E. 1991. Mobilization of cadmium and other metals from two soils by root exudates of *Zea may*. L., *Nicotiana tabbicum* L., and *Nicotiana rustica* L. *Plant and soil*, 137: 187-196.
- [12] Song, J., Zhao, F. J., Luo, Y. M., McGrath, S. P., Zhang, H. 2004. Copper uptake by *Elsholtzia splendens* and *Silene vulgaris* and assessment of copper phytoavailability in contaminated soils. *Environmental Pollution*, 128: 307-315.
- [13] Ye, Z. H., Baker, A. J. M., Wong, M. H. and Willis, A. J. 2003. Copper tolerance, uptake and accumulation by *Phragmites australis*. *Chemosphere*, 50: 795-800.
- [14] Singer, M. J. and Munns, D. N. 2002. "Soils: An Introduction". Prentice Hall, New Jersey.
- [15] Asami, T. 1981. Maximum allowable limits of heavy metals in rice and soils. In: Kitagishi, K., Yamane, I. (Eds.) "Heavy Metal Pollution in Soils of Japan". Japan Scientific Society Press. Tokyo, Japan. 257-274.
- [16] Avigdor, L. T. 1987. Food contaminants: safety and regulatory aspects. *Swiss Food*, 9: 13-35.
- [17] Wenzel, W. W., Adriano, D. C., Salt, D. and Smith, R. 1999. Phytoremediation: A plant-microbe-based remediation system. In: Adriano, D. C., Bollag, J. M., Frankenberger, J. and Sims, R. C. (Eds.) "Bioremediation of Contaminated Soils". American Society of Agronomy, Inc. Madison, WI, U.S.A. 457-508.