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Cadmium Uptake by Plant and Transport in Soil Column under Industrial Wastewater Irrigation: A Case Study

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ABSTARCT: Development of industry in Sistan and Baluchestan (SB) province in Iran, has increased the amount of Cadmium (Cd) in industrial wastewater, which is used as a secondary water supply in this area. The present study aimed to investigate the variation of Cd concentration in soil column and cultivated cucumber plant in greenhouse under short-term simulated industrial wastewater irrigation. To simulate industrial wastewater, two different solutions with concentration of 0.2 and 1 ppm of Cd were used and labeled medium and strong wastewater. The Cd concentration of higher organs and roots of plants and soil in three different depths (shallow, 20, and 30 cm) were analyzed during 65 days in six days of plant growth period. Results demonstrated that the medium and strong wastewater were unable to contaminate the fruit. However, despite a considerable amount of Cd absorption by root in the first days, Cd concentration decreased significantly during next days to 253.17 ppb in the last day of sampling. In addition, a direct relationship between Cd concentration and time was observed in soil. Furthermore, in the last day of experiment, Cd accumulated more than 1689, 175, and 124 ppb in shallow layer and depths of 20 and 30 cm of soil using 0.2 ppm Cd solution, respectively.

Key word: Contaminated soil, Industrial wastewater, Cadmium, Plant uptake, Irrigation

INTRODUCTION

Heavy metal contamination in water and soil resources has become a global concern in the modern world. Due to a direct interaction between these sources and the food chain, the excessive concentration of heavy metals is a serious threat to human life (Gao. *et al.,* 2011). Furthermore, heavy metal penetration to ground water via contaminated soil plays a vital role in health and environmental aspects. Cd is one of the most poisonous heavy metals without biological function, which is easily absorbed by plants (Robinson *et al.,* 2000). Inevitably, the industrial wastewater usage for farmland-irrigation has dramatically increased because of the water shortage crisis and fertility benefits. This practical use is one of the main causes of Cd entrance to soil, plant and any living creatures. Regarding the long Cd biological half-life (10-30 years), its accumulation in some organs like kidney and liver makes functional disorders such as Proteinuria (Ingwersen 2001; Massadeh *et al.*, 2004). Cd and its compounds are water soluble, mobile in most soils and added to soil by wastewater reuse, chemical fertilizer application or atmospheric deposition (Pandit *et al.*, 2012). For example, Moaref et al. (2014) studied the level of trace elements in wet precipitation and dry deposition in the southwest of Iran. However, the industrial use of Cd and sewage sludge have been identified as major sources of widespread Cd distribution in the environment and human foodstuffs (Tang *et al.*, 2011).

The Cd mobility in soil and its uptake by plant depend on various soil and plant physicochemical factors including pH, CEC, organic carbon, clay content, and environment temperature (Adams *et al.*, 2004; Tack *et al.*, 1998; Guala *et al.*, 2013; Ingwersen and Streck, 2006; Kimberly *et al.*, 1999; Verma *et al.*, 2007). Based on a number of studies (Adams *et al.*, 2004; John *et al.*, 1972), as the pH increases, the less concentration of Cd uptake by plant tissues occurs. In other words, there is a negative

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correlation between pH and Cd uptake (Handreck 1994). Because, lower pH results in more metal solubility and consequently more concentration of heavy metal in soil solution can exist and finally more mobility to root can be observed (LeCoultre 2001). Wang et al. (2006) studied the effects of soil pH on Cd and Zn uptake by Thlaspi caerulescens. They found that reduction of pH, inclines the amount of soluble Cd in soil, so the time of phyto-remediation shortens. A few studies demonstrated that the Cd uptake by cucumber fails to be affected by pH. In fact, against other crops especially leafy vegetables, cucumber's ability to Cd uptake is not under the influence of pH variation (FalahiArdakani *et al.,* 1988; Huang *et al.,* 2003).

Despite a considerable amount of literature on the effect of CEC on Cd availability for plant, it remains an unclear process (Alloway 1995; Fageria *et al.,* 2010). For example, Haghiri et al. (1974) showed that CEC enhancement decreases the Cd concentration in oat shoots. Similarly, Hinesly et al. (1982) approved that there is an inverse relation between the inverse proportion of Cd uptake by plant and soil CEC in the soils spiked with $CdCl_2$. While, they indicated no relation between CEC and Cd uptake in soils under sewage sludge. In an innovative work by Cheng and Huang (2007), it was concluded that the low CEC of edible parts of the root in different plants is a reason why the mentioned parts absorb less Cd rather than other root tissues. Generally, EC rises the chloride concentration in soil and consequently chloro-complexation of Cd boosts the concentration of soluble Cd and eventually the phytoavailability of Cd enhances (Khoshgoftar *et al.,* 2004, Lopez-Chuken *et al.,* 2011).

