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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):

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

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.

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