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Impact of Phosphate Fertilizer on Cadmium Accumulation in Soil and Vegetable Crops

Y. S. Al-Faiyz · M. M. El-Garawany ·
F. N. Assubaie · M. A. Al-Eed

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There is indirect evidence of heavy metal build-up in some agricultural soils due to long-term application of inorganic phosphate fertilizers (Ewa et al. 1999). Trace elements are normally found in phosphate fertilizers (Lee et al. 1997; Todorova and Dombalov, 1995), and fertilization for long periods increases their concentration in soils (He and Singh, 1993b; Taylor, 1997). These elements are absorbed by plants, and some are contaminants, which might become a risk for the environment and health. Among these elements is cadmium, which is considered to be one of the most dangerous heavy metals (Lee et al. 1997 because of its high mobility (Barcelo and Pochenrieder, 1992) and its ability to accumulate in plants in large quantities without any visible signs (Lehoczky et al. 1996).

The uptake of Cd by plants increases with an increased application rate of phosphate fertilizers (Pezzarossa et al. 1993). Thus, increased Cd in the soil leads to increased Cd in crop plants (Zarcinas et al 1999). Cd accumulation in plant tissues varies with the crop species and plant part (Moral et al. 1994). Cd has the ability to be transferred to the aerial parts of tomato plants (Moral et al. 1994). Lettuce can also accumulate Cd in its leaves in high concentrations (Lehoczky et al. 1996). Therefore, the study of the impact of phosphate fertilizer on Cd accumulation in the soil and in vegetable crops is very important. Thus we investigated the impact of heavy phosphate fertilizer application on the distribution and accumulation of Cd in three vegetable crop plants (tomatoes, radishes, and lettuce).

M. M. El-Garawany
Soil Fertility and Plant Nutrition, Research Department of Soil, Water and Environmental Research Institute, Agricultural Research Center, Cairo, Egypt

Y. S. Al-Faiyz (✉) · F. N. Assubaie · M. A. Al-Eed
Department of Chemistry, College of Sciences, King Faisal University, Post Office 420, Al-Hassa 31982, Saudi Arabia
e-mail: yalfayz@kfu.edu.sa

Materials and Methods

The effects of different levels of superphosphate were evaluated in three field experiments in 2001/2002, on tomato (cv. *Carmello*), lettuce (cv. Dark green), and radish (cv. *Baldy*) plants at the Agricultural and Veterinary Training Research Station, King Faisal University, Al-Hassa, Saudi Arabia. The soil had a loamy sand texture (82% sand, 7% silt, and 11% clay) and, initially, a pH of 7.8 pH and electrical conductivity of 0.54 dS/m; the available phosphorus was 5 ppm and the available Cd was 0.0085 ppm. Phosphate fertilizer was applied in the form of triple superphosphate (45%–47% P2O5). Fertilization treatments were repeated on the same plots. The Cd content was 2.9 ppm in the triple superphosphate. Phosphate treatments were to supply 0, 24, 48, 72 kg P2O5/donum (donum = 1000m2). One crop was used for each experiment. The four fertilization treatments were arranged in a randomized complete block design with four replicates. The total number of plots/crops was 16. The experimental unit was 10 rows, each 10 m long with 25 cm between rows.

According to the most suitable sowing dates, tomatoes were planted on 12 November, while radishes and lettuce were planted on 11 and 19 February, respectively, each year. The treatments were applied in three equal doses at 4, 7, and 10 weeks after planting. All other agricultural practices were applied as recommended for commercial production of these crops.

At harvest, five plants were randomly taken as a sample from each plot. Vegetative parts (leaves, stems, and roots) were cut, washed with tap water, rinsed with deionized water, and dried at 70°C in a drying oven to a constant weight, and then ground using a gate mill for chemical analysis.

Subsamples of ground stems (200 mg), leaves (200 mg), and roots (100 mg) were digested in a mixture of concentrated HNO_3 and $HClO_4$ (4:1, by volume) and the P and Cd elements in the solution were determined with inductively coupled plasma atomic emission spectroscopy. A certified standard reference material (SRM 1515, apple leaves) of the National Institute of Standards and Technology, USA, was used in the digestion and analysis as part of the QA/QC protocol. Reagent blanks and analytical duplicates were used where appropriate to ensure accuracy and precision in the analysis. The recovery rates were approximately 90 ± 6% for Cd and P in the plant reference material. Soil samples were digested first with 65% and 72% $HClO_4$, and then with 40% HF. The 'plant available' metal concentrations in the soil were determined after extraction with 0.005 M diethylenetriamine pentaacetic acid (DTPA) (Lindsay and Norvell, 1978). All digested plant and soil materials and soil extracts were analyzed for Cd using inductively coupled plasma mass spectometry. The data reported in this paper are the mean values of four replicates.

