018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable 5.2.4 - Annex 5

Cadmium (Cd) and Lead (Pb) concentration effects on yields of some vegetables due to uptake from irrigation water in Ghana

And

Influence of Transpiration on Cadmium (Cd) and Lead (Pb) uptake by Cabbage, Carrots and Lettuce from Irrigation Water in Ghana

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

5.2.4 Action Research and Demonstrations on the Use of Water for Urban Agriculture
Work package 5.2

The aim of work package 5.2 is to contribute to a paradigm shift in wastewater management and sanitation towards a recycling-oriented closed loop approach. The work package is being implemented in three cities; Accra, Beijing and Lima, and includes the identification and integration of appropriate productive re-use of urban freshwater, storm and waste-water for agriculture into the policy and planning frameworks of these cities.

The deliverables of the work package follow a sequence of implementation. Based on a situation and stakeholder review (del. 5.2.1), working groups are formed, meet and are linked to the Learning alliances (del. 5.2.2), they receive training in multi-stakeholder action planning (del. 5.2.3 A), and are involved in, and informed on, specific research by consultants, MSc and PhD or action research linked to the demonstrations, (all under del. 5.2.4). Information has been disseminated in publications, magazines and newsletters (del. 5.2.5), and guidelines and related training material has been developed (del 5.2.3 B and C). The leading institutes here are ETC (WP coordinator), IWMI (Accra), IGSNRR (Beijing) and IPES (Lima), other institutions involved were WUR, IRC and NRI- GUEL.

As part of deliverable 5.2.4, this product contains information on other research in Accra, including the research by KNUST.
Contributing products included in this document are:

5.2.4 Af MSc Thesis (Briefing Sheet) Addressing pollution and river recovery processes in the middle catchment of the Densu River Basin in Ghana Edmund Kyei Akoto-Danso University of Ghana, Legon.
The Full MSc report is listed under PhD and MSc reports, theme 5

5.2.4 Ag Analysis of domestic water use for commercial activities among the poor in Alajo and Sabon Zongo communities of Accra, Ghana. Kihinde Odunuga
5.2.4 Ak1 KNUST Cadmium (Cd) and Lead (Pb) concentrations effects on yields of some vegetables due to uptake from irrigation water in Ghana. 2008. E. Mensah; Herbert E. Allen; Ryo Shoji; S.N. Odai and David M. Metzler. International Journal of Agricultural Research, 3(4): 243-251
5.2.4 Ak 2 KNUST Influence of transpiration on cadmium and lead uptake by cabbage, carrots and lettuce from irrigation water in Ghana. 2008 E. Mensah; S.N. Odai; E. Ofori and N. Kyei-Baffour Asian Journal of Agricultural Research, 2(2): 56-60.
5.2.4 Ak 3 KNUST Influence of cadmium and lead concentrations of irrigation water on dry matter yield of vegetables. 2009. E. Mensah; M. Bonsu; S.N. Odai; r. Shoji; N. Kyei-Baffour and E. Ofori, Journal of Environmental Science and Technology, 2(1): 68-72

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Cadmium (Cd) and Lead (Pb) Concentrations Effects on Yields of Some Vegetables Due to Uptake from Irrigation Water in Ghana

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Abstract: Heavy metal contamination of agricultural soils from wastewater irrigation is of serious concern since it has implications on human health. Systemic health problems can develop as a result of excessive accumulation of dietary heavy metals such as cadmium (Cd), lead (Pb) and chromium (Cr) in the human body. A study was carried out at the Kwame Nkrumah University of Science and Technology (KNUST) campus in Ghana using water to which Cd and Pb had been added to irrigate cabbage, carrots and lettuce. Cadmium and Pb solutions of concentrations 0, 0.05 and 0.1 mg L^{-1} and 0, 30 and 50 mg L^{-1}, respectively were formulated and used to irrigate the crops. Plant and soil samples from the experimental fields were collected for laboratory analysis. Results showed reduction in yields of lettuce from the treatments. Cadmium treatment of lettuce with 0.05 mg L^{-1} concentration of irrigation water reduced yield by 11% whilst 0.1 mg L^{-1} Cd concentration of irrigation water treated lettuce yield reduced by 16%. However, there were increases of 61 and 53%, respectively in yields of carrots irrigated with water containing 0.05 and 0.1 mg L^{-1} Cd in comparison with carrots irrigated with water containing 0 mg L^{-1}. Yields of crops irrigated with irrigation water containing Pb concentrations of 30 and 50 mg L^{-1} were reduced compared with yields from the control plots. Plant Cd and Pb concentrations increased with irrigation water concentrations significantly with p-value of Cd <0.0001 and for Pb <0.05. Cadmium concentrations for cabbage were between 0.09 and 1.11 mg kg^{-1} whilst carrots and lettuce had values between 0.04, 1, 0.12 and 1.02 mg kg^{-1}, respectively. Lead concentrations in cabbage ranged between 0.18 and 15.2 mg kg^{-1}, for carrots and lettuce they were 0.43 to 6.24 mg kg^{-1} and 1.41 to 187 mg kg^{-1}, respectively.

Key words: Cadmium, lead, uptake, irrigation water, carrots, cabbage, lettuce

INTRODUCTION

According to Nouri (1980) deposition of metals to soil may be deleterious to crop growth and soil productivity and may also produce crops containing unacceptably high metal levels for animal and

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human health. The uptake of heavy metals and their distribution in crops differ among species and among cultivars within particular species. Variation of Cd uptake by cultivars has been reported of, for example, potato (McLaughlin *et al*., 1994), wheat (Chaudri *et al*., 2001; Oliver *et al*., 1995), maize (Florijn and van Beusichem, 1993) and spinach and carrots (He and Singh, 1994). Heavy metal contamination of agricultural soils from wastewater irrigation is also of serious concern as a result of human health implications (Hough *et al*., 2003; Mensah *et al*., 2007; Sipitey, 2007). Serious systemic health problems can develop as a result of excessive accumulation of dietary heavy metals such as cadmium (Cd), lead (Pb) and chromium (Cr) in the human body (Oliver, 1997). Heavy metals are not degradable; hence, they can accumulate to toxic levels in soils due to long term application and in the body of consumers of produce from such soils (Bohn *et al*., 1985). Produce from contaminated soils or irrigation water application has a higher probability of increasing the metal concentration to high levels, beyond the permissible level for human consumption. Metals, in ionic form in soil solution, get to the roots of plants by mass flow (transpiration flux) and diffusion (Marschner, 1995). Root solute uptake is coupled with the root water uptake (Ingwersen, 2001). Accordingly, the root metal uptake may depend on the water uptake rate even when active uptake is dominant. The use of industrial and municipal wastewater for vegetable production is a common practice in many parts of the world (Feigin *et al*., 1991; Urie, 1986), particularly in developing countries including Ghana (Cornish *et al*., 1999). Access to adequate high quality water for irrigation in the urban/peri-urban communities of Ghana has been a major concern (Cornish *et al*., 1999). About 80-90% of vegetables consumed by the people in the urban communities are produced in the urban/ peri-urban areas where high quality water may not be accessible. Where accessible, the high cost of irrigation water makes its use prohibitive. Growers of vegetables therefore use wastewater from drains that receive effluents from all sources and other urban polluted water bodies. A few of them use hand-dug wells if the water table is high. Irrigation of crops is by the use of watering cans and the method is either broadcasting or planting bed specific with an application rate that could be about 25-30 L m^{-2} for a single application.

