Cadmium Accumulation in Soil and in Some Vegetable Crops induced by Phosphate Fertilizer

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ABSTRACT

To evaluate the impact of four levels of phosphorus fertilizer on cadmium (Cd) accumulation in soil and in the vegetative parts of tomato (*Lycopersicum esculentum L.*), lettuce (*Lactuca sativa L.*) and radish (*Raphanus sativus L.*), three field experiments using loamy sandy soil, in West Al-Nubaria area, Abu-El-Atta Village, were conducted in 2004 and 2005 winter seasons. The levels of triple super-phosphate fertilizer (45-47% P_2O_5) used were 0, 100, 200, and 300 kg P_2O_5/fed (fed = fedan =4200 m^2). Different rates of triple super-phosphate had significant effects on Cd concentration in the plant tissues of the three studied crops. Phosphate increased Cd accumulation in plant parts, with more evident effect with the highest rate. The range of Cd concentration in tomato fruit juice (0.08-0.12 mg kg^{-1}) was higher than that in tomato fruit flesh (0.009-0.020 mg kg^{-1}). Cd concentration in radish ranged between 0.65-0.76 mg kg^{-1} which was higher than that in lettuce 0.12 - 0.24 mg kg^{-1} or in tomato fruits (0.100 – 0.176 mg kg^{-1}) at the applied levels of phosphate fertilizer. In lettuce plants, the Cd concentration in root was higher than that of shoots while the opposite was found in radish plants. Soil available cadmium and phosphorus levels after harvest increased significantly with increasing application rates of phosphorus in the three experiments.

The application of phosphate fertilizer, although it had notable benefits to soil fertility, it was associated with possible negative effects due to increased P availability and Cd accumulation which affect both soil water quality and soil ecology.

Keywords: Fertilizer, cadmium, phosphate, phosphorus, tomato, lettuce, radish.

INTRODUCTION

To face the problem of entrance of potentially toxic heavy metals in the soil-plant ecosystem, which could have negative effects on the environment along with occasional irreversible pollution, effective soil management and soil biology measures must be taken into account. There is some indirect evidence of possible heavy metal build-up in some agricultural soils because of 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, 1993 and 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 Cd, Cr, Ni, Pb and the micronutrients Cu and Zn can be mentioned (Lee et al., 1997 and Jeng and Singh, 1993). Of the heavy metals cadmium (Cd) is considered a widespread contaminants (Oliver, 1997). Cadmium is one of the most dangerous heavy metals for its high mobility and its presence in small concentrations which may show toxic effects on sensitive plants (Barcelo and Pochenrieder, 1990). This heavy metal poses considerable threats to public health, since it can readily and easily be transferred to edible portions of food crops than that of other contaminant elements (Zarcinas et al., 1996). Cd is especially dangerous because of its ability to accumulate in plants in large quantities without any visible signs (Lehoczky et al. 1996).

The uptake of Cd by plant tissues increases with increasing application rate of phosphate fertilizers (Pezzarossa et al., 1993). Thus, Cd increase in soil will leads to its increase in crop plants (Webber, 2003). The Cd accumulation in plant tissues varies with crop species and plant part (Moral et al., 1994). Cd has the ability to be transferred to aerial parts of tomato plants (Moral et al., 1994). Lettuce, also, can accumulate Cd in its leaves in high concentrations (Lehoczky et al. 1996; Lehoczky and Horvath 1998). Broad-leaved vegetables such as lettuce, accumulate more cadmium than most other plants (Webber, 2003).

The objective of this study was to investigate the impact of heavy phosphate fertilizer application on the distribution and accumulation of Cd in three vegetable crop plants (tomato, radish, and lettuce).

MATERIALS AND METHODS

The effects of different levels of super-phosphate have been evaluated in three field experiments in 2004/2005, on tomato (cv. Carmello), lettuce (cv. Dark green) and radish (cv.Baldy) at the West Al-Nubaria

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area, Abu-El-Atta Village. The soil has loamy sand texture (82% sand, 7% silt and 11% clay) and, initially, 7.8 pH, 0.54 dS/m EC, available phosphorus was 5 mg kg^{-1} and available Cd was 0.0085 mg kg^{-1}. Phosphate fertilizer was applied in the form of triple superphosphate (45-47% P_2O_5). Fertilization treatments have been repeated on the same plots. The Cd content in triple superphosphate was analyzed and its value was 2.9 ppm. Phosphate treatments were to supply 0, 100, 200, 300 kg P_2O_5 /fed. There was one crop for each experiment. The four fertilization treatments were arranged in a randomized complete block design with four replicates. The total number of plots/crop was 16. The experimental unit was 10 rows, each 10 meter long with 25 cm between rows.