Resuts and Discussion

Data were subjected to a statistical analysis of variance, and when the F ratio was significant, the least significant difference (LSD) test was applied using the SPSS statistical package version 9.0 for Windows 98 to compare treatment means. Using the same data, a correlation analysis was also calculated to evaluate the extent of the association and its significance.

The results of the present study revealed that the Cd content of tomato plant parts increased with increasing phosphate fertilization levels as compared with the untreated control (Table 1). Thus, the Cd level in the plant tissues depended on the concentration of available Cd in the soil, which corroborates earlier results in rice (*Oryza sativa L*), sweet corn (*Zea mays L*), and tomato (*Lycopersicon esculentum*) (Reddy and Patrick, 1977; Mahler et al. 1980).

The results presented in Table 1 show that the distribution of the metal taken up was not homogenous; a higher proportion remained in the roots than was transported to the shoots. This observation is consistent with findings reported by Petterson (1976), who indicated that when cucumber (*Cucumis sativus* L.), wheat (*Triticum aestivum* L.), oat (*Avena sativa* L), and tomato (*Lycopersicon esculentum*) are grown in nutrient solution with 1, 10, and 100 μM Cd, the shoot and root Cd content increases 5 to 10 times if the metal concentration increases 10 times.

Table 1 Effect of phosphate fertilizer treatments on Cd concentrations in the tomato cultivar "Carmello"

Phosphorus Treatment ($kg\ P_2O_5/dn$*)	Cd (ppm**)			
	Fruits		Roots + Shoots	Whole plant
	Juice	Flesh		
0	0.080	0.009	0.212	0.100
24	0.090	0.010	0.228	0.109
48	0.100	0.015	0.228	0.114
72	0.120	0.020	0.387	0.176
$LSD_{0.05}$***	0.032	0.004	0.057	0.029

* dn = donum = 1000 m^2

** ppm = mg/kg dry weight

*** $LSD_{0.05}$: Least significant differences at 0.05 significant level

The results also demonstrate that the Cd content was highest in the roots (Table 1) and decreased during ontogenesis (Table 1). Thus, the root system of the tomato seems to act as the first barrier to Cd in the soil. In spite of the different mobility of metals in plants, the root system accumulates them to a significantly higher extent than do the above-ground organs. As a result, the root system is one of the targets of their toxic effect. A similar conclusion was drawn by Ernst et al. (1992).

There are significant differences in the Cd concentration in different parts of the plants. Nevertheless, variations in the Cd concentration as a function of the rate of application of phosphate fertilizer were clear cut. The Cd concentration in various plant parts is generally higher at 72 kg P_2O_5/dn treatment. The increase of the Cd concentration at other P_2O_5 levels, however, was not significant between treatments. The Cd concentrations were highest in the roots and shoots, then the juice, and lowest in the flesh. The concentrations of Cd ranged between 0.009 and 0.020 ppm, 0.08 and 0.120 ppm, and 0.212 and 0.387 ppm in tomato flesh, juice, and roots + shoots, respectively. These results indicate that the vegetative parts, especially the roots, restricted the transportation of the ion to tomato fruits and reduced its accumulation in the tomato fruit. In other words, Cd preferentially accumulated in the roots and shoots, with low transport to the fruit. The data revealed that the concentration of Cd in different tissues of tomato plants increased with increasing levels of P. In general, the pronounced concentration of Cd in the vegetative parts of the tomato might be due to the presence of Cd in phosphate fertilizer, which increased with increased application. Increasing the rate of the phosphate fertilizer application

Table 2 Effect of phosphate fertilizer treatments on the Cd concentrations in the lettuce cultivar "dark green".