In Ghana, there has been limited study of metal uptake by crops and there has not been any study on metal uptake by vegetables from irrigation water due to transpiration. This study was carried out at the Kwame Nkrumah University of Science and Technology (KNUST) campus using water to which Cd and Pb had been added to irrigate cabbage, carrots and lettuce. The objectives of the study were to determine (1) whether or not plant Cd and Pb concentrations increased with increase of their concentrations in irrigation water, (2) changes of plant Cd and Pb concentrations as the plants grew and (3) Cd and Pb concentration effects on cabbage, carrots and lettuce yields.

MATERIALS AND METHODS

Experimental Field

Experimental mini plots of 1.8×1.8 m were set up on an experimental field at KNUST agricultural experimental land with grass vegetation from May to September 2005. Cabbage, carrots and lettuce were grown in three replicates on the plots. Cadmium and Pb solutions of 0, 0.05 and 0.1 mg L^{-1} and 0, 30 and 50 mg L^{-1}, respectively, were formulated and used to irrigate the crops. Cadmium and lead nitrate salts were added to 200 L capacity containers filled to the 200 L mark with treated water from the main supply and stirred to obtain the predetermined Cd and Pb solution concentrations and a sample tested to confirm the predetermined concentrations.

The crops were irrigated each other day using 11 L of the solution per plot per irrigation. A plastic watering can was used to avoid introduction of additional metal which would have been the case if a galvanized container had been used. Treatment with Cd and Pb solutions started on the day of transplantation of the seedlings of cabbage and lettuce.

Sample Collection

Plant samples were collected at three different growth stages during the plants' growth which was divided almost into three equal segments. Lettuce samples were collected after 20, 40 and 55 days whilst cabbage and carrot samples were collected 40, 70 and 100 days after transplantation and sowing. The plant samples were washed with distilled water, chopped into pieces on a washed and rinsed kitchen chopping board with distilled water rinsed kitchen knife to an average size of 2 cm^2, sun-dried for about 6 h before oven-drying at 80°C for about 20 h. The dried samples were milled to <1 mm particle size.

Analysis of Samples

The plant samples were digested using EPA Method 3052 (USEPA, 1996). Nine millilter of HNO_3 and 2 mL of HCl were added to 0.25 g of plant sample in a Teflon tube. The content of the Teflon tube was digested using MRS 200 microwave digester. The samples were left in the microwave after digestion until the temperature reduced to about 30°C. The digested sample in a solution form was poured into a 15 mL centrifuge tube. One millilter of the digested sample was diluted in a ratio of 1:4 using deionized water in a 15 mL centrifuge tube before analyzing it for Cd and Pb with an Agilent 7500 ICP-MS. A standard reference material 1573a of tomato leaves certified by National Institute of Standards and Technology (NIST) was also digested and analyzed for Cd as a quality assurance control.

Data generated were analyzed statistically using the SAS software package to establish the significance of relationships between the various parameters being considered.

RESULTS

Crop yields were influenced by Cd and Pb concentrations. The yields of lettuce from the Cd treatment plots were on the average 3.26, 2.92 and 2.7 t ha^{-1} for 0, 0.05 and 0.1 mg L^{-1} irrigation water concentrations, respectively. The yields for the plots treated with 0.05 and 0.1 mg L^{-1} of Cd were reduced by 11 and 16%, respectively, of the yield of the control treatments (0 mg L^{-1}). In the case of Pb treatments of lettuce the yields were 4.44, 3.83 and 2.52 t ha^{-1} for 0, 30 and 50 mg L^{-1} irrigation water treatments, respectively. Comparing the yields from 30 and 50 mg L^{-1} irrigation water treatments to that of 0 mg L^{-1} irrigation water, there were reductions of 14 and 43%, respectively.

Carrots responded differently to Cd and Pb in the irrigation water. Plots with carrots irrigated with Cd solutions yielded 3.98, 10.18 and 8.54 t ha^{-1} for 0, 0.05 and 0.1 mg L^{-1} concentration treatment plots, respectively. A comparison of the yields from 0.05 and 0.1 mg L^{-1} treatment plots with those from 0 mg L^{-1} plots showed increases of 61 and 53%, respectively. Yields from Pb irrigated carrot plots were 6.86, 4.86 and 6.05 t ha^{-1} for 0, 30 and 50 mg L^{-1} irrigation water treatments, respectively. There were reductions of 29 and 12%, respectively, comparing yields from 30 and 50 mg L^{-1} irrigation water treatments with yields from 0 mg L^{-1} irrigation water treatments.

Plant Cd and Pb concentrations increased with irrigation water concentrations. The increase was significant with p-value for Cd less than 0.001 and for Pb less than 0.05. The increases were however not linear. Plant metal concentration varied with the type of crop (Table 1).

Cadmium concentrations for cabbage were between 0.09 and 1.11 mg kg^{-1} whilst carrots and lettuce had values of 0.04 to 1.0 and 0.12 to 1.02 mg kg^{-1}, respectively. Lead concentrations in cabbage ranged between 0.18 and 15.2 mg kg^{-1} and for carrots and lettuce they were 0.43 to 6.24 and 1.41 to 187.4 mg kg^{-1}, respectively. Cadmium and Pb concentrations in lettuce were the highest among the three crops.

Cadmium and Pb concentrations of the first set of harvested cabbage samples were very high. This might be due to the fact that the samples were leaves and not cubs, the edible part because at the time of the first sampling the head had not formed.

Table 1: Relationship between cadmium (Cd) and lead (Pb) concentrations in cabbage, carrots and lettuce crops and irrigation water (IW)

Crop	Days	IW conc. ($mg\ L^{-1}$)	Av crop Cd conc. ($mg\ kg^{-1}$ dry wt.)	IW conc. ($mg\ L^{-1}$)	Av crop Pb conc. ($mg\ kg^{-1}$ dry wt.)
Cabbage	40	0.00	0.249 (0.125)*	0	0.601 (0.095)*
		0.05	0.542 (0.284)*	30	11.76 (3.98)*
		0.10	0.961 (0.215)*	50	15.22 (5.82)*
	70	0.00	0.093 (0.024)*	0	0.183 (0.015)*
		0.05	0.389 (0.067)*	30	0.367 (0.093)*
		0.10	0.592 (0.142)*	50	0.499 (0.082)*
	100	0.00	0.344 (0.185)*	0	0.216 (0.125)*
		0.05	0.85 (0.219)*	30	0.874 (0.185)*
		0.10	1.11 (0.328)*	50	0.945 (0.426)*
Carrots	40	0.00	0.062 (0.021)*	0	0.557 (0.298)*
		0.05	1.038 (0.334)*	30	3.22 (0.912)*
		0.10	0.732 (0.295)*	50	6.07 (1.09)*
	70	0.00	0.432 (0.041)*	0	0.73 (0.262)*
		0.05	0.701 (0.168)*	30	2.61 (0.656)*
		0.10	0.898 (0.688)*	50	4.32 (1.17)*
	100	0.00	0.181 (0.029)*	0	0.427 (0.18)*
		0.05	0.997 (0.208)*	30	4.54 (1.23)*
		0.10	0.799 (0.298)*	50	6.24 (2.64)*
Lettuce	20	0.00	0.263 (0.082)*	0	1.41 (0.563)*
		0.05	0.602 (0.238)*	30	21.80 (4.45)*
		0.10	0.549 (0.181)*	50	21.90 (3.62)*
	40	0.00	0.241 (0.092)*	0	1.62 (0.827)*
		0.05	1.00 (0.843)*	30	79.20 (24.9)*
		0.10	0.534 (0.101)*	50	82.40 (22.90)*
	55	0.00	0.121 (0.053)*	0	2.25 (0.812)*
		0.05	0.968 (0.392)*	30	133.60 (44.6)*
		0.10	1.022 (0.311)*	50	187.40 (39.9)*

( )*: Standard deviation values in parenthesis

From the data in Table 1 there were no systematic increases with time of Cd concentrations for any of the crops. However, Pb concentrations in lettuce increased consistently during the period of growth with time and irrigation water concentration.

