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EFFECT OF CADMIUM APPLICATION AND SOIL pH ON GROWTH AND CADMIUM ACCUMULATION IN ROOTS, SHOOTS AND SEEDS OF PEA PLANTS

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ABSTRACT: A pot experiment was conducted under greenhouse conditions to study the effect of four Cadmium (Cd) levels (0, 15, 30 and 60 mg kg^{-1} soil) as Cd SO_4 and three soil pH values (5.5, 6.8 and 8.2) and their combinations on growth, Cd distribution and Cd accumulation in pea plants. Soil Cd application into the soil and soil pH significantly affected extractable Cd from the soil, plant dry matter yield and Cd accumulation in plant tissues. Roots accumulated the highest concentrations of Cd compared with other plant organs. Also, increase soil Cd application due to reduction in shoot dry weight more than root dry weight. Cd concentration and uptake in roots, shoots and seeds of pea plants grown at pH 5.5 were significantly higher than in plants grown at pH 8.2. The translocation of Cd from roots to shoots was influenced by Cd application and soil pH.

INTRODUCTION

Accumulation of heavy metals in agricultural soils has become a major concern for food crop production. Cadmium (Cd) is recognized as one of the most hazardous elements which is not essential for plant growth (Kabata-Pendias and Pendias, 1992). Since cadmium is known to be easily taken up by plants and translocated within the plant (John *et al.*, 1972 and Turner, 1973). A clear understanding of its bioavailability to plants is essential to reducing Cd entry into the food chain with potentially harmful effects on human health (Yantiang Guo, 1995). It is well known that Cd concentration in plant tissues is usually directly related to the concentration of plant available Cd in soil (Braumemer *et al.*, 1986). However, a number of soil factors can alter Cd uptake and accumulation in plants. Soil pH is a factor most frequently observed to affect Cd availability to plants (Xian and Shokohifard, 1989). Acidic conditions in soil often enhance the solubility of heavy metals, especially Cd. An increase in the dissolved concentration of heavy metals may represent toxicity and contamination problems in soils. The behaviour of heavy metals in plant-soil environments is dependent on the chemical speciation and the relative distribution of chemical forms of metals in soil solutions. These, in turn, will influence the availability and mobility of Cd in soils (Del Castilho and Chardon, 1995; Reddy *et al.*, 1995 and Abou Seada *et al.*, 1997). Little information is available on Cd uptake by pea plants or distrubution of Cd within the plant including accumulation in the seeds. However, only a few studies have examined Cd uptake by pea plants grown in Cd-contaminated and/or non-contaminated soils (Cieslinski *et al.*, 1994; 1995).

The present study was initiated to investigate Cd uptake by pea plants grown in sandy soil under greenhouse conditions and Cd distribution within plants as affected by Cd application and soil pH.

MATERIALS AND METHODS

The pot experiment was conducted under greenhouse conditions with pea plants (*Pisum sativum* L.) in sand culture at the Experimental Farm of the Faculty of Agric., Minufiya University, Shibin El-Kom. A surface soil samples (0 – 30 cm) were collected from an area adjacent to Quasna City. Soil samples were air-dried and ground, to pass through 2 mn seives. Some physical and chemical analysis for this soil were carried out according to Black (1965) and illustrated in Table (1).

Plastic pots (30 cm internal diameter) were filled with 7 kg air dried sand soil. Pea seeds were germinated and after 15 days from

Table (1): Some physical and chemical characteristics of the soil used.

Property	Values	Property	Values
Mechanical analysis:		**Soluble ions meq/100 g soil:**	
Sand %	95.2	$Ca^{2+} + Mg^{2+}$	4.6
Silt %	2.4	Na^{+}	1.45
Clay %	2.4	K^{+}	0.07
Soil texture	Sandy	$HCO^{-}_{3} + CO^{=}_{3}$	0.6
Chemical analysis:		Cl^{-}	1.5
OM %	0.26	$SO^{=}_{4}$	4.02
pH (1 : 2.5 soil : water)	7.97	Total N%	0.06
EC dSm^{-1}	1.1	Cd ppm	0.24

Table (2): Effect of soil Cd application and different soil pH on DTPA on Cd concentration (ppm) in soil.

Cd applied (mg . kg^{-1})	Soil pH values			Mean
	5.5	6.8	8.2	
0	0.30	0.25	0.14	0.23
15	12.28	10.23	8.55	10.33
30	20.65	28.68	29.77	29.70
60	50.78	46.33	37.37	44.83
Mean	23.50	21.37	18.96	-

L.S.D. 5% Cd 0.66 pH 0.57 Cd × pH 1.15

complete germination, plants were thinned to 4 uniform seedlings per pot.