Phosphorus Treatment ($kg\ P_2O_5/dn$)*	Cd (ppm**)		
	Leaves	Roots	Whole plant
0	0.07	0.16	0.12
24	0.08	0.23	0.17
48	0.11	0.34	0.03
72	0.13	0.37	0.24
$LSD_{0.05}$***	0.02	0.07	0.04

* dn = donum = $1000m^2$

** ppm = mg/kg dry weight

*** $LSD_{0.05}$: Least significant differences at 0.05 significant level

Table 3 Effect of phosphate fertilizer treatments on the Cd concentration in the radish cultivar "Baldy"

Phosphorus Treatment ($kg\ P_2O_5/dn$)*	Cd (ppm**)	
	Leaves	Roots
0	0.78	0.51
24	0.90	0.52
48	1.01	0.52
72	1.04	0.54
$LSD_{0.05}$***	0.04	0.03

* dn = donum = $1000m^2$

** ppm = mg/kg dry weight

*** $LSD_{0.05}$: Least significant differences at 0.05 significant level

increased the soil DTPA-extractable Cd, leading to an increased uptake of Cd by tomato plants and its accumulation in the vegetative parts, and indicating a reduced translocation of Cd from the vegetative to the reproductive organs. These results are in agreement with those of Pezzarossa et al. (1993). ACMS (2003) reported that health authorities have set an upper limit for Cd in root, tuber, and leafy vegetables. This is called the "Maximum Permitted Concentration (MPC)" and is set at 0.1 milligrams per kilogram (mg/kg) of fresh weight.

The data presented in Table 2 indicate that Cd concentrations in leaves and roots of lettuce plants after harvest varied from 0.07 ppm to 0.3 ppm in response to the application of different levels of P_2O_5. The data indicate that, generally, Cd concentrations in both leaves and roots increased with an increased P_2O_5 level. There were significant differences between P_2O_5 treatments. The difference in the Cd content in leaves between treatments with 24 and 48 kg P_2O_5/dn as well as that in the roots between treatments with 0 and 24 kg P_2O_5/dn and between 48 and 72 kg P_2O_5 /dn were not significantly different. In the whole plant, the Cd content was not significantly different between the 48 and 72 kg P_2O_5/dn treatments. The maximum concentration of Cd occurred at the 24 kg P_2O_5/dn level in the leaf and root samples. The results demonstrate that P_2O_5 application causes a more significant buildup of Cd in the roots than in the leaves at the applied levels of P_2O_5. The Cd concentrations in the leaves ranged between 0.07 with no treatment and 0.13 ppm at 72 kg P_2O_5/dn, whereas in roots, the levels varied between 0.16 and 0.37 ppm. This can be attributed to the enrichment of Cd in the soil from phosphate fertilizer, which consequently increased the Cd concentrations in the plant tissues. These results are in agreement with the findings of Moral et al. (1994) and Pezzarossa et al. (1993). The data shown in Table 2 show that P_2O_5 fertilization increased Cd accumulation in the roots more than in the leaves. The results also indicated that lettuce roots obtained Cd from the soil and transported it to the shoots to varying degrees, but most of the absorbed Cd remained in the root or was redistributed to the root from the shoots. This suggestion was confirmed by the study of Cataldo et al. (1983), who reported that normally Cd ions are retained mainly in the roots, and only small amounts are transported to the shoots. Greger and Lindberg (1986) reported a 4- to 10-fold increase in the Cd content in the roots of the sugar beet (*Beta vulgaris* L.) when the Cd concentration was raised from 5 to 10 μM. They also reported that the Cd content of the shoots was only 10% to 20% that of the roots. A similar result was observed when weeds were grown in clay soil and irrigated with different concentrations (5, 10, 20 mg/kg) of Cd (Ewais 1997). Ewais further revealed that most of the Cd was accumulated in the roots (81%), and only 19% was transported to the shoots. In this respect, lettuce plants might be considered "Cd shoot excluders," with Cd accumulating at higher concentrations in the roots than in the shoots. This strategy is one of several that plants use to tolerate Cd (Weigel and Jager 1980). This might be due to hindrance of the transportation of Cd to the leaves, which would contradict the findings of Moral et al. (1994).

Table 3 shows the effect of applying P_2O_5 at four different levels (0, 24, 48, and 72 kg P_2O_5/dn) on the Cd concentration in radish plants. The Cd concentrations in the leaves were 0.78 ppm at 0 level of P and reached 1.04 ppm at 72 kg P_2O_5/dn of P. Statistical analysis revealed significant increases in the Cd concentrations in the leaves with respect to control plants with increasing levels of P treatments. When the P_2O_5 level was increased from 48 to 72 kg/dn, however, the resultant increase in Cd concentration in leaves was not significant. There were no significant variations in Cd concentrations in the roots between P_2O_5 treatments. The Cd concentrations ranged between 0.51 ppm and 0.54 ppm at 48 kg P_2O_5/dn and 72 kg P_2O_5/dn, respectively. The data indicate that the leaves