Related studies have assessed heavy metals transportation in soil and their uptake by plants but there is no significant work on Cd transport in soil and plant simultaneously (Legind *et al.,* 2012). In this research, the transport of Cd in different depths (shallow layer, 20 and 30 cm) of soil column was investigated to assess groundwater resources contamination through wastewater irrigation in a short period of time. Furthermore, Cd concentrations in different parts of cucumber plant were examined to understand the effects of Cd on the food chain.

MATERIALS & METHODS

Two industrial estates around the Zahedan and Chabahar cities located in SB province are the main industrial wastewater producers (Fig.1). Because of their significant amount of wastewater production, local farmers may use these alternative water resources for irrigation. Three samples of wastewater were collected from each estate. The average concentration of Cd in industrial wastewater was determined by Atomic Absorption Spectrophotometer (AAS) and ranged from 0.18 to 0.21 ppm. To do this measurement, 100 ml of wastewater was directly aspirated to AAS in the laboratory by a lab expert (Singh *et al.,* 2010). However, the existence of metalworking fluid in the wastewater stops the plant's growth due to its complex biocides and chemicals (Cheng *et al.,* 2005). It was unreasonable and uneconomic to treat metalworking fluids, therefore the wastewater was simulated by Cd standard solution

Fig.1. Map of the sampling sites in SB province

(1000 mg/l) produced by Merck Millipore, Germany. Solutions were prepared in 2 different concentrations; 0.2 and 1 ppm, will be referred to medium and strong wastewater, respectively in this study.

Two plots in the greenhouse of university of SB located in southeast of Iran, were selected for experiments. The dimensions of each plot were 2×3 m^2 and an uncultivated gap was considered between them. The plots were filled by Zahedan and Chabahar farmlands soil. Although rip irrigation is normally used in local greenhouses, for reaching highest amount of Cd absorption by plant, the plots were irrigated by the furrow method (Mojiri and Hamidi, 2011). Cucumber seeds were manually planted with a row spacing of 25 cm on hills with the width of 10 cm and 7 cm above the surface of the soil. The plots were irrigated by urban water until the plants were roughly 5 cm tall with two leaves. After the plants were 5 cm tall, they were irrigated by simulated wastewaters.

Before planting, to determine the soil properties and Cd concentration, different samples were collected from various depths of soil (up to 30 cm) and transported to the laboratory. In the laboratory, after air drying, unwanted materials such as root and stones were removed and lumps of soil were crushed to finer components, and then samples were sieved with a 2 mm mesh. The physicochemical properties including soil texture (Klute, 1986), pH, cation exchange capacity (CEC), electrical conductivity, organic matter and saturated moisture were measured in accordance with soil analysis methods (Black, 1965), that are shown in Table 1. In addition, soil samples were digested with a mixture of 3:1 ($HCl:HNO_3$) to measure the concentration of Cd by AAS (Baker and Amacher, 1982).

During the growth period, plant samplings started at the day after wastewater irrigation on a regular basis. For each sampling, at least three plants were picked up from the root zone. Therefore, the whole plant consists of root, stem, leaves, and fruit, which were collected and placed in zip locked plastics. In the laboratory, root, stems and leaves were separated and washed with deionized water then dried in the room temperature and finally in an oven at 70ºC for a 24 h period. Eventually, they were powdered. One gr of dried powdered of each plant's part was digested with HNO_3. The Cd concentration was analyzed by AAS (Nouri *et al.*, 2009). The different depths of soil (shallow layer, 20 and 30 cm) were manually sampled from where the cucumbers were exactly planted.

RESULTS & DISCUSSION

Cd transportation in different depths of soil is one of the main objectives in this study. During a 65-day experimentation in the plot A, which was irrigated by 0.2 ppm of Cd solution, the variation of Cd concentration in different soil depths changed and the results illustrated in Figs 2, 3, and 4.

Fig. 2, shows that during five times of wastewater application up to the second sampling, the concentration of Cd in the shallow layer increased dramatically to reach more than 1500 ppb. An irrigation with urban water between the second and the third sampling made a large amount of Cd to be leached to the deeper depths, therefore, the Cd concentration decreased by approximately 1000ppb. Since then, the more wastewater irrigation was applied, the more Cd was accumulated in the surface layer of soil until the fifth sampling. While in the last two weeks, fall in amount of accumulated Cd seems to be related to the more leaching of Cd towards the depths of 20 and 30 cm which will be discussed in the following paragraphs.

As it is observed in Fig. 2, a Gaussian function with two terms (Equation. 1) fits the Cd concentration points taken from experiments.

Here $Cdc_0(t)$ is the concentration of Cd in the shallow layer of soil (ppb) and t shows the time (day).