Plant Cd and Pb uptake rates of the three crops, in mg day^{-1}, increased with irrigation water concentrations by a trend similar to those of plant and irrigation water concentrations relationships (Fig. 1a, b).

For both Cd and Pb, lettuce had the highest concentration values. Also Cd and Pb concentrations in all plants increased with time. Those of lettuce were significant. Langmuir model equation for metal uptake in plants was fitted to data points to show the trend of plant Cd and Pb concentrations as the irrigation water concentration varies.

The Langmuir equation is shown in Eq. 1

$$C_{plant} = \frac{K \times Cw}{(1 + n \times K \times Cw)} \tag{1}$$

Where:

C_{plant} = Plant metal concentration ($mg\ kg^{-1}$)
C_W = Irrigation water metal concentration ($mg\ L^{-1}$)
K and n = Constants

Plant Cd and Pb concentrations of the three crops using the Langmuir equation gave a correlation coefficient of 0.999 when related to measured values and a RMSE range of 0.054-0.25 for Cd and 0.11-1.30 for Pb.

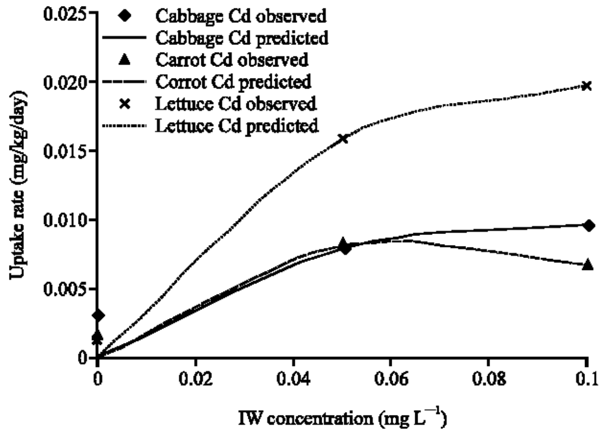

Fig. 1a: Plant Cd uptake rate (mg/kg/day) and irrigation water concentration (mg L^{-1}) relationship for measured and predicted

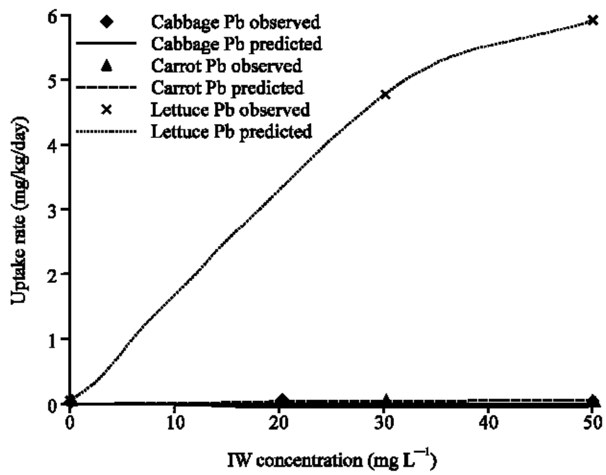

Fig. 1b: Plant Pb uptake rate (mg/kg/day) and irrigation water concentration (mg L^{-1}) relationship for measured and predicted values

DISCUSSION

Crop yield was affected by irrigation water concentration of Cd and Pb. For lettuce there were reductions for both Cd and Pb treatments with increase in concentrations of Cd and Pb in irrigation water. Yields from 0.05 mg L^{-1} Cd treatments concentration reduced by 10.7% of the control (0 mg L^{-1}) whilst treatment with 0.1 mg L^{-1} Cd concentration reduced by 16.4%. For Pb the yield was reduced from that of the control by 13.7 and 43.2% for 30 and 50 mg L^{-1}, respectively. Reduction in yield with Cd and Pb treatments may be as a result of exposure to metals in the irrigation water by passive means of transpiration that creates a potential force to draw water of less nutrient and high Cd and Pb content. The Cd and Pb in the irrigation water compete with plant metal macro and micro nutrients like Ca and Mg required by plants for healthy growth, thus creating nutritional imbalance (Nouri *et al*., 2001). For example, at a dose of 20 mg L^{-1} there was 63% reduction in size of alfalfa shoot size and a lethal effect on the plant at a dose of 40 mg L^{-1}. Öncel *et al*. (2000) found that Cd reduces the level of chlorophyll a and b.

In the results the yield of Cd treated carrots showed a different trend compared with lettuce. Yields from 0.05 and 0.1 mg L^{-1} treated plots increased by 60.9 and 53.3%, respectively, as compared with yields from 0 mg L^{-1} treated plots. This may be ascribed to Cd forming soluble complexes with some soil constituents that were taken up by carrots as nutrients on those plots (Oliver and Naidu, 2003).

Cadmium and Pb concentrations of cabbage, carrots and lettuce increased with Cd and Pb concentrations in irrigation water. Root solute uptake is coupled with the root water uptake (Ingwersen and Streck, 2005) in support of present results. The root solute uptake may depend on the water uptake rate even when active uptake is dominant. During periods of high temperatures there is the likelihood of high decomposition rate of organic matter taking place leading to the release of heavy metals in soil solution to make them mobile or available for uptake by plants (McGrath *et al*., 1994). There is also an increase of saturation deficit at high temperatures. Average maximum daytime temperature during the period of the experiment at the experimental location was about 32°C and relative humidity in the day was around 40-60% although the period was supposed to be the major rainy season. The crops' Cd and Pb concentrations were found to be high and the values are comparable with results obtained from a study on wastewater irrigation of crops in India by Singh *et al*. (2004). Higher Cd and Pb concentrations in the crops found in the present study may therefore be ascribed to high transpiration rates. Marschner (1995) reported from a study of Cd uptake by crops that crop Cd uptake was by mass flow with the transpiration flux. The crops' Cd and Pb concentrations determined in this study are comparable to those in similar studies carried out in Ethiopia (Rahlenbeck *et al*., 1999) and India (Singh *et al*., 2004).

Root solute uptake is assumed to be linearly proportional to the product of soil solution concentration and water uptake (Christensen and Tjell, 1984; Behrendt *et al*., 1995; Trapp, 2000; Schoups and Hopmans, 2002; Grant *et al*., 1998). This may be a reason for the crops (cabbage, carrots and lettuce) Cd and Pb concentrations increasing with the concentrations of the irrigation water as shown in Fig. 1.

Cadmium and Pb concentrations of the cabbage, carrots and lettuce increased as the plants grew as shown in Table 1. Plant metal content varies with time of harvesting and stage of maturity (Sauerbeck, 1991). This was confirmed by the results of a study on barley plants by Nouri *et al*. (2001) and on maize by Chrysafopoulou *et al*. (2005). However the magnitude of time dependence of plant Cd and Pb concentration variations differed among crops and metals according to the study.