A nutrient solution similar to that recommended by Hoagland and Arnon (1950) was used once a week for each pot in this experiment. Soil pH was adjusted at three pH levels namely, 5.5, 6.8 and 8.2 by supply of acid (0.1 N HCl) and alkahi (0.1 N NaOH). Also, the distilled water for irrigation was adjusted at the same pH levels.

After 25 days from sowing, cadmium was added as Cd SO_4 at the levels of 0, 15, 30 and 60 mg/kg soil. These levels were chosen to be near from those found in the extremely polluted areas. Each treatment was replicated three tims in a completely randomized. block design. Two plant samples were taken at flowering and at harvesting stages and separated to roots, shoots and seeds. The plant materials were divided into two parts, the first portion was dried at 105°C to determine the dry weight and the second one was dried at 70°C for chemical analysis. Cd was extracted in soil by DTPA using method of Lindsay and Norvell (1978). Plant samples were digested using $HCLO_4$ and H_2SO_4 acids (Jackson, 1960). The concentration of Cd in soil and plant samples were determined using the atomic absorption spectrophotometer (Model Phillips Pu 9100). All data were statistically analyzed according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

1. Cd content in soil:

Data in Table (2) show the influence of Cd application on the DTPA Cd at different pH. It was noticed that increasing the soil Cd levels stimulated the Cd recovery, particularly at pH 5.5. Increasing the pH resulted in a decrease in the DTPA soluble Cd. Wherever, Cd was found to be most mobile in acidic soils within a pH ranged between 4.5 to 5.5 and it was more readily adsorbed by soil particles and bound by organic compounds at higher soil pH (Binghan *et al.*, 1980). These results are in full agreement with those reported by Kabata-Pendias and Pendias (1992) and Cieslinski *et al.* (1996).

In this respect, Nouri and Reddy (1995) and Jeng and Singh (1995) decleared that when soil pH decreased, the mobility of Cd and other trace metals increased with changing soil acidity.

Concerning the interaction between soil pH and the soil Cd application on the extractable Cd-DTPA, it could be noticed that, the combined treatment of pH 5.5 value and 60 mg Cd kg^{-1} gave the highest Cd-extract content (50.78 mg Cd kg^{-1}). This may be due to the influence of reducing soil pH and Cd addition on increasing DTPA-extractable Cd in the soil (Cieslinski *et al.*, 1996).

2. Plant growth:

Average shoot dry weight varied widely among pea plants, but was the highest for all parts of plants grown in non-Cd treated soil (Tables 3 and 4). Shoot dry weight was higher at soil pH 6.8 than at soil pH 8.2 in both growth stages. Increasing the Cd concentration in soil significantly decreased dry weight of pea shoots in both growth stages.

At the lower pH (5.5), dry weight of shoot significantly decreased with applied Cd more than that observed at higher pH (8.2). Application of 60 mg Cd kg^{-1} of soil at different soil pH reduced shoots dry weight at flowering stage to 77, 58 and 58% of control plants, respectively. This may be ascribed to Carlson *et al.* (1975) who reported that plants exposed to high soil Cd concentration had considerably reduced chlorophyll content in their leaves, which decreased plant biomass productivity. The inhibitory effect of Cd on plants to different reasons. a) inhibiting water transport to the shoots, b) decreasing the uptake of essential elements by the roots, c) reducing the stomatal aperature and CO_2 uptake, consequently decreasing the photosynthesis (Greger, 1989).

Increased soil pH rescued bioavailability and has been shown to influence Cd sorption and hence the concentration of Cd in soil solution (Alloway *et al.*, 1994).

The obtained data for the effect of different soil pH with the amount of applied Cd at 15 mg Cd^{-1} of soil with pH 8.2 excelled that one at pH 5.5. Shoots dry weight of pea plants grown in soil treated with 30 mg Cd kg^{-1} soil were not influenced by soil pH. However, at 60 mg Cd kg^{-1} soil, increases accured in shoots dry

Table (3): Effect of Cd application and different soil pH on dry weights (g / plant) of pea plants at flowering stage.

Cd applied (mg . kg^{-1})	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	2.31	1.94	1.82	2.02
15	1.70	1.52	1.61	1.61
30	1.07	1.37	1.37	1.27
60	0.84	1.15	0.82	0.94
Mean	1.48	1.50	1.41	1.46
		Shoots		