Table 1. Physicochemical properties of soil

Texture	Moisture (%)	pH	CEC (cmol/kg)	EC (Ds/m)	OC (%)	Cd(ppb)
Sandy	2.41	7.1	4.4	6.29	0.15	ND*

* Not Determined

$$Cdc_0(t) = 1747exp(-((t-11)/9.601)^2 + 1608exp(-((t-50.98)/22.02)^2 \quad (1)$$

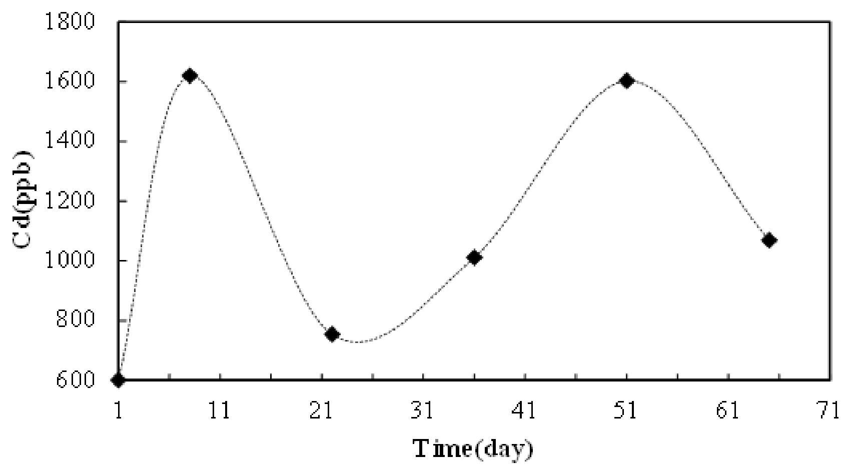

Fig. 2. Cd concentration over time in surface layer of soil

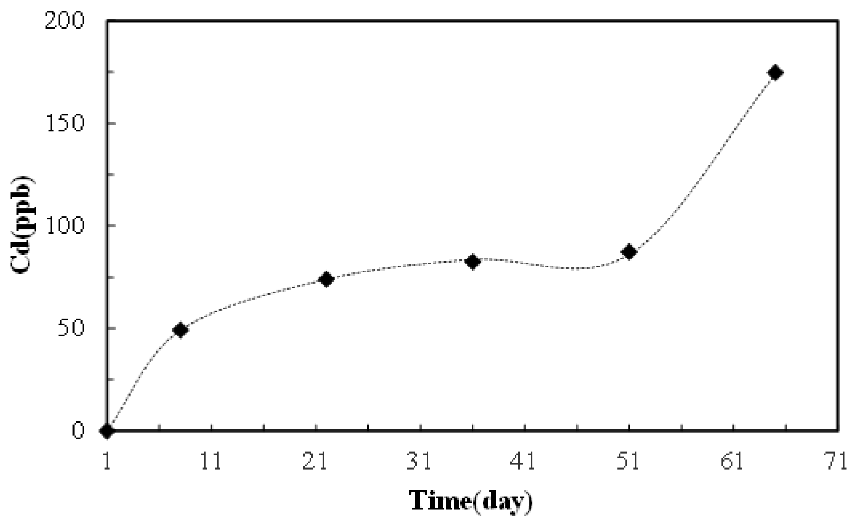

Fig. 3. Cd concentration over time in depth of 20 cm

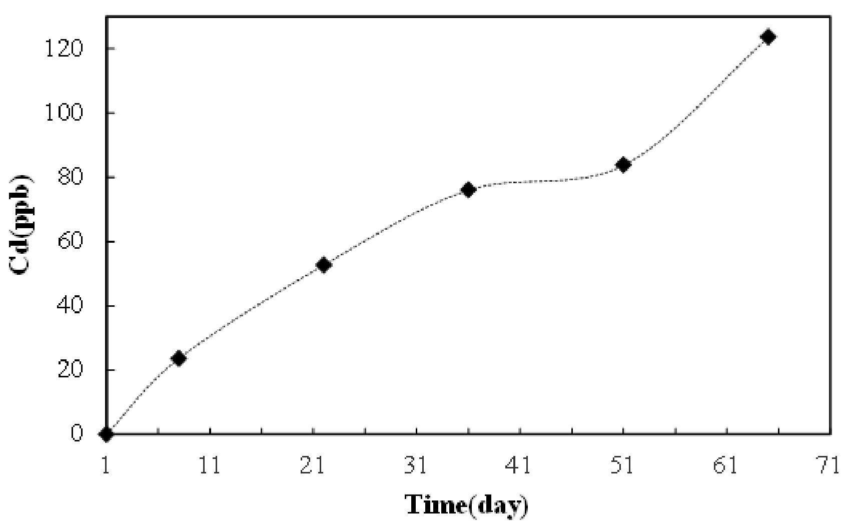

Fig. 4. Cd concentration over time in depth of 30 cm

For the second depth (20 cm), as illustrated in Fig. 3, Cd concentration had an increasing trend. Indeed this trend was expected before, as it was known that Cd transport towards the depth of soil has a low rate. Comparing the last section of Fig. 2 and 3 approves that an increase in Cd concentration by last two weeks was owing to leaching from shallow depth.

