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EFFECT OF CADMIUM AND ZINC ADDITIONS ON CADMIUM CONCENTRATIONS IN SOIL AND POTATO TUBERS (SOLANUM TUBEROSUM L.)

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ABSTRACT

The addition of cadmium (Cd) to cultivated land from various sources could raise its concentration in foodstuff. This has recently been of great concern because of its potential health hazards. The present study was initiated to investigate the effect of addition of various levels of Cd and Zn on Cd content of soil and its concentration and uptake by potato tubers. Effect of four levels of Cd; 0, 0.5, 2.5 and 12.5 mgkg^{-1} applied in the form of $CdCl_2$ and three levels of zinc (0, 5, and 20 mgkg^{-1}) applied in the form of $ZnSO_4$, were studied in a Lysimeter experiment. Cadmium was detected in the potato tubers besides testing its total level in the surface soil layer (0 – 15 cm) and the subsurface soil layer (15 – 30 cm), after the experiment termination.

The obtained results indicated that cadmium concentration reached 0.44, 1.18, and 9.89 mg Cd kg^{-1} in the surface soil layer (0-15cm) as a result of addition of 0.5, 2.5 and 12.5 mg Cd kg^{-1}, respectively. Only slight increase of Cd content was detected in the second layer (15-30 cm.). The results also indicate that addition of Cd resulted in a significant increase in the uptake of Cd by Potato tubers, especially at the higher rates of addition. However, addition of Cd did not influence potato yield. Application of zinc was found to markedly decrease the Cd concentration in potato tubers, only at the higher rates of Cd addition.

INTRODUCTION

Cadmium can be easily absorbed and translocated to food crops in quantities that are not phytotoxic, yet may be harmful to human health (Chaney, 1980). Recently, much concern has been given to the cadmium content of plants. This concern arises from investigations that revealed potential harmful health effects from high dietary intake of cadmium (Oliver, 1997).

Cadmium occurs naturally in minute quantities in most soils, but can accumulate in agricultural soils from various sources such as atmospheric emissions, emissions from municipal solid waste incinerators, coal burning, road dust, fertilizers, and sewage sludge (McLaughlin and Singh, 1999).

Cadmium uptake by crops is influenced by several factors. Chief among them is the concentration of Cd in the soil solution (Kabata-Pendias and Pendias, 1992; Alloway, 1986; Mullins *et al.*, 1986). Other important factors include, soil acidity (pH) (Hahne and Kroontje, 1973), soil micronutrients content (Oliver *et al.*, 1994), soil salinity (Bingham *et al.*, 1983). Also, crop species and cultivars differ widely in their ability to absorb, accumulate and tolerate Cd .

Therefore, crop selection (Peterson and Alloway 1979) and soil management practices such as site selection (Chaney and Hornick 1978; Chaney *et al.*, 1993), fertilizers management (McLoughlin *et al.*, 1996; He and Singh, 1993), liming (Sparrow and Salardini, 1997; Singh and Myhr, 1998), zinc applicatioins (Abdel-Sabour et al., 1988; Choudhary et al., 1994), irrigation water quality (McLaughlin *et al.*, 1994), and other management factors should be tested and employed to reduce hazards of Cd in foodstuffs. The effect of zinc addition on Cd uptake has received considerable attention (Honma and Hirata, 1978). Many researchers have demonstrated that Zn application has decreased the uptake of cadmium (Abdel-Sabour *et al.*, 1988). Contrary to these results, White and Chaney (1980) found no benefit of Zn addition. In general, application of Zn may reduce Cd concentration in crops, particularly where Zn levels are marginal to deficient. Further research is needed to confirm under what conditions Zn application will be effective in reducing crop-Cd concentration.

Therefore, the primary objective of this study was to determine the influence of cadmium and zinc additions on cadmium concentrations in soil and potato tubers.