The uptake and distribution of metals in crops differs among species and cultivars within a species (Ingwersen and Streck, 2005). Lettuce had the highest Cd and Pb concentrations amongst the three crops tested in this study, confirming Cd concentration in lettuce as reported by other researchers (Petterson, 1997) and from studies on crops like carrots and spinach (He and Singh, 1994). Sauerbeck (1991) indicated that when plants are young mineral absorption is relatively rapid and dry matter production is rather slow. But later when large and active photosynthetic areas are being formed, dry matter production may outstrip absorption of mineral elements, leading to a reduction in their level. During this time there is also a redistribution of elements within the plant and variation between and within different organs may be quite large (Moreno, 1996). Lead is usually accumulated in the roots and only a very small amount is accumulated in the shoots. However some plants translocate Pb effectively to shoots without chelators that aid Pb translocation from roots (Chrysafopoulou *et al*., 2005). High Pb concentrations in lettuce showed the probability of lettuce being one of such plants that effectively translocate Pb from roots to shoots. High Pb concentrations in plants may be an indication of metal uptake from irrigation water by transpiration since Pb concentrations in plants do not exceed 10 mg kg^{-1} with the exception of leafy plants such as lettuce (Kabata-Pendias and Pendias, 1986).

CONCLUSION

Irrigation water quality is essential to ensure the quality of the produce for which the water is used. The use of irrigation water of high metal concentration leads to increase of plant metal concentration and as the water concentration of the metal increased there was also an increase in plant concentration. Plant Cd and Pb concentrations showed increases with time. Cadmium concentrations in lettuce increased by 66% for a period of 20 days that of carrots increased by 42% and for cabbage the increase was 118% for 40 days. Lead concentrations in lettuce increased by 130% for the same number of days as Cd. For carrots Pb concentration increased by 44% and Pb concentration in cabbage increased by 89% for 40 days. However the amount of metal increment depended on the stage of plant maturity.

Irrigation water containing elevated metal concentration generally reduced the yield of crops. Crop yield reduction by the effect of Cd ranged between 10.2 and 16.4% whilst reduction of crop yield by Pb was between 13.7 and 43.2%, depending on the irrigation water concentration. Thus, the Cd and Pb concentrations of irrigation water negatively affect food security.

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REFERENCES

Behrendt, H., R. Bruggenmann and M. Morgenstern, 1995. Numerical and analytical model of pesticide root uptake model comparison and sensitivities. Chemosphere, 30: 1905-1920.

Bohn, H.L., B.L. McNeal and A.G. O' Connor, 1985. Soil Chemistry. 2nd Edn. Wiley-Interscience Publications, NY, USA., pp: 341.

Chaudri, A.M., C.M.G. Allain, S.H. Badawy, M.L. Adams, S.P. McGrath and B.J. Chambers, 2001. Cadmium content of wheat grain from a long-term field experiment with sewage sludge. J. Environ. Qual., 30: 1575-1580.

Christensen, T. and J. Tjell, 1984. Interpretation of Experimental Results on Cadmium Crop Uptake from Sewage Sludge Amended Soil. In: Processing and Use of Sewage Sludge, Hermite, P.D.L. and H. Ott (Eds.). Reidel, Dordrecht. The Netherlands, pp: 358-369.

Chrysafopoulou, E., J. Kadukova and N. Kalogerakis, 2005. A whole-plant mathematical model for the phytoextraction of lead (Pb) by maize. Environ. Int., 31: 255-262.

Cornish, G.A., E. Mensah and P. Ghesquire, 1999. Water quality and peri-urban irrigation: An assessment of surface water quality for irrigation and its implications for human health in the peri-urban zone of Kumasi, Ghana. KAR Project R 7132. Report OD/TN 95.

Feigin, A., I. Ravina and J. Shalhevet, 1991. Irrigation with Treated Sewage Effluent. Springer-Verlag, Berlin.

Florijn, P.J. and M.L. van Beusichem, 1993. Uptake and distribution of cadmium in maize inbred lines. Plant Soil, 150: 25-32.

Grant, C.A., W.T. Buckley, L.D. Bailey and F. Selles, 1998. Cadmium accumulation in crops. Can. J. Plant Sci., 78: 1-18.

He, Q.B. and B.R. Singh, 1994. Crop uptake of cadmium from phosphorus fertilizers: Yield and cadmium content. Water Air Soil Pollut., 74: 251-265.

Hough, R.L., S.D. Young and N.M.J. Crout, 2003. Modelling of Cd, Cu, Ni, Pb and Zn uptake, by winter wheat and forage maize, from a sewage disposal farm. Soil Use Manage., 19: 19-27.

Ingwersen, J., 2001. The environmental fate of cadmium in the soils of the wastewater irrigation area of Braunschweig Measurement, modeling and assessment [Online]. Ph.D Thesis, http://opus.tu-bs.de/opus/volltexte/2001/266 (verified 4 Jan. 2005). Tech. Univ. Carolo Wilhelmina, Braunschweig, Germany.

Ingwersen, J. and T. Streck, 2005. A regional-scale study on the crop uptake of cadmium from sandy soils: Measurement and modeling. J. Environ. Qual., 34: 1026-1035.

Kabata-Pendias, A. and H. Pendias, 1986. Trace Elements in Soils and Plants. CRC Press, Boca Raton, Florida.

Marschner, H., 1995. Mineral Nutrition of Higher Plants. Academic Press, London.

McGrath, S.P., A.C. Chang, A.L. Page and E. Wilter, 1994. Land application of sewage sludge: Scientific perspectives of heavy metal loading limits in Europe and the United States. Environ. Rev., 2: 108-118.

McLaughlin, M.J., C.M.J. Williams, A. McKay, R. Kirkman, J. Gunton, K.J. Jackson, R. Thompson, B. Dowling, D. Partington, M.K. Smart and K.G. Tiller, 1994. Effect of cultivar on uptake of cadmium by potato tubers. Aust. J. Agric. Res., 45: 1483-1495.

Mensah, E., N. Kyei-Baffour, E. Ofori and G. Obeng, 2007. Heavy metal concentrations in irrigated vegetables in Ghana. Proceedings of 1st International Conference on Environmental Research Technology and Policy (ERTEP), Accra, Ghana.

Moreno, J.L., 1996. Transference of heavy metals from a calcareous soil amended with sewage sludge compost of Barley plants. Bioresour. Technol., 55: 251-260.

Nouri, J., 1980. Heavy metals in sewage sludge, soils amended with sludge and their uptake by crop plants. Ph.D Thesis, University of London.

Nouri, J., P.J. Peterson and J.B. Alloway, 2001. Effect of variation in harvest time on the uptake of metals by barley plants from soil amended with sludge and compost. J. Biol. Sci., 1: 1056-1059.

Oliver, D. and R. Naidu, 2003. Uptake of copper (Cu), lead (Pb), cadmium (Cd), Arsenic (As) and dichlorodiphenyltrichloroethane (DDT) by vegetables grown in urban environments. Proceedings of the 5th National Workshop on the Assessment of Site Contamination. National Environment Protection Council Service Corporation.

Oliver, D.P., J.W. Gartell, K.G. Tiller, R. Correll, G.D. Cozens and B.L. Youngberg, 1995. Differential response of Australian wheat cultivars to cadmium concentration in wheat grain. Aust. J. Agric. Res., 46: 873-886.

Oliver, M.A., 1997. Soil and human health: A review. Eur. J. Soil Sci., 48: 573-592.

Öncel, I., Y. Kele and A.S. Üstün, 2000. Interactive effects of temperature and heavy metal stress on the growth and some biochemical compounds in wheat seedlings. Environ. Pollut., 107: 315-320.

Petterson, O., 1997. Differences in cadmium uptake between plant species and cultivars. Swed. J. Agric. Res., 7: 21-24.