A five order polynomial function (Equation. 2) can fit precisely the experimental data. This fitted curve with high performance shows the ascending trend of Cd accumulation in the soil column.

$$Cdc_{20}(t) = 2.78\times 10^{-6} t^5 - 7.131\times 10^{-4} t^4 + 0.02613t^3 - 0.7808t^2 + 12.38t - 11.62 \quad (2)$$

Therein, $Cdc_{20}(t)$ is the Cd concentration in the depth of 20 cm (ppb) and t indicates the time (day).
Increasing trend of Cd concentration at 20 cm soil depth during the experiment time, took place again at the depth of 30 cm. As shown in Fig. 4, Cd concentration increased slowly until fiftieth day.

$$Cdc_{30}(t) = 15.25\times 10^{-6} t^5 - 21.83\times 10^{-4} t^4 + 0.0113t^3 - 0.267t^2 + 5.085t - 4.829 \quad (3)$$

Therein, $Cdc_{30}(t)$ is the Cd concentration in the depth of 30 cm (ppb) and t indicates the time (day).

After each sampling Cd concentration in the root, shoots plus leaves, and cucumber fruits of plant were measured. The roots as a barrier adsorb larger portion of applied Cd and do not transport them into other edible and non-edible parts of plants (Yim and Tam., 1999; Cheng and Huang., 2007). The inverse relationship between CEC in soil and Cd uptake by root was studied by Haghiri (1974) and Perlman (1978). However, they neglected the effect of growth time and CEC variation over time. According to Fig. 5, the root started to adsorb Cd since first days of irrigation. Between first and second sampling, the root received the greatest amount of Cd (> 3500 ppb).Just at this period of time the value of CEC in the root zone reduced regard to Fig. 6, CEC is the capability of soil to save the cations in itself, therefore as the CEC decreased, the more Cd was transported to the root. The second reason for the Cd increase in the root was a consequence of rapid growth of root epidermis which absorb more water and subsequently more Cd along with(Pulford and Watson, 2003). Whilst, after reaching the maximum absorption at the second sampling day, the accumulated Cd in the root reduced smoothly until the day of 51. This reduction was associated with CEC increase based on Fig. 6. Furthermore, during the last two weeks of growth, as the CEC considerably decreased, Cd concentration increased.

Generally, shoots takes up slower Cd in comparison to roots or ground parts. In other words about 70-90% of Cd remains in the root tissue because of the absorption to negative charged cell walls as well as accumulation in cytoplasm and vacuoles (Nylund, 2003). The variation of Cd concentration is illustrated in Fig. 7. By comparing the amount of Cd in both stem and leaves with the range of Cd concentration in roots, the previous claim is proved to accumulate more Cd in root. The Cd in the first days of sampling again was intended to increase in shoot because the root also absorbs a high degree of Cd then translocates it to higher organs through the xylem (Nylund, 2003). The sin-wave shape of Cd movement to higher organs reveals its dynamic behavior over time. This phenomena can be predicted by a Gaussian function with two terms which is presented in Equation. 4

$$Cdc_h(t) = 156.8exp(-((t-9.087)/8.339)^2 + 135.1exp(-((t-49.55)/183.73)^2 \quad (4)$$

Therein, $Cdc_h(t)$ is the Cd concentration in higher organs and t is a time indicator.

In the first plot irrigated with medium industrial wastewater, cucumber fruit absorbed no Cd, although the Cd concentration measurements were done for three times.

In this research wastewater including 1 ppm Cd was used to synthesize the strong wastewater, 5 times of medium strength. With regard to industrial development in local areas, it is predicted to have a medium or even strong industrial wastewater in the near future. This high amount of Cd in irrigation water turned the leaves colour to yellow and most of the plants died. So to continue the experiments, sampling was limited to two times; in the first and 65th day in a row similar to the first plot. As it can be seen in Table. 2. three times irrigation with strong wastewater caused accumulating more than 4540 ppb of Cd concentration in surface layer of the soil, however it fell down to 72.45 and 33.29 ppb in the depths of 20 and 30 cm respectively. After 13 times irrigation same as the first plot, in the last day of sampling the Cd concentration in the surface layer peaked at 17791 ppb and this considerable increase also was observed in deeper depths to be 1717.79 and 726.45 ppb. The