MATERIALS AND METHODS

The experiment was conducted on lysimeters at the College of Agriculture, King Saud University Educational Farm located in Riyadh. The lysimeters were constructed using steel containers 58 cm inside diameters and 88 cm depth. Each lysimeter was equipped with a drainage hole fitted at 5 cm from the bottom. The bottom was covered by concrete layer. A layer of sorted gravel was placed at the base of each lysimeter to facilitate drainage. A plastic jerry-can 5L capacity was allotted to each lysimeter and placed at lower level to collect drainage water. A surface sandy loam (Torrifluvent) calcareous soil was collected from the College of Agriculture, King Saud University Experimental and Research Farm at Dirab, 25 km south west of Riyadh. Selected soil properties were determined by standard procedures. Sand silt and clay were 790. 100 and 110 g kg^{-1}. Organic matter, pH and $CaCO_3$ were 5 g kg^{-1} 7.3, and 292g kg^{-1}. Available N, P. and K were 0.035, 0.009, 0.175 g kg-1. The lysimeters were filled up to 15 cm from the surface. Net soil depth was 50 cm. Treatments consisted of four Cd rates (0, 0.5, 2.5 and 12.5 mg Cd kg^{-1}) and three zinc rates (0, 5, and 20 mg Zn kg^{-1}). Treatments were replicated three times and arranged in a completely randomized block design. Potato [*Solanum tubrosum* (*L.*) Spuata] was planted at in each lysimeter. Irrigation with tap water was provided according to plant requirements. At maturity the potatoes tubers were harvested from each lysimeter and their weight was recorded. Tubers were oven-dried at 70°C for 24 hr, and total Cd content was determined in tubers by digesting the material by perchloric-sulfuric acid mixture according to the method described by Page (1982). Soil samples were collected from each lysimeter at (0-15 and 15-30 cm) depth for analysis. The obtained data were statistically analyzed using ANOVA procedure and the differences among the means, were separated according to L.S.D. method (SAS, 1982).

RESULTS AND DISCUSSION

Total cadmium levels tested in 0-15cm layer of the soil are given in Table 1. The data show that applying the various rates of Cd resulted in a significant increase in the first layer of soil (0-15 cm.). Cadmium concentration reached 0.44, 1.18, and 9.89 mgkg as a result of addition of 0.5, 2.5 and 12.5 mg Cd kg^{-1} soil, respectively. The obtained values of total cadmium in the control are similar to the lower limit given by Holmgren *et al.* (1993), in their study on soils of the United States (0.2 $mgkg^{-1}$). However, they are much lower than the upper limit given by the same investigators (2.5 $mgkg^{-1}$). On the other hand, testing the values of total Cd in the second layer of the soil (15-30cm). Table (2) showed that only slight increase of Cd content was detected in the this layer.

In light of the lower accumulation of Cd in the second layer, it was possible to conclude that the major portion of added Cd accumulated in the first layer and the mobility of the added Cd in the current study was very low. Similar results were presented by Biddappa *et al.* (1982). The mobility of Cd depends on the quantity added, and the soil characteristics. Generally, sorption is the main process that determines the amount of Cd available for leaching (Boekhold and Van der Zee, 1992).

Considering the high $CaCO_3$ content (29.2%) and the slight alkaline nature (pH7.3) of the soils under investigation, it seems that most of the added Cd was precipitated in the first layer of the soil. The precipitation of Cd occurs mainly under conditions of high anion concentrations and at high pH. The formation of $CdCO_3$ through

Table (1) :Effect of applied Cd and Zn on total Cd content in soil (0-15cm) layer

Zinc Rates (mg Kg^{-1})	Cadmium Rates (mg Kg^{-1})				
	0	0.5	2.5	12.5	Mean
0	0.13	0.41	0.90	9.73	2.80
5	0.17	0.44	1.49	9.57	2.92
20	0.29	0.46	1.12	10.38	3.06
Mean	0.20	0.44	1.18	9.89	

LSD (0.05) for Cd means = 0.96
LSD (0.05) for Zn means = 0.83
Cd×Zn = N.S.

Precipitation processes and its role in limiting the mobility of Cd has been reported by Tiller *et al.* (1994).

As for the effect of Zn application, the results, in general, demonstrated that application of various levels of Zn did not result in any significant change of Cd concentration in the soil (Tables 1 and 2). Differences due to interactions among Cd and Zn were not significant

Table (2): Effect of appliedCd and Zn on total Cd content in soil (15-30cm) layer

Zinc Rates (mg Kg^{-1})	Cadmium Rates (mg Kg^{-1})				
	0	0.5	2.5	12.5	Mean
0	0.10	0.27	0.50	0.74	0.40
5	0.23	0.27	0.62	0.71	0.46
20	0.26	0.29	0.72	0.58	0.46
Mean	0.19	0.27	0.62	0.68	

LSD (0.05) for Cd means = 0.08
LSD (0.05) for Zn means = 0.07

The concentration of Cd in potato tubers is shown in Table 3. The data indicated that addition of various rates of Cd resulted in a significant increase in the Cadmium concentration in potato tubers. The concentration of Cd in the tubers reached 1.06, 1.05, and 1.15 mgkg^{-1} as a result of addition of 0.5, 2.5 and 12.5 mg Cd kg^{-1}, respectively. Prediction of Cd availability in soils to crops has been the subject of a number of investigators (He and Singh, 1994; Narwal and Singh, 1998). Kuisnamurti *et al.* (1995) found a good correlation (R^2=0.88) between Cd in the soil and that in wheat grain under field conditions on 11 soils.