According to the most suitable sowing dates, tomato was planted on 12th November, while radish and lettuce were grown on 11th and 19th of February respectively each year. The treatments were broadcast 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 taken as a random sample from each plot. Vegetative parts (leaves, stems, and roots) were cut, washed with tap water and rinsed with deionised water and dried at 70°C in a drying oven to a constant weight and ground using a gate mill for chemical analysis.

Plant and soil analysis

Subsamples of ground stem samples (200 mg), leaves samples (200 mg) and root samples (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 ICP-AES (Chen et al., 2004). 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 (Quality Assurance/Quality Control according to EPA protocol). Reagent blank and analytical duplicates were also used where appropriate to ensure accuracy and precision in the analysis. The recovery rates were around 90 ± 6% for Cd and P in the plant reference material. Soil samples were digested first with 65% and 72% $HClO_4$ (Walts, 1971) and then, with 40% HF. The 'plant available' metal concentrations in soil were determined after extraction with 0.005 M DTPA (Lindsay and Norvell, 1978). All plant and soil materials digested and soil extracts were analyzed for Cd, using inductively coupled plasma spectromertry (ICP-MS). The data reported in this paper were the mean values of the four replicates.

Statistical analysis

Data were subjected to the 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 treatments means. Using the same data, a correlation analysis was also calculated, to evaluate the extent of association and its significance.

RESULTS AND DISCUSSION

Cadmium concentration in tomato plant

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

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

The results also demonstrated that Cd content was highest in the roots (Table 1) and decreases during ontogenesis (Table 1). Thus, the root system of 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 and as a result it is one of the targets of their toxic effect. Similar conclusion was drawn by Ernst et al. (1992).

There are significant differences in the Cd concentration in different parts of the plants. However, the variation of Cd concentration as a function of the rate of application of phosphate fertilizer did show a clear cut. Cd concentration in various plants parts is generally higher at 200kg P_2O_5/fed treatment. However, the increase of the Cd concentration at other P_2O_5 levels was not significant between treatments. The Cd concentrations were in the following order: flesh < juice < roots + shoots. The concentrations of Cd ranged between 0.009 and 0.020 mg kg^{-1}, 0.08 and 0.120 mg kg^{-1} and 0.212 and 0.387 mg kg^{-1} in tomato flesh, juce and roots + shoots, respectively. These results illustrated that vegetative parts especially the roots restricted the transportation of the ion to tomato fruits and reduced its accumulation in the tomato fruits. In other words, Cd was preferentially accumulated in roots and shoots with low transport to fruits. The data revealed that the concentration of Cd in different tissues of tomato plants raised with increasing phosphorus. In general, the pronounced concentration of Cd in vegetative parts of tomato may be due to the presence of Cd in phosphate fertilizer, which increased with increasing application rate. Increasing phosphate fertilizer application increased soil DTPA-extractable Cd. This would have been responsible for increasing the uptake of Cd by tomato plants, and the accumulation in the vegetative parts, indicated the existence of a reduced translocation of this metal 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 cadmium 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.

Cadmium concentration in lettuce plant

Data presented in Table 2 indicated that Cd concentrations in leaves and roots of lettuce plant after harvest varied between a minimum of 0.07 mg kg^{-1} and a maximum of 0.3 mg kg^{-1} in response to application of different levels of P_2O_5. The data indicated that generally, Cd concentrations in both leaves and roots increased with the increase of P_2O_5 level. Significant differences were found between P_2O_5 treatments but no significant different in Cd content in leaves were observed between treatments 100 and 200 kg P_2O_5/fed and also, in the roots no significant differences were found between 0 and 100 kg P_2O_5/fed and between 200 and 300 kg P_2O_5 /fed treatments. In the whole plant, the Cd content was not significantly different between the 200 and the 300 kg P_2O_5/fed treatments. The maximum concentration of Cd was found at the 100 kg P_2O_5/fed level in the leaf and root samples. The results showed that P_2O_5 application caused a significant build up of Cd in roots than in leaves at the applied levels of P_2O_5. The Cd concentration in leaves ranged between 0.07 at zero treatment and 0.13 mg kg^{-1} at 300 kg P_2O_5/fed, whereas in roots, it varied between 0.16 and 0.37 mg kg^{-1}. This can be attributed to the enrichment in Cd in the soil from phosphate fertilizer which consequently increased Cd concentration in plant tissues. These results are in agreement with the finding of Moral et al. (1994) and Pezzarossa et al. (1993). The Data of Table 2, also showed that P_2O_5 fertilization increased Cd accumulation in the roots more than its accumulation in the leaves. The results also indicated that lettuce roots observed Cd from the soil and transport it to the shoots to different degrees, but most of the absorbed Cd remains in the root or redistributed to the root from the shoots. This suggestion is confirmed by the study of Cataldo et al., (1983) who reported that normally Cd ions are mainly retained in the roots, and only small amounts are transported to the shoots. Greger and Lindberg (1986) reported a 4 – 10 times increase in the Cd content of sugar beet, *Beta vulgaris* L., roots when Cd concentration was raised from 5 - 10μM. They also found that the Cd content of the shoots was only 10 – 20% of that of the roots. A similar behavior was observed when weeds were grown in clay soil and irrigated with different concentration (5, 10, 20 mg/kg) of Cd (Ewais, 1997). The author further revealed that most of the Cd was accumulated in roots (81%) and only 19% were transported to the shoots. In this respect, lettuce plant may be considered as 'Cd shoot excluders' with Cd accumulating at higher concentrations in roots than in shoots. This behaviour is one of several strategies for plants to tolerate Cd (Weigel and Jager, 1980). This may be due to the hindrance of the transportation of Cd to the leaves. This claim contradicts the findings of Moral et al. (1994).