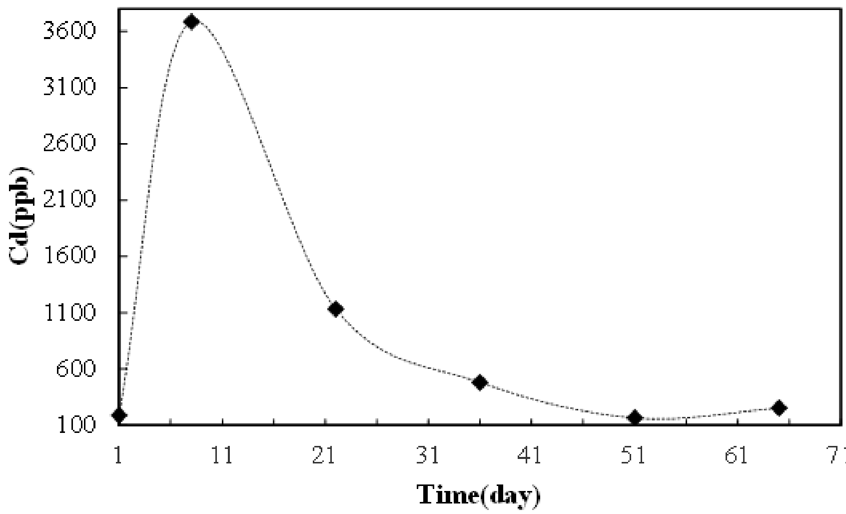

Fig. 5. Cd concentration over time in root

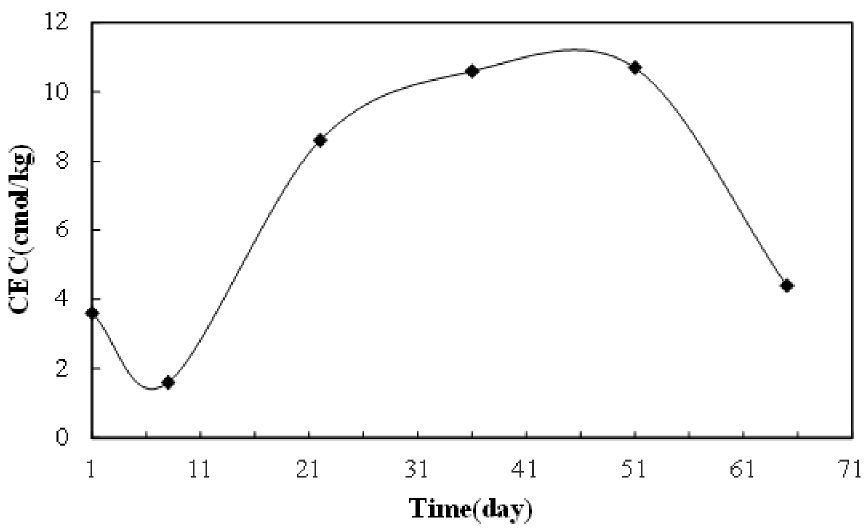

Fig. 6. CEC values over time in soil

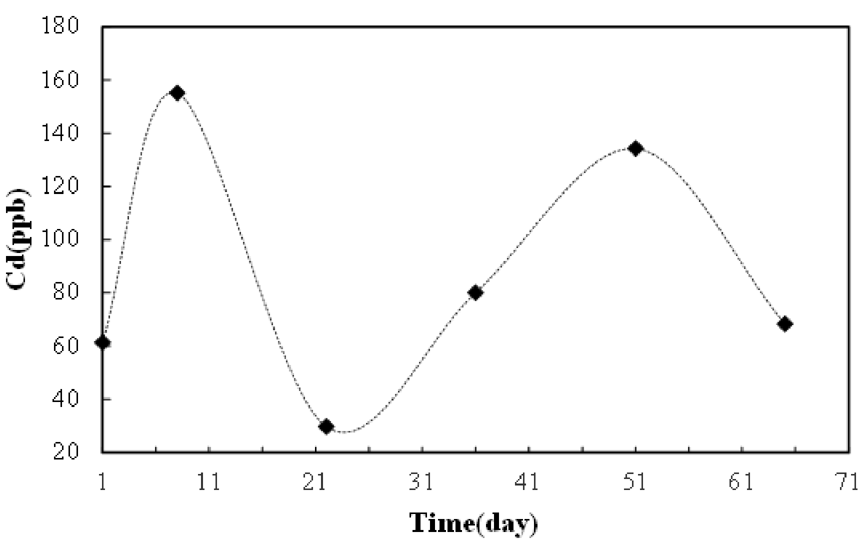

Fig. 7. Cd concentration over time in higher organs

Table 2. Cd concentration in plot B

Cd (ppb) (Higher organs)	Cd (ppb) (root)	Cd (ppb) (h=30)	Cd (ppb) (h=20)	Cd (ppb) (h=0)	Time (day)
1006.27	9147.79	33	72	4540	1
186.97	2791.4	726	1717	17791	65