Table 4 Effect of phosphate treatments on the concentration of available P and Cd in sandy soils after harvesting tomato, lettuce, and radish plants

Phosphorus treatment (kg P_2O_5/donm)	Available element (ppm) in soil		Correlation coefficient between P and Cd
	P	Cd	
Tomato plant experiment			
0	5.31	0.40	
24	13.2	0.40	
48	14.7	0.45	
72	17.2	0.51	0.975*
Radish plant experiment			
0	5.3	0.40	
24	7.8	0.41	
48	8.5	0.43	
72	9.7	0.45	0.921*
Lettuce plant experiment			
0	5.3	0.40	
24	6.3	0.39	
48	6.5	0.42	
72	7.3	0.44	0.898*

Correlation coefficient between Cd of leaves and available P in soil is 0.737*

accumulated more Cd than the roots at all levels of P. This tendency toward increasing Cd concentration in leaves might be due to active transport. These findings are in agreement with the study of Pezzarossa et al. (1993).

Pezzarossa et al. reported that the application of Cd-bearing phosphate fertilizer increased the Cd levels in soils and plants. These results are also in agreement with the findings of Moral et al. (1994) and Webber (2003), who reported that Cd accumulation in plant materials varies with crop type and plant part and that Cd has the ability to be transported to the aerial parts. Also, Petterson (1976) claimed that there were significant differences between plant species in their response to different Cd concentrations.

Another view was postulated by Schierup and Larsen (1981), who reported that differences in the ability of plants to accumulate heavy metals is related to differences in their root morphology. The investigators suggested that plants with numerous roots would accumulate more metals than plants with a few thick roots.

Table 4 shows the average Cd and P content in the soils of the three crops. The ranges of available Cd in the soil were 0.40 to 0.45 mg/kg and 0.38 to 0.44 mg/kg in soils of radish and lettuce plants, respectively. The same trend was observed for available P in the soil with increasing P_2O_5 levels.

Available P varied from 5.32 to 17.2, 5.3 to 9.7, and 5.0 to 7.3 mg/kg in the soils of tomato, radish, and lettuce plants, respectively. The variations in Cd and P levels in the soils might be due to the amounts of phosphate fertilizer added to the soils.

There was a significantly positive correlation between available P and Cd in the three experiments (0.975, 0.921, and 0.898), which could be due to the presence of Cd in the phosphate fertilizer as a contaminant. Also, there was a significantly positive correlation (0.737) between the concentration of Cd in plants and the available P in all the experimental soils. It could be concluded that excess P facilitates the accumulation of Cd in both the soil and the vegetative parts of tomato, lettuce, and radish plants. Similarly, Pezzarossa et al. (1993) observed that the Cd concentration in edible plant parts is dependent on P_2O_5 application.

Environmental quality cannot be ensured by simply controlling the concentration of heavy metals added therein, because soils make up a complicated and heterogeneous system (Chen et al. 2001).

Other criteria are also used to evaluate soil contamination by heavy metals, such as background concentrations, which represent natural elemental concentrations in the soil before human influence (Chen et al. 1999). The baseline background concentration of Cd in this study was 0.40 and the treated soils of the three crops slightly surpassed the background level of Cd. Soil contamination, however, might be considered when the concentration of an element in the soil is two or three times greater than the mean background level (Logan and Miller, 1983) and none of the treatments reached that level.

The Cd concentration in the soils of the experimental site increased slightly due to the application of phosphate fertilizers, but the concentration did not reach contamination levels in the three experiments.

An intensive increase in the rate of the application of phosphate fertilizer leads to the accumulation of available Cd in the soil, which in turn affects the plant's Cd content. The data show significant correlations between available P and Cd, both in the soil and in the plant tissue. The ability of a plant to accumulate Cd might depend on the crop type and plant part. To avoid the side effects or toxicity of Cd on animals and humans, we recommend using fertilizers low in Cd and avoiding overuse of P_2O_5 fertilizers.

In conclusion, the results of the present study indicate that most of the Cd absorbed accumulates in the roots of tomato and lettuce plants, while it is freely translocated to the leaves in radishes. Comparisons of the Cd concentration in the three plants at different levels of P_2O_5 revealed that radish plants accumulated more Cd than both lettuce and tomato plants. Radish plants accumulated Cd from 4.3 to 7.8 times more than tomato plants, while in lettuce plants the range was from 3.23 to 5.6 times. Our results are in close agreement with those reported by Webber (2003).