In the current study, the results showed that the lower rate of Cd addition resulted in a significant increase in Cd concentration in the tubers. However, further increases in Cd additions resulted in only little insignificant effect on tuber Cd concentrations. This aspect of Cd behavior is critical to the discussion of critical levels in soils, for if Cd concentration in plant does not increase significantly at the higher rates of addition (2.5 and 12.5mgkg^{-1}), then relatively higher Cd loadings to soil can be tolerated and critical soil concentration can be set higher.

Results in Table 3 show that application of Zn to the soil, significantly, decreases the Cd concentration in the potato tubers. The decrease in Cd concentration with

increasing Zn application were from 1.01 to 0.84 and 0.76 with application of 5 and 20 mgkg^{-1} Zn, respectively . Generally increasing rates of Zn up to 20 mgkg^{-1} significantly decreased Cd concentration in tubers. These results are in agreement with those of Honma and Hirata (1978) and Abel-Sabour *et al.* (1988), who observed decreases in the Cd concentration in Swiss chard, maize and rice following the amilioration of Zn deficiency. This effect has been demonstrated in both common and durum wheat, and is particularly well expressed under conditions of Zn deficiency (Oliver *et al.*, 1994) However, the studies of Abdel-Sabour *et al.* (1988) were made in the glasshouse with only one soil type and those of Honma and Hirata (1978) were in solution cultures.

Table (3): Effect of applied Cd and Zn on Cd concentration in potato tubers

Zinc Rates (mg Kg^{-1})	Cadmium Rates (mg Kg^{-1})				
	0	0.5	2.5	12.5	Mean
0	0.26	1.25	1.22	1.32	1.01 a
5	0.22	1.09	0.94	1.10	0.84 b
20	0.18	0.84	0.98	1.03	0.76 b
Mean	0.22 b	1.06 a	1.05 a	1.15 a	

LSD (0.05) for Cd means = 0.20
LSD (0.05) for Zn means = 0.17

The uptake of Cd by potato tubers as indicated in Table 4 was generally similar to Cd concentration in the potato tubers (Table 3). Results of the present study indicated that Cd uptake is significantly increased with addition of Cd and closely associated with Cd concentration. As for the effect of Zn addition, the result also indicated a significant decrease in Cd uptake by potato tubers with increase in Zn addition especially, at the higher rates of addition.

The possible explanations for the decrease in Cd uptake as soil Zn supply increased, may be due to direct competition between Zn and Cd (Robson and Pitman, 1983) or alternatively, loss of membrane integrity in root cells under conditions of Zn deficiency (Welch et al, 1982) where applications of Zn to the soil may alleviate the deficiency and restore the integrity of the root membrane and hence, the amount of Cd accumulated by plants would decrease. Thus, plants grown under Zn deficient conditions may accumulate more Cd, provided there are significant concentrations of Cd in soil solution, than when grown in the presence of sufficient Zn in a manner similar to the accumulation of excess P and other elements when Zn is deficient.

The effect of various levels of Cd and Zn on potato yield is presented in Table 5. Statistical analysis revealed that potato yield was not influenced by Cd or Zn addition. This can be explained by the fact that Cd is a zootoxic element, i.e., more toxic to animals than plants (Daves and Coker, 1979). It can be seen from the obtained results, that potato yield varies from 0.82 to 0.94 kg/ lyseimeter, and only insignificant decrease in yield occurred as a result of Cd addition. These results are in agreement with those obtained by Garsia Lopez (1996) in his study on the effect of cadmium concentration on lettuce growth.Earlier, Chaney (1980) also mentioned that Cd is generally not pytotoxic to plants.