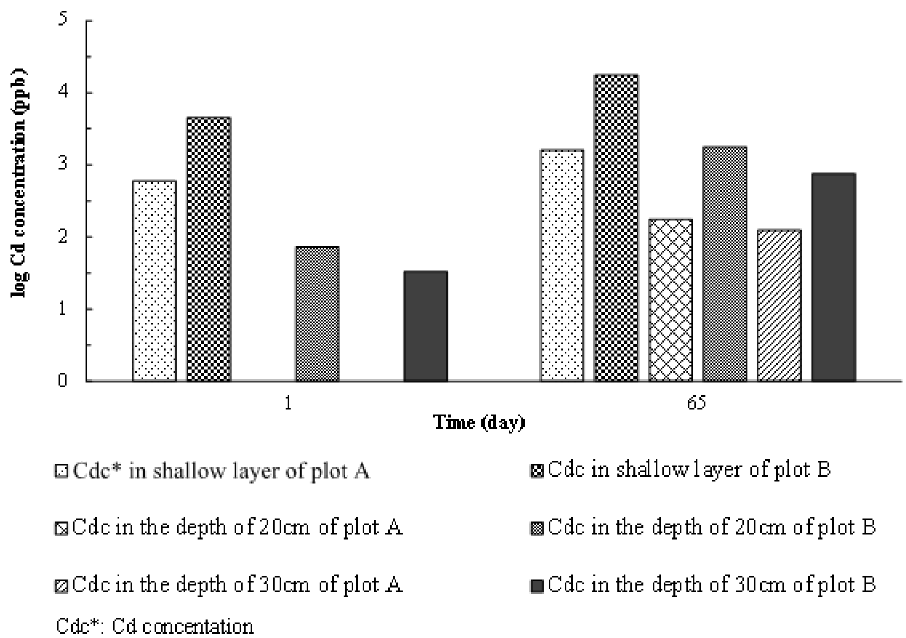

Fig. 8. The Cd concentration accumulation in various depth of both plots

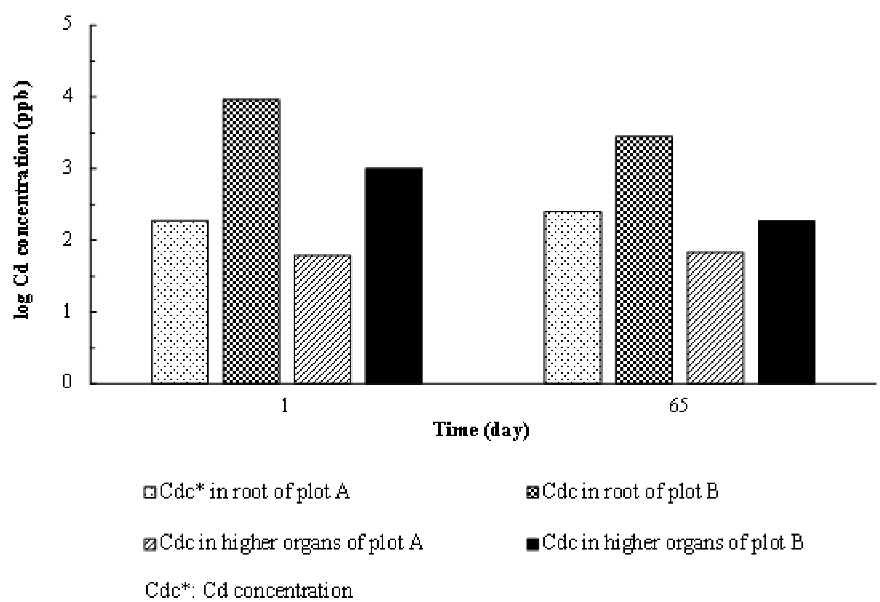

Fig. 9. The Cd concentration in root and higher organs of both plots

physicochemical properties of the soil fail to change significantly.

The Cd concentration grew in different plant tissues with a direct function of Cd concentration in wastewater (Table 2). But Cd concentration in the root was faced with 6356.39 reduction since the first day. For the higher organs, Cd concentration sharply lowered to 186.97 at the day of 65. Fortunately, the fruit again was safe against the Cd absorption.

When simulated wastewater is used for irrigation, the Cd concentration plays a vital role in Cd accumulation within various depths of soil. As indicated in Fig. 8, in a logarithmic scale, the Cd concentration in the first day of sampling in both plots and surface layer was accumulated and it significantly increased in the last day of experiment. In plot A, Cd was detected in neither depths of 20 nor 30 cm. However, in the same time Cd was transferred to the depth of soil in the plot B. In the last day, both plots included Cd concentration in their lower depth, whereas, the plot B absorbed more Cd in the depths.

Cd concentration in the irrigation water directly affected the Cd uptake by the root and higher organs and it is observed clearly in Fig. 9. The amount of Cd absorbed by root in the plot B was considerably greater than the root grown in the plot A. The high amount of Cd in simulated wastewater made the greater uptake of Cd by higher organs in the plant cultivated in the plot B. In the last days of experiment, the Cd concentration of roots and higher organs reduced considerably in both plots.