Table 1. Effect of phosphate fertilizer treatments on Cd concentration in tomato cultivar "Carmalo"

Phosphorus Treatment (kg P_2O_5/fed*)	Cd (mg kg^{-1})			
	Fruits		Roots + Shoots	Whole plant
	Juice	Flesh		
0	0.080	0.009	0.212	0.100
100	0.090	0.010	0.228	0.109
200	0.100	0.015	0.228	0.114
300	0.120	0.020	0.387	0.176
$LSD_{0.05}$**	0.032	0.004	0.057	0.029

* fed is fedan = 4200m²,

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

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

Phosphorus Treatment (kg P_2O_5/fed*)	Cd (mg kg^{-1})		
	Leaves	Roots	Whole plant
0	0.07	0.16	0.12
100	0.08	0.23	0.17
200	0.11	0.34	0.03
300	0.13	0.37	0.24
$LSD_{0.05}$**	0.02	0.07	0.04

* fed is fedan = 4200m^2

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

Cadmium concentration in radish plant

Table 3 showed the effect of applying P_2O_5 at four different levels (0, 100, 200, and 300 kg P_2O_5/fed) on the Cd concentration in radish plants. The concentration of Cd in the leaves was 0.78 mg kg^{-1} at 0 level of P and reached 1.04 mg kg^{-1} at 300 kg P_2O_5/fed of P. Statistical analysis revealed significant increases in Cd concentration of leaves with increasing levels of phosphorus treatments with respect to control plants. However, when the P_2O_5 level is increased from 200 to 300 kg/fed, the resultant increase in Cd concentration in leaves is not significant. No significant variations were observed in Cd concentration in the roots between P_2O_5 treatments. The Cd concentrations ranged between 0.51 mg kg^{-1} and 0.54 mg kg^{-1} at 200 kg P_2O_5/fed and 300 kg P_2O_5/fed, respectively. The data showed that the leaves accumulated more Cd than roots under all levels of P. This tendency towards increasing Cd concentration in leaves may be attributed to active transport. These findings are in agreement with the study of Pezzarossa et al. (1993). They reported that the application of Cd bearing phosphate fertilizer increased the Cd level in soils and plants. These results also are 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 Cd has the ability to be transported to aerial parts. Also, Petterson (1976) claimed that there were significant differences between plant species in their response to different Cd concentration.

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 a plant with numerous roots would accumulate more metals than one with few thick roots.

In conclusion, the results of the present investigation showed that most of the Cd absorbed is mainly accumulated in the roots of tomato and lettuce plant, while it is translocate freely to the leaves in case of radish. Comparing Cd concentration in the three plants at different levels of P_2O_5 revealed that the radish plant accumulated more Cd than both of 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) who reported that broad-leaved vegetables accumulate more cadmium than most other plants.

Cadmium and phosphorus concentrations in the soil

Table 4 shows the average content of Cd and P in soils of the three crops. The ranges of available Cd in the soil were 0.40-0.45 mg kg^{-1} and 0.38-0.44 mg kg^{-1} in soils of radish and lettuce, 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^{-1} in the soils of tomato, radish and the lettuce respectively. The variation of Cd and P in the soils might be due to the amounts of phosphate fertilizer added to the soil.