Rahlenbeck, S.I., A. Burberg and R.D. Zimmermann, 1999. Lead and cadmium in Ethiopian vegetables. Bull. Environ. Contam. Toxicol., 62: 30-33.

Sauerbeck, D.R., 1991. Plant, element and soil properties governing plant uptake and availability of heavy metals derived from sewage sludge. Water Air Soil Pollut., 227: 57-58.

Schoups, G. and J.W. Hopmans, 2002. Analytical model for vadose zone solute transport with root water and solute uptake. Vadose Zone J., 1: 158-171.

Singh, K.P., D. Mohon, S. Sinha and R. Dalwani, 2004. Impact assessment of treated/untreated wastewater toxicants discharge by sewage treatment plants on health, agricultural and environmental quality in wastewater disposal area. Chemosphere, 55: 227-255.

Sipitey, D., 2007. Heavy metals uptake by vegetables cultivated on waste dump sites in Kumasi, Ghana. M.Sc. Thesis, College of Engineering, KNUST, Kumasi, Ghana.

Trapp, S., 2000. Modeling uptake into roots and subsequent translocation of neutral and ionisable organic compounds. Pest Manage. Sci., 56: 767-778.

Urie, D.H., 1986. The Status of Wastewater Irrigation of Forests. In: the Forest Alternative for Treatment and Utilization of Municipal and Industrial Wastes, Cole, D.W., C.L. Henry and W.L. Nutter (Eds.). University of Washington Press, Seattle, WA, USA., pp: 26-40.

USEPA, 1996. EPA Method 3052, Microwave assisted acid digestion of siliceous and organically based matrices. US Environmental Protection Agency, Research Triangle Park, NC.

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Influence of Transpiration on Cadmium (Cd) and Lead (Pb) Uptake by Cabbage, Carrots and Lettuce from Irrigation Water in Ghana

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Abstract: A study was conducted on Cd and Pb concentrations effects on transpiration rates of cabbage, lettuce and carrots. The vegetables were established on experimental plots and irrigated with irrigation water of 0.05 and 0.1 mg L^{-1} of Cd and 30 and 50 mg L^{-1} of Pb, all values above the permissible FAO/WHO standards for crop irrigation. The field experiment was carried out on a sandy soil. Cadmium concentration of 0.05 mg L^{-1} of irrigation water reduced transpiration rates of cabbage and lettuce by 55.9 and 10.7%, respectively but increased for carrots by 268%, compared to the control (0 mg L^{-1} concentration of irrigation water). At Cd irrigation water concentration of 0.1 mg L^{-1} the transpiration rates of cabbage and lettuce reduced by 60.97 and 16.56%, respectively whilst that of carrots increased by 186.9%. For Pb treated irrigation water, the transpiration rates of 30 mg L^{-1} of Pb concentration in the irrigation water reduced by 56.6, 11.1 and 35.9% for cabbage, lettuce and carrots, respectively. At 50 mg L^{-1} Pb concentration in the irrigation water, the transpiration rates of cabbage, lettuce and carrots reduced by 72.9, 41.7 and 24.5%, respectively, compared to the control (0 mg L^{-1} concentration of irrigation water) samples.

Key words: Cadmium uptake, lead uptake, transpiration, irrigation water, vegetable

INTRODUCTION

The use of industrial and municipal wastewater is a common practice in many parts of the world, particularly in developing countries including Ghana. Access to adequate water of acceptable quality for irrigation in the urban/peri-urban communities of Ghana has been a major concern. About 80-90% of vegetables consumed by the people in the urban communities are produced in the urban/peri-urban areas where water of acceptable quality may not be accessible (Cornish *et al*., 1999). Where accessible, the high cost of irrigation water makes its use prohibitive. Growers of vegetables therefore use wastewater from drains that receive effluents from all sources and other urban polluted water bodies. Therefore heavy metal contamination of agricultural soils and produce from wastewater irrigation is of serious concern as a result of human health implications.

Market survey of commonly consumed vegetables in Ghana showed higher than the permissible values recommended by World Health Organization (1989). Hence the objective of this study was to find out the extent that transpiration influences Cd and Pb uptake by some selected vegetables irrigated with wastewater containing high Cd and Pb concentrations.

Researchers from several countries have found linear relationships between dry matter yield and cumulative transpiration of plants grown in containers or between dry matter and cumulative water use (transpiration and soil evaporation) as established in field experiments (Hanks and Rasmussen, 1982). Bierhuizen and Slatyer (1965) introduced an equation proposed to be universally applicable for different climatic regions:

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$$Y = kT/\Delta e$$

where, Δe is the saturation deficit of the air (Pa), k is a crop-specific constant (Pa), T is cumulative transpiration (kg m^{-2}, product of column of liquid transpired and density of liquid) and Y is the plant yield (kg m^{-2}).

Ions are dumped into the root xylem by the vascular system and are swept along in the transpiration stream at concentrations that depend on the rate of water entry into the xylem. The amount of ions absorbed is proportional to the rate that dry mass accumulates. Inorganic ions like those of salts of heavy metals generally are absorbed most rapidly during most phases of growth (Kramer and Boyer, 1995).

The occurrence of soil dehydration decreases the uptake of ions because of the accompanied reduction of transpiration, decreasing the bulk flow of soil solution to the root. Since water for shoot growth has to be extracted from the same xylem as transpiration that sets up and increases tension in the xylem thereby affecting the growth of surrounding tissues. The increased xylem tension by transpiration creates a competition between water for growth and transpiration (Kramer and Boyer, 1995). Water to be used for transpiration evaporates close to the xylem vessels and thus bypassing many of the cells outside of the xylem.

Plants grown on heavy metal containing substrates such as Cd show disturbed water balance. Poschenrieder ***et al.*** (1989) reported that Cd-treated plants showed lower leaf relative water content and higher stomatal resistance than the controls of an experimental setup.

Transpiration rates are influenced by the local meteorological events such as wind, radiation and air humidity therefore the relationship between metal uptake and water use rate becomes location specific.

MATERIALS AND METHODS

Mini-experimental plots of 1.8×1.8 m were set up on an experimental field at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, agricultural experimental land (usually with grass vegetation) from May to September, 2005. Kumasi lies approximately on latitude 6° 41^1 N and longitude 1° 38^1 W. Rainfall in Kumasi is bimodal with a mean annual total of about 1,302 mm. The minor dry season occurs in August and the major dry season starts from mid-November and ends in February. The main wet season is from March to July whilst the minor rainy season extends from September to November. Temperatures are uniformly high throughout the year. The lowest mean annual temperature of about 24.6°C is usually recorded in August and the highest mean monthly temperature of about 28.8°C occurs in February. Morning relative humidity is uniformly high throughout the year. The mean monthly figures range between 84.4 and 95.6% at 06:00 h and 39.6 and 75.1% at 15:00 h. The annual evapo-transpiration in Kumasi is about 1234 mm with monthly values ranging from 107 to 144 mm in the major dry season and 71 to 118 mm in the rainy season. The plots were used to grow cabbage, carrots and lettuce in three replications. Cadmium and Pb solutions of 0, 0.05 and 0.1 mg L^{-1} and 0, 30 and 50 mg L^{-1}, respectively, were formulated and used to irrigate the crops. These values were used to establish the impact on crop concentration of Cd and Pb when irrigation water concentrations exceed the FAO permissible values of 0.05 mg L^{-1} of Cd and 20.0 mg L^{-1} of Pb. Cadmium and Pb nitrates salts ($Cd(NO_3)_2$ and $Pb(NO_3)_2$) were added to 200 L capacity containers filled to the 200 L mark with treated water from the mains supply and stirred thoroughly to obtain the predetermined Cd and Pb solution concentrations and tested to confirm the concentrations. The crops were irrigated every other day using 11 L per plot on each occasion. A plastic watering can was used to avoid introduction of additional metal which would have been the case if a galvanized container had been used.