He reported that broadleaf vegetables accumulate more Cd than most other plants.

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References

ACMS, 2003. Australian cadmium minimization strategy, available at http://www.cadmium-management.org.au/about.html

Barcelo J, Poschenrieder C (1990) Plant water relations as affected by heavy metal stress: a review. J Plant Nutr 13:1–37

Cataldo, Dominic A, Garland, Thomas R, Wildung Raymond E (1983) Cadmium uptake kinetics in intact soybean plants. Plant Physiol 73:844–848

Chen HM, Zheng CR, Tu C, Zhou DM (2001) Studies on loading capacity of agricultural soils for heavy metals and its applications in China. Appl Geochem 16:1397–1403

Chen M, Lena QM, Harris WG (1999) Baseline concentrations of 15 trace elements in Florida surface soils. J Environ Qual 28:1173–1181

Ernst W HO, Verkleij JAC, Schat H (1992) Metal tolerance in plants. Acta Bot Neerlandica 41:229–249

Ewa IOM, Oladipo MOA, Dim LA (1999) Horizontal and vertical distribution of selected metals in the Kubani river, Nigeria as determined by *neutron activation analysis*. Comm Soil Sci Plant Anal 30:1081–1090

Ewais EA (1997) Effects of Cd, Ni and Pb on growth, chlorophyll content and proteins of weeds. Biol Plant 39:403–410

Greger M, Lindberg S (1986) Effects of Cd and EDTA on young sugar beet, Beta vulgris. L. Cd uptake and sugar accumulation. Physiol Plant 66:69–74

He QB, Singh BR (1993) Crop uptake of cadmium from phosphorous fertilizer: yield and cadmium content. Water Air Soil Pollut 74:251–265

Lee BD, Carter BJ, Basta NT, Weaver B (1997) Factors influencing heavy metal distribution in six Oklahoma benchmark soils. Soil Sci Soc American J 61:218–223

Lehoczky EI, Marth P (1996) Cd content of plants as affected by soil Cd concentration. Commun Soil Sci Plant Anal 27:1765–1777

Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci American J 42:421–428

Logan TJ, Miller RH (1983) Background levels of heavy metals in Ohio farm soils. Soil contamination analysis. Res Circ Ohio Agric Res Dev Ctr Wooster 275:3–15

Mahler RJ, Bingham FT, Spoito G, (1980) Cadmium-enriched sewage sludge application to acid calcareous soil. Relation between treatment, Cd in saturation extract, and Cd uptake. J Environ Qual 19:357–364

Moral RG, Palacios I, Gomez JN, Mataix J (1994) Distribution and accumulation of heavy metals (Cd, Ni, and Cr) in tomato plants. Fresenius Environ Bull 3:395–399

Petterson O (1976) Heavy metals ion uptake by plants from nutrient solutions with metal ion, plant species and growth period variations. Plant Soil 45:445–459

Pezzarossa BG, Petruzzelli FM, Tognon F (1993) Effect of repeated phosphate fertilization on the heavy metal accumulation in soil and plants under protected cultivation. Commun Soil Sci Plant Anal 24:2307–2319

Reddy CN, Patrick WH (1977) Effect of redox potential and pH on the uptake of cadmium and lead by rice plants. J Environ Qual 6:259–262

Schierup H, Larson VD (1981) Macrophyte cycling of Zn, Cu, Pb and Cd in littoral zone of a polluted and non-polluted lake. I. Availability uptake and translocation of heavy metals in phragmites Australia (CAV). Aquat Bot 11:179–210

Taylor MD (1997) Accumulation of cadmium derived from fertilizers in New Zealand soils. Sci Total Environ 208:123–126

Todorova EI, Dombalov IP (1995) Production of phosphoric acid with low content of impurities. Fert Res 41:125–128

Weigel HJ, Jager HJ (1980) Different effects of cadmium in vitra and in vivo on enzyme activities in beans (Phaseolus vulgaris L. c.v. Sankt Andreas) Z Pflanzen Physiol 97:103–113

Zarcinas B, Cozens G, Ishak C, Pongsakul P, McLaughlin M (1999) Assessment of pollution of agricultural land and crops by heavy metals and other contaminants. Termination Report of ACIAR Project No. 94.957.CSIRO Land and Water Consultancy Report CSIRO