CONCLUSIONS

A short time study on Cd transport in plant and soil system due to wastewater irrigation resulted following cases. Irrigation with industrial wastewater including 0.2 (plot A) and 1 ppm Cd (plot B) failed to contaminate the cucumber fruits until the first harvesting. In general, a very abrupt reduction in amount of Cd concentration in higher organs of plot B was resulted, while this trend was more constant for cucumber planted in plot A. The root system had a similar capacity to uptake Cd in both plots due to a same ranges of Cd absorption. In spite of a huge amount of applied Cd to plot B, Cd concentration decreased and in the plot A it seemed that the root was not intended to absorb high amount of Cd. Therefore, it is concluded that plant, as an active and alive creature, is able to resist against toxic elements uptake in large doses to protect its life. In different depths of soil, Cd accumulation remarkably increased along with wastewater application. It can be poisonous to human's food-chain because of entering to groundwater and other aquatic environments.

REFERENCES

Adams, M. L., Zhao, F. J., McGrath, S. P., Nicholson, F. A. and Chambers, B. J. (2004). Predicting Cadmium Concentrations in Wheat and Barley Grain Using Soil Properties. Journal of Environmental Quality, **33(2),** 532-541.

Alloway, B. J. (1995). Heavy Metals in Soils, 2nd edition, (Glasgow: Blackie Academic and Professional)

Baker, D.E. and Amacher, M.C. (1982). Nickel, copper, zinc, and cadmium. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis, (Part 2. Chemical and Microbiological Properties. 2nd edition, 323-336. Agronomy Monograph 9. American Society of Agronomy, Madison, WI.)

Black C. A. (1965). Methods of Soil Analysis, Part 2. 2nd edition. Agronomy Monograph. 9, ASA, Madison, WI

Cheng, C., Phipps, D. and Alkhaddar, R. M. (2005). Treatment of spent metalworking fluids. Water Research, **39(17),** 4051–4063.

Cheng, S. F., and Huang, C. Y. (2007). Accumulation of Cadmium Uptake from Soil in the Edible Root of Root Vegetables. Journal of Environmental Engineering Management, **17(2),** 137-142.

Fageria, N. K., Baligar, V. C. and Jones, C. A. (2010). Growth and Mineral Nutrition of Field Crops, Third Edition, CRC Press.

Falahi-Ardakani, A., Corey, K.A. and Gouin, F.R. (1988). Influence of pH on cadmium and zinc concentration of cucumber grown in sewage sludge. HortScience, **23,** 1015-1017.

Gao, X., Flaten, D. F., Tenuta, M., Grimmett, M. G., Gawalko, E. J. and Grant, C. A. (2011). Soil solution dynamics and plant uptake of cadmium and zinc by durum wheat following phosphate fertilization. Plant and Soil, **338(1-2),** 423-434.

Guala, S. D., Vega, F. A. and Covelo, F. A. (2013). Modeling the plant–soil interaction in presence of heavy metal pollution and acidity variations. Environmental Monitoring and Assessment, **185(1),** 73-80.

Haghiri, F. (1974). Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc, and soil temperature. Journal of Environmental Quality, **3(2),** 180-183.

Handreck, K. A. (1994). Effect of pH on the uptake of cadmium, copper, and zinc from soilless media containing sewage sludge. Communications in Soil Science and Plant Analysis, **25(1-2),** 1913-1927.

Hinesly, T. D., Redborg, K. E., Ziegler, E. L. and Alexander, J. D. (1982). Effect of Soil Cation Exchange Capacity on the Uptake of Cadmium by Corn. Soil Science Society of America Journal, **46(3),** 490-497.

Huang, B., Kuo, S. and Bembenek, R. (2003). Cadmium Uptake by Cucumber from Soil Amended with Phosphorus Fertilizers. Journal of the American Society for Horticultural Science, **128(4),** 615-620.

Ingwersen, J. (2001). The Environmental Fate of Cadmium in the Soils of the Waste Water Irrigation Area of Braunschweig - Measurement, Modelling and Assessment, PhD Thesis, Technical University Carolo-Wilhelmina, Germany.

Ingwersen, J. and Streck, T. (2006). Modeling the environmental fate of cadmium in a large wastewater irrigation area. Journal of Environmental Quality, **35(5),** 1026–1035.

John, M. K., VanLaerhoven, C. J. and Chuah, H. H. (1972). Factors affecting plant uptake and phytotoxicity of cadmium added to soils. Environmental Science and Technology, **12(6),** 1005–1009.

Khoshgoftar, A. H., Shariatmadari, H., Karimian, N., Kalbasi, M., Van der Zee, S. E. A. T. M., and Parker, D. R. (2004). Salinity and Zinc Application Effects on Phytoavailability of Cadmium and Zinc. Soil Science Society of America Journal, **68(6),** 1885-1889.

Kimberly, M. F. H. and William, H. (1999). Trace metals in Montreal urban soils and the leaves of Teraxacumofficinale, Canadian Journal of Soil Science, **79 (2),** 385–387.