The vegetables were sampled at maturity stages, washed with distilled water, chopped into pieces on a washed and rinsed kitchen chopping board to an average size of 2 cm^2, sun-dried for about 6 h before oven-drying at 80°C for about 20 h. The dried samples were milled to < 1 mm sizes.

The plant samples were digested using EPA Method 3052 (USEPA, 1996). Nine milliliter of HNO_3 and 2 mL of HCl were added to 0.25 g of plant sample in a Teflon tube. The content of the Teflon tube after assembling the unit was weighed and assembled in a rotor tightened using a torque wrench and placed in a MRS-200 microwave digester. The microwave, which had been temperature programmed, was then switched on. The samples were left in the microwave after digestion until the temperature reduced to about 30°C. Teflon heads were unscrewed and removed from the rotor. Each Teflon tube was reweighed to check for any loss of the content of the tube. The digested sample in a solution form was poured into a 15 mL centrifuge tube. One milliliter of the digested sample was diluted in a ratio of 1:4 using deionized water in a 15 mL centrifuge tube before analyzing it for Cd and Pb with an Agilent 7500 ICP-MS. A standard reference material 1573a of tomato leaves certified by National Institute of Standards and Technology (NIST) in the USA was also digested and analyzed for Cd as a quality assurance control.

Local meteorological data (wind speed, temperature, radiation and relative humidity) within the period of the experiment gathered at the weather station of the Department of Mechanical Engineering, KNUST, were used to calculate the cumulative transpiration rates (m as column of water transpired) of the vegetables from the various experimental plots using the equation:

$$T_p = \frac{\Delta e}{\rho_w k_p} Y$$

where, Δe (Pa) is the average saturation deficit of the atmosphere during the main vegetation period; k_p (Pa) is a crop-specific constant and ρ_w (kg m^{-3}) is the density of water. The mean saturation deficit during the main vegetation period (Δe) was obtained by averaging hourly values for the period between 0630 and 2030 h during the main vegetation period (Ehlers, 1989).

The hourly values of the saturation deficit Δe_{ji} (Pa) of the atmosphere at the ith hour of the jth day were calculated as follows (Maidment, 1993):

$$\Delta e_{ji} = 6.108(100 - rH_{ji})\exp\left(\frac{17.27T_{ji}}{237.7 + T_{ji}}\right)$$

where, T_{ji} (°C) denotes the air temperature and rH_{ji} (%) the relative humidity at the ith hour of the jth day of a year.

Data generated were analyzed statistically using the SAS software package.

RESULTS AND DISCUSSION

Average daily temperatures recorded during the period of the experiment ranged between 24.7 and 33.1°C. The highest temperatures were recorded in the month of August. For relative humidity the values ranged between 85.6 and 94.7% at 06:00 h. At 15:00 h the values ranged between 68.8 and 76.9%.

The transpiration rates of the vegetables were affected by Cd and Pb concentrations of irrigation water (Table 1). Irrigation water with Cd concentration of 0.05 mg L^{-1} reduced the transpiration rates of cabbage and lettuce by 55.87 and 10.66%, respectively but increased that for carrots by 268.4% compared to the controlled crops. At Cd irrigation water concentration of 0.1 mg L^{-1}, transpiration rates of cabbage and lettuce reduced by 60.97 and 16.56%, respectively while transpiration rates of carrots increased by 186.86%.

Table 1: Relationship between irrigation water Cd and Pb concentrations and cumulative transpiration rates of the irrigated vegetables

Element	Crop	Irrigation water concentration (mg L^{-1})	Transpiration rates (kg m^{-2})
Cd	Cabbage	0.00	4.935
		0.05	2.178
		0.10	1.926
	Carrots	0.00	3.685
		0.05	9.890
		0.10	6.886
	Lettuce	0.00	11.590
		0.05	10.354
		0.10	9.668
Pb	Cabbage	0.00	4.935
		30.00	2.142
		50.00	1.340
	Carrots	0.00	3.685
		30.00	2.363
		50.00	2.780
	Lettuce	0.00	11.590
		30.00	10.299
		50.00	6.762

For Pb treated 30 mg L^{-1} concentration of irrigation water, the transpiration rates of cabbage, lettuce and carrots were reduced by 56.6, 11.14 and 35.88%, respectively. At 50 mg L^{-1} Pb concentration of irrigation water the transpiration rates of cabbage, lettuce and carrots reduced by 72.85, 41.66 and 24.56%, respectively, compared to the controlled samples.

Some studies carried out worldwide have shown or established that heavy metals do affect the cumulative transpiration rates of crops due to their uptake. For example, a study by Veselov *et al*. (2003) showed that Cd treatment of wheat seedlings led to an inhibition of growth rate, transpiration and ion uptake. These results are in accordance with reports indicating inhibition of water conductance in roots by toxic metals (Barcelo and Poschenreider, 1990). The decrease in transpiration of Cd-treated plants is likely to be due to stomatal closure. Cd-induced reduction in stomatal conductivity is in accordance with the literature (Pearson and Kirkham, 1981). Bazzaz *et al*. (1974) attributed reduction in transpiration in response to Cd to (a) increasing resistance to water flow in the stem and (b) inhibition of stomatal opening and increasing stomatal resistance. The inhibition of stomatal opening suggests that Cd has direct effects on the ion and water movement in the guard cells. The effect of Pb-contaminated solution on crop was found to be less significant, possibly due to the lower absolute toxicity of Pb and the restricted transport to the shoot (Marschner, 1995).

Another effect of transpiration in soil is that it lowers the soil water content which may affect the solution-phase concentration of heavy metal and in consequence its plant uptake. Whether transpiration and root uptake respectively increases or decreases the metal solution-phase concentration depends on the uptake mechanism. For passive uptake mechanism, water removal by plant roots has no effect on the metal solution-phase concentration. For an active uptake, soil water is depleted and metal concentration decreases (Ingwersen and Streck, 2005).

CONCLUSION

The study showed that the presence of Cd and Pb in irrigation water reduces the transpiration rates of irrigated crops. Transpiration from carrots may be increased by the presence of Cd in irrigation water and Pb may reduce the transpiration rate of carrots as experienced in cabbage and lettuce by both Cd and Pb.

REFERENCES

Barcelo, J. and C. Poschenreider, 1990. Plant water relations as affected by heavy metals: A review. J. Plant Nutr., 13: 1-37.

Bazzaz, F.A., G.L. Rolfe and R.W. Carson, 1974. Effects of cadmium on photosynthesis and transpiration of excised leaves of corn and sunflower. Physiol. Plant., 32: 373-376.

Bierhuizen, J.F. and R.O. Slatyer, 1965. Effect of atmospheric concentration of water vapour and CO_2 in determining transpiration-photosynthesis relationships of cotton leaves. Agric. Meteorol., 2: 259-270.

Cornish, G.A., E. Mensah and P. Ghesquire, 1999. Water quality and peri-urban irrigation: An assessment of surface water quality for irrigation and its implications for human health in the peri-urban zone of Kumasi, Ghana. KAR Project R 7132. Report OD/TN 95.

Ehlers, W., 1989. Transpiration efficiency of oat. Agron. J., 81: 810-817.

Hanks, R. L. and V. P. Rasmussen, 1982. Predicting crop production as related to plant water stress. Adv. Agron., 35: 193-215.