Table (4) Effect of applied Cd and Zn on Cd uptake by potato tubers

Zinc Rates (mg Kg^{-1})	Cadmium Rates (mg Kg^{-1})				
	0	0.5	2.5	12.5	Mean
0	0.04	0.18	0.19	0.22	0.16 a
5	0.03	0.19	0.15	0.16	0.13 ab
20	0.03	0.12	0.13	0.13	0.10 b
Mean	0.03 b	0.16 a	0.16 a	0.17 a	

LSD (0.05) for Cd means = 0.04
LSD (0.05) for Zn means = 0.04
Cd×Zn = N.S.

Table (5) Effect of applied Cd and Zn on potato yield

Zinc Rates (mg Kg^{-1})	Cadmium Rates (mg Kg^{-1})				
	0	0.5	2.5	12.5	Mean
0	0.96	0.79	0.85	0.89	0.87 a
5	0.82	0.98	0.94	0.84	0.90 a
20	1.04	0.78	0.74	0.71	0.82 a
Mean	0.94 a	0.85 a	0.85 a	0.82 a	

LSD (0.05) for Cd means = 0.18
LSD (0.05) for Zn means = 0.15
Cd×Zn N.S.

Table 6 shows simple linear correlation between Cd concentration in the first soil layer (0-15cm) and its concentration in second soil layer (15-30 cm), Cd concentration and Cd uptake by potato tubers. The results showed that tuber Cd concentrations in the first soil layer were positively correlated with its concentration in the second soil layer (r=0.62***), Cd concentration in the tubers (r=0.52**) and Cd uptake (r=0.46**). The results showed that Cd concentration and its uptake by the potato tubers were strongly correlated.

Table (6):Simple linear correlation matrix between Cd concentration in the first soil layer, second soil layer, Cd concentration and uptake by potato tubers.

	Soil A (0-15cm)	Soil B (15-30cm)	Conc.	uptake	Yield
Soil A (0-15cm)	1	0.626***	0.407*	0.339*	-0.171
Soil B (15-30cm)		1	0.524**	0.466**	-0.151
Conc.			1	0.911***	-0.267
Uptake				1	0.107
Yield					1

*, **, ***, significant at P=0.05, 0.01, 0.001, respectively

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تأثير إضافات الكادميوم والزنك على تركيز الكادميوم في التربة ودرنات البطاطس

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زاد الإهتمام في الآونة الأخيرة بالآثار الصحية الضارة التي يمكن أن يحدثها تلوث الأطعمة بالكادميوم والناتج من إضافته للتربة والمياه من مصادر مختلفة. يهدف هذا البحث إلى دراسة تأثير إضافة مستويات مختلفة من الكادميوم و الزنك على تركيز الكادميوم في التربة و على إمتصاصه و تراكمه في درنات البطاطس.أضيف الكادميوم بمعدلات صفر، ٠,٥، ٢,٥، ١٢,٥ ملجم كادميوم/كجم تربة على صورة كلوريد الكادميوم . بينما أضيف الزنك بمعدلات صفر، ٥، ٢٥ ملجم زنك/كجم تربة على صورة كبريتات الزنك. تم جمع محصول البطاطس وقدر الوزن الرطب و الجاف للدرنات وقدر محتوى الكادميوم بها وكذلك الكمية الكلية الممتصة بواسطة الدرنات والكمية الكلية من الكادميوم في العمق الأول للتربة (صفر-١٥سم) والعمق الثاني (١٥-٣٠سم) وذلك بعد إنتهاء التجربة.

أشارت النتائج المتحصل عليها إلى أن:

إضافات الكادميوم بمعدلاته المختلفة أدت إلى إرتفاع مستوى الكادميوم الكلي في العمق الأول للتربة حيث بلغ ٠,٤٤، ١,١٨، ٩,٨٩، ملجم كادميوم/كجم وذلك عند إضافة ٠,٥، ٢,٥ ، ١٢,٥ملجم كادميوم/كجم تربة على الترتيب، بينما كانت هذه الزيادة طفيفة نسبياً في العمق الثاني للتربة

أوضحت النتائج أن زيادة معدل الإضافة من الكادميوم أدت إلى زيادة معنوية في تركيز الكادميوم وكذلك إمتصاصه بواسطة درنات البطاطس، بينما أدت إضافات الزنك إلى إنخفاض معنوي في تركيز الكادميوم وإمتصاصه بواسطة درنات البطاطس خاصة عند التركيزات العالية للكادميوم. ولم تحُدث إضافات كل من الكادميوم والزنك أي تأثير على إنتاجية البطاطس.