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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

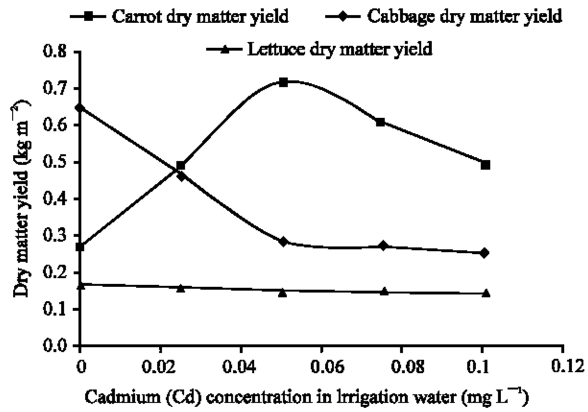

Fig. 1: Relationship between cabbage, carrots and lettuce dry matter yields and irrigation water concentrations of Cd

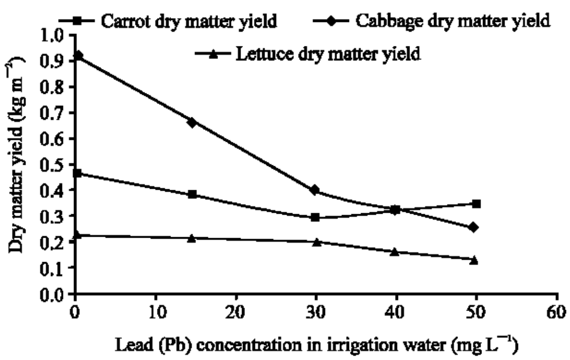

Fig. 2: Relationship between cabbage, carrots and lettuce dry matter yields and irrigation water concentrations of Pb

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.

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