Ingwersen, J. and T. Streck, 2005. A regional- scale study on the crop uptake of cadmium from sandy soils: Measurement and modelling. J. Environ. Qual., 34: 1026-1035.

Kramer, P.J. and J.S. Boyer, 1995. Water Relations Of Plants And Soil. Elsevier Science (USA), Academic Press, pp: 285-365.

Maidment, D.R., 1993. Handbook of Hydrology. McGraw-Hill, New York.

Marschner, H., 1995. Mineral Nutrition of Higher Plants. Academic Press, London.

Pearson, C. and K. Kirkham, 1981. Water relation of wheat cultivars grown with cadmium. J. Plant Nutr., 3: 309-318.

Poschenrieder, C., B. Gunse and J. Barcelo, 1989. Influence of cadmium on water relations, stomatal resistance and abscisic acid content in expanding bean leaves. Plant Physiol., 90: 1365-1371.

USEPA, 1996. EPA Method 3052, Microwave assisted acid digestion of siliceous and organically based matrices. US Environmental Protection Agency, Research Triangle Park, NC.

Veselov, G., G. Kudoyarova, M. Symonyan and S.T. Veselov, 2003. Effect of cadmium on ion uptake, transpiration and cytokinin content in wheat seedlings. Bulg. J. Plant Physiol., Special Issue, pp: 353-359.

World Health Organization, 1989. Toxicological evaluation of certain food additives and contaminants. Report of 33rd Meeting, Joint FAO/WHO Joint Expert Committee on Food Additives, No. 24, International Programme on Chemical Safety, WHO, Geneva.

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Influence of Cadmium and Lead Concentrations of Irrigation Water on Dry Matter Yield of Vegetables

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Abstract: The aim of the study was to find out the extent that cadmium and lead concentrations in irrigation water affect yield of vegetables like cabbage, lettuce and carrots negatively or positively. Experimental plots were established to produce cabbage, carrots and lettuce. The crops were irrigated with irrigation water of 0.05 and 0.1 mg L^{-1} Cd and 30 and 50 mg L^{-1} Pb concentrations. Results of analyzed crops samples showed that generally, there was a reduction of dry matter yield of crops produced. Dry matter yield of cabbage and lettuce treated with 0.05 mg L^{-1} Cd concentration of irrigation water reduced by 56.10 and 10.65%, respectively. At 0.1 mg L^{-1} Cd irrigation water concentration the reduction of cabbage and lettuce dry matter yield were 61.17 and 16.57%, respectively, compared with values of controlled crops. However, in the case of carrots there were increases in dry matter yield of 268 and 187%, respectively irrigating with water with Cd concentrations of 0.05 and 0.1 mg L^{-1}. With Pb irrigated vegetables, dry matter yield for all the three crops reduced at all Pb irrigation water concentrations. Dry matter yield of Pb treated cabbage reduced by 56.6, 13.54% for lettuce and 35.83% for carrots at 30 mg L^{-1} Pb irrigation water concentration. At 50 mg L^{-1} Pb irrigation water concentration, dry matter contents of cabbage, lettuce and carrots reduced by 72.85, 43.23 and 24.57%, respectively, compared with values from controlled plots.

Key words: Heavy metals, vegetables, dry matter yield, irrigation water, transpiration, wastewater

INTRODUCTION

Hazardous heavy metals like cadmium (Cd) and lead (Pb) found in agricultural soils originate from many sources including paints, gasoline additives, smelting and refining of Pb, pesticide production and Pb acid battery disposal (Eick *et al*., 1999; Paff and Bosilovich, 1995), phosphate fertilizers, sewage sludge, wastewater for irrigation and waste from smelting sites (Ingwersen and Streck, 2005; Alloway and Ayres, 1993; Ross, 1994). The yield of a crop and its development is a function of the quality and quantity of water supplied to the crop in its root zone (Rao and Mathur, 1994). It also is a function of soil texture and nutrient availability.

Heavy metal contamination of agricultural soils from wastewater irrigation is of serious concern as a result of human and plant health implications. Heavy metals can be of detrimental significance to the ecology, biological systems and the health of animals, plants and humans. Cadmium and Pb are two

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heavy metals which are pollutants and toxins without any known functions in any organism. High Cd concentrations can lead to toxicity symptoms like chlorosis and reduced growth of the leaves of crops. The severity of Cd phytotoxicity is found most evident from dry matter yield in both leaves and roots of crops (Michalska and Asp, 2001). Most agricultural crops grow well when the pH of the soil is between 6.0 and 7.0, because nutrients are more available at pH of about 6.5 (McConnel *et al*., 1993). Other researchers have found that yield of crops increases with increasing soil pH and an optimal pH value was between 6.5 and 7.0 (Smith, 1993). Soil pH of less than 6.0 makes it more acidic which affects crop yield. A reduction in dry matter yield of crops reduces the production level of the crop per unit area. This goes to reduce food security and nutrient intake resulting in malnutrition and poor health of people in a community and reduces the socio-economic status of producers of such crops. The development of the community at large gets threatened. The objective of this study was to determine the impact of Cd and Pb concentrations in irrigation water on the yield of vegetables (cabbage, carrots and lettuce).

MATERIALS AND METHODS

Mini-experimental plots of 1.8×1.8 m were set up on an experimental field at the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, agricultural experimental land with grass vegetation from May to September, 2005. Kumasi lies approximately on latitude $6^0\,41^1$ N and longitude $1^0\,38^1$ W. The plots were used to grow cabbage, carrots and lettuce in three replicates. Cadmium and Pb solutions of 0, 0.05 and 0.1 mg L^{-1} and 0, 30 and 50 mg L^{-1}, respectively, were formulated and used to irrigate the crops. These values were used to establish the impact on crop concentration when irrigation water concentrations exceed the FAO permissible values of 0.05 mg L^{-1} of Cd and 20.0 mg L^{-1} of Pb. Cadmium and Pb nitrates salts ($Cd(NO_3)_2$ and $Pb(NO_3)_2$) were added to 200 L capacity containers filled to the 200 L mark with treated water from the mains supply and stirred thoroughly to obtain the predetermined Cd and Pb solution concentrations. The crops were irrigated each other day using 11 L per plot on each occasion. A plastic watering can was used to avoid introduction of additional metal which would have been the case if a galvanized container had been used.

The vegetables were sampled at maturity stages, washed with distilled water, chopped into pieces on a washed and rinsed kitchen chopping board to an average size of 2 cm^2, sun-dried for about 6 h before oven-drying at 80°C for about 20 h. The dried samples were milled to <1 mm.

The plant samples were digested using EPA Method 3052 (USEPA, 1996). Nine milliliter of HNO_3 and 2 mL of HCl were added to 0.25 g of plant sample in a Teflon tube. The content of the Teflon tube after assembling the unit was weighed and assembled in a rotor tightened using a torque wrench and placed in a MRS-200 microwave digester. The microwave, which had been temperature programmed, was then switched on. The samples were left in the microwave after digestion until the temperature reduced to about 30°C. Teflon heads were unscrewed and removed from the rotor. Each Teflon tube was reweighed to check for any loss of the content of the tube. The digested sample in a solution form was poured into a 15 mL centrifuge tube. One milliliter of the digested sample was diluted in a ratio of 1:4 using deionized water in a 15 mL centrifuge tube before analyzing it for Cd and Pb with an Agilent 7500 ICP-MS. A standard reference material 1573a of tomato leaves certified by National Institute of Standards and Technology (NIST) was also digested and analyzed for Cd as a quality assurance control. Data generated were analyzed statistically using the SAS software package.