Significant positive correlation coefficients (0.975, 0.921 and 0.898) were found between available P and Cd in the three experiments, which could be due to the presence of this heavy metal in the phosphate fertilizer as contaminant (Nicholson and Jones, 1994 and Gimeno-Garcia et al., 1996). Also a positive and significant correlation coefficient (0.737) was found between the concentration of Cd in plants and the available P of all experimental soils. It could be concluded that the excess P helps in the accumulation of Cd in both soil and vegetative parts of tomato, lettuce and radish. Similarly, Pezzarossa et al. (1993) observed that Cd concentration in edible parts of plants was 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 hetero generous system (Chen et al., 2001).

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

Phosphorus Treatment ($kg\ P_2O_5/fed^*$)	Cd ($mg\ kg^{-1}$)	
	leaves	Roots
0	0.78	0.51
100	0.90	0.52
200	1.01	0.52
300	1.04	0.54
$LSD_{0.05}$**	0.04	0.03

* fed is fedan = $4200m^2$,

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

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

Phosphorus Treatment ($kg\ P_2O_5/fed$)	Available element ($mg\ kg^{-1}$) in soil		Correlation coefficient between P and Cd
	P	Cd	
	tomato plant experiment		
0	5.31	0.40	
100	13.2	0.40	
200	14.7	0.45	
300	17.2	0.51	0.975*
	radish plant experiment		
0	5.3	0.40	
100	7.8	0.41	
200	8.5	0.43	
300	9.7	0.45	0.921*
	lettuce plant experiment		
0	5.3	0.40	
100	6.3	0.39	
200	6.5	0.42	
300	7.3	0.44	0.898*

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

There are other criteria to evaluate soil contamination by heavy metals such as background concentrations which represents natural elemental concentration in soils without human influence (Chen et al., 1999). The base line background concentration of Cd in this study is 0.40 and the treated soils of the three crops slightly surpass the background level of cadmium. However, soil contamination may be considered when concentration of an element in soils is two or three times greater than the mean background levels (Logan and Miller, 1983) and none of the treatments reached that level.

The concentration of Cd in 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 of phosphate fertilizer application lead to the accumulation of available Cd in the soil that in turn affects the Cd content in plants. The data showed that significant correlations between available P and Cd both in soil and plant tissue. The ability of plant to accumulate Cd may depend on crop type and plant part. To avoid the side effects or toxicity of Cd on animals and humans, we recommend using fertilizers low in cadmium and avoiding overuse of P_2O_5 fertilizers.

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الملخص العربي

تراكم الكادميوم فى التربة وبعض محاصيل الخضر التي يسببها السماد الفوسفاتي

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أجريت ثلاثة تجارب في شتاء ٢٠٠٤/٢٠٠٥م في ارض لومية رملية في منطقة غرب النوبارية بقرية ابو العطا لتقيم أربعة مستويات من السماد الفوسفاتي علي تراكم الكادميوم في التربة والأجزاء المختلفة لبعض من نباتات الخضار الطماطم والخيار و الفجل. مستويات السماد الفوسفاتي هي صفر، ١٠٠، ٢٠٠، ٣٠٠ كجم P_2O_5 لكل فدان (الفدان = ٤٢٠٠م^{٢}). أظهرت المعدلات المختلفة من السماد الفوسفاتي تأثير معنوي علي تركيزات الكادميوم في أنسجة النبات للمحاصيل الثلاثة المدروسة. زاد السماد الفوسفاتي من تراكم الكادميوم في أجزاء النبات وكان أكثر وضوحا في المعدلات العالية. كان مدي تركيز الكادميوم في عصير الطماطم (0.12 – 0.08 ملجم كجم$^{-١}$) أعلي من لحم ثمار الطماطم (0.020 – 0.009 ملجم كجم$^{-١}$). تراوح تركيز الكادميوم في الفجل بين 0.65 - 0.76 ملجم كجم$^{-١}$ الذي كان اعلي من التركيز في الخس 0.12 – 0.24 ملجم كجم$^{-١}$ او في ثمار الطماطم 0.100- 0.176 ملجم كجم$^{-١}$ لكل مستويات الفوسفور المضافة. في نباتات الخس كان تركيز الكادميوم في الجذور أعلي منها في السيقان وعكس ذلك ظهر في الفجل. زادت كميات الفوسفور والكادميوم المتاح في التربة معنويا مع زيادة معدلات الفوسفور المضاف في التجارب الثلاثة بعد الحصاد. بالرغم من أن إضافة الأسمدة الفوسفاتية لها فوائد ملحوظة علي خصوبة التربة ولكن ذلك مرتبط بتأثير سلبي محتمل لتراكم الكادميوم الذي يؤثر علي كلا من نوعية المياه والتربة وبيئة التربة.