Klute, A. (1986). Methods of soil analysis. Part 1 – Physical and mineralogical methods, 2nd ed. SSSA Book Series No. 5. SSSA and ASA, Madison, WI.

LeCoultre, T. D. (2001). A Meta-Analysis and Risk Assessment of Heavy Metal Uptake in Medium Garden Vegetables. Dissertation, East Tennessee State University.

Lee, S. Allen, E. H., Huang, C. P., Sparks, D. L., Sandres, P. F. and Peijnenburg, W. J. G. M. (1996). Predicting Soil"Water Partition Coefficients for Cadmium, Environmental Science and Technology, **30 (12),** 3418–3424.

Legind, C. N., Rein, A. Serre, J., Brochier, V., Haudin, C-S., Cambier, P., Houot, S. and Trapp, S. (2012). Simultaneous Simulations of Uptake in Plants and Leaching to Groundwater of Cadmium and Lead for Arable Land Amended with Compost or Farmyard Manure. Plose One, **7(10),** 1-13.

Lopez-Chuken, U. J., Lopez-Dominguez, U., Perra-Saldivar, R., Moreno-Jimenes, E., Hinojosa-Reyes, L., Guzman-Mar, J. L. and Oliviera-Saenz, E. (2011). Implications of chloride-enhanced cadmium uptake in saline agriculture: modeling cadmium uptake by maize and tobacco, International Journal of Environmental Science and Technology, **9(1),** 69-77.

Massadeh, A. M., Tahat, M., Jaradat, Q. M., and Al-Momani, I. F. (2004). Lead and cadmium contamination in roadside soils in Irbid City, Jordan: A case study. Soil & Sediment Contamination, **13(4),** 347-359.

Moaref, S., Sekhavatjou, M.S., and Hosseini Alhashemi, A. (2014). Determination of Trace Elements Concentration in wet and dry Atmospheric Deposition and Surface soil in the Largest Industrial city, Southwest of Iran. International Journal of Environmental Research, **8(2),** 335-346.

Mojiri, A. and Hamidi, A. A. (2011). Effects of Municipal Wastewater on Accumulation of Heavy Metals in Soil and Wheat (TriricumAestivum L.) with Two Irrigation Methods. Romanian Agricultural Research, **28,** 217-222.

Nouri, J., Khorasani, N., Lorestani, B., Karami, M., Hassani, A. H. and Yousefi, N. (2009). Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. Environmental and Earth Science, **59(2),** 315-323.

Nylund, E. (2003). Cadmium uptake in willow (Salix viminalis L.) and spring wheat (Triticumaestivum L.) in relation to plant growth and Cd concentration in soil solution. Dissertation, Swedish University of Agriculture Sciences.

Pandit, T. K., Naik, S. K., Patra, P. K. and Das, D. K. (2012). Influence of Lime and Organic Matter on the Mobility of Cadmium in Cadmium-Contaminated Soil in Relation to Nutrition of Spinach. Soil and Sediment Contamination: An International Journal, **21(4),** 419-433.

Perlman, A. (1978). Advances in applied microbiology, 23, Academic Press.

Pulford, I. D., and Watson, C. (2003). Phytoremediation of heavy metal –contaminated land by trees (a review). Environment International, **29(4),** 529-540.

Robinson, B. H., Mills, T. M., Petit, D., Fung, L.E., Green S. R. and Clothier, B. E. (2000). Natural and induced cadmium-accumulation in poplar and willow: Implications for phytoremediation. Plant and Soil, **227(1-2),** 301-306.

Singh, A., Sharma, K. A., Agrawal, M. and Marshal, M F. (2010). Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. Tropical Ecology, **51(2),** 375-387.

Tack, F. M. G., Esteban-Mozo, J., and Verloo, M. G. (1998). Cadmium uptake by cucumber plants as affected by fluctuations in nutrient solution cadmium concentration during growth. Communications in Soil Science and Plant Analysis, **29(19&20),** 3015-3021.

Tang, J., Bai, X., and Zhang, W. (2011). Cadmium pollution and its transfer in agricultural systems in the suburbs of Tianjin, China. Soil and Sediment Contamination: An International Journal, **20(6),** 722-732.

Verma, P., George, K. V., Singh, H. V. and Singh, R. N. (2007). Modeling cadmium accumulation in radish, carrot, spinach and cabbage. Applied Mathematical Modelling, **31(8),** 1652-1661.

Wang, A. S., Angle, J. S., Chaney, R. L., Delorme, T. A. and Reeves, R. D. (2006). Soil pH Effects on Uptake of Cd and Zn by Thlaspi caerulescens. Plant and Soil, **281(1-2),** 325-337.

Yim, M.W. and Tam, N. F. Y. (1999). Effects of Wastewater-borne Heavy Metals on Mangrove Plants and Soil Microbial Activities. Marine Pollution Bulletin, **39(1-2),** 179–186.