RESULTS

Generally, there were reductions in values of dry matter of cabbage and lettuce treated with increased Cd irrigation water concentrations by 56.1 and 10.65% respectively at 0.05 mg L^{-1}. At 0.1 mg L^{-1} Cd irrigation water concentration the reduction of dry matter yield of cabbage and

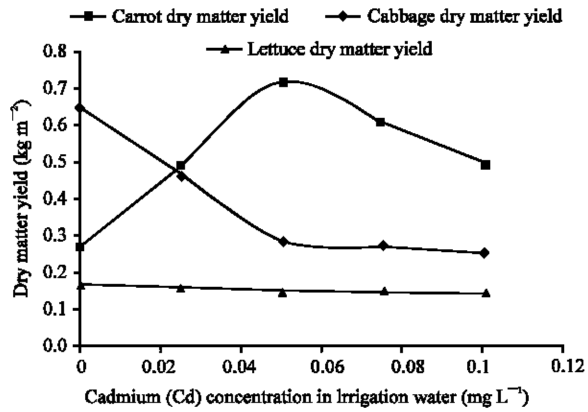

Fig. 1: Relationship between cabbage, carrots and lettuce dry matter yields and irrigation water concentrations of Cd

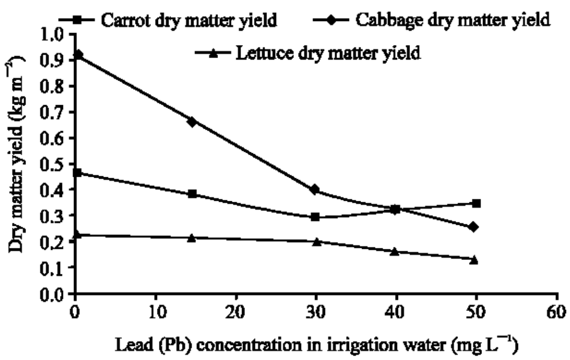

Fig. 2: Relationship between cabbage, carrots and lettuce dry matter yields and irrigation water concentrations of Pb

lettuce were 61.17 and 16.57%, respectively. With carrots dry matter increased by 268 and 187%, respectively at irrigation water Cd concentration of 0.05 and 0.1 mg L^{-1} (Fig. 1).

With Pb treated vegetables, the trend of dry matter reduction with increase in irrigation water Pb concentration for cabbage and lettuce was the same as Cd treated samples. Dry matter of Pb treated cabbage reduced by 56.6, 13.54% of lettuce and 35.83% of carrots at Pb concentration of irrigation water of 30 mg L^{-1}. At 50 mg L^{-1} Pb concentration the dry matter content of cabbage, lettuce and carrots reduced by 72.85, 43.23 and 24.57% respectively, compared with dry matter content of the controlled crops (Fig. 2).

DISCUSSION

Some studies carried out worldwide have shown or established that heavy metals do affect the dry matter content of crops due to their uptake. A study by Michalska and Asp (2001) on three lettuce cultivars in hydroponic culture showed that the Roxette cultivar was strongly affected by the presence of heavy metals compared with the other cultivars. The effect of Pb-contaminated solution on crop was found to be less significant, possibly due to the lower absolute toxicity of Pb and the restricted transport to the shoot (Marschner, 1995). The presence of Pb in nutrient solution resulted in a higher yield of leaves but not of the roots. John and van Laerhoven (1976) found that the presence of 0.1 ppm (0.48 μM) and 0.5 ppm (2.4 μM) Pb caused significant yield increase of some lettuce cultivars. Yields were depressed by two treatments of 0.5 μM Cd and 0.5 μM Pb treatments. Cadmium was shown to cause reduction of fresh and dry matter yield (John, 1977). The presence of both Cd and Pb in the solution caused similar reduction of the yield as Cd alone. Khan and Frankland (1983) observed a similar effect, where 50 μg Cd combined with 1000 μg Pb reduced very considerably the yield of radish plants.

Cadmium at 0.5 μM drastically decreased dry yield of leaves and roots of lettuce cultivars in a hydroponic experiment. Also Cd and Pb together caused significant reduction of the yield of both plant parts. Lead alone did not affect the yield or caused a slight increase of the yield. The lettuce plants kept most of the accumulated Cd and Pb in the roots but a larger proportion of Cd was transported to the shoot compared to Pb.

CONCLUSION

Irrigation water quality has significant impact on the quality and yield of the produce. Results of the study showed that irrigation water metal concentration generally reduced yield of vegetables. Dry matter yield of cabbage and lettuce treated with Cd reduced by percentages commensurate with the Cd concentration in irrigation water. The higher the Cd concentration the higher the percentage reduction of dry matter yields of cabbage and lettuce. Contrary, Cd led to increase of dry matter of carrots, while dry matter yields of lead treated cabbage, lettuce and carrots reduced. The percentage reduction depended on the Pb concentration of the irrigation water with higher percentage reduction corresponding to higher Pb concentrations of irrigation water.

REFERENCES

Alloway, B.J. and D.C. Ayres, 1993. Chemical Principles of Environmental Pollution. 2nd Edn., Blackie Academic and Professional, London. ISBN: 9780751403800.

Eick, M.J., J.D. Peak, P.V. Brady and J.D. Pesek, 1999. Kinetics of lead adsorption/desorption on goethite: Residence time effect. Soil Sci., 164: 28-39.

Ingwersen, J. and T. Streck, 2005. A regional-scale study on the crop uptake of cadmium from sandy soils: Measurement and modeling. J. Environ. Qual., 34: 1026-1035-1035.

John, M.K. and C.J. van Laerhoven, 1976. Differential effects of cadmium on lettuce varieties. Environ. Pollut., 10: 163-173.

John, M.K., 1977. Varietal response to lead by lettuce. Water Air Soil. Pollut., 8: 133-144.

Khan, D.H. and B. Frankland, 1983. Effects of cadmium and lead on radish plants with particular reference to movement of metals through soil profile and plant. Plant Soil., 70: 335-345.

Marschner, H., 1995. Mineral Nutrition of Higher Plant. 2nd Edn., Academic Press Ltd., London, UK.

McConnel, D.B., A. Shiralipour and W.H. Smith, 1993. Residual effect of municipal solid waste and biosolid compost on soil fertility, nutritional status and performance of grapevine. J. Environ. Qual., 2: 89-89.

Michalska, M. and H. Asp, 2001. Influence of lead and cadmium on growth, heavy metal uptake, and nutrient concentration of three lettuce cultivars grown in hydroponic culture. Commun. Soil. Sci. Plant Anal., 32: 571-583.

Paff, S.W. and B.E. Bosilovich, 1995. Use of Pb reclamation in secondary lead smelters for the remediation of lead contaminated sites. J. Hazard Mater., 40: 39-64.

Rao, S. and S. Mathur, 1994. Modeling heavy metal (cadmium) uptake by soil-plant root system. J. Irrig Drainage Eng., 120: 89-95.

Ross, S.M., 1994. Sources and Forms of Potentially Toxic Metals in Soil-Plant Systems. In: Toxic Metals in Soil-Plant Systems, Ross, S.M. (Ed.). John Wiley and Sons, Chichester, UK., ISBN: 0-471-94279-0, pp: 3-26.

Smith, S.R., 1993. Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. II. Cadmium uptake by crops and implications for human dietary intake. Environ. Pollut., 86: 5-13.

USEPA, 1996. EPA Method 3052, Microwave assisted acid digestion of siliceous and organically based matrices. US Environmental Protection Agency, Research Triangle Park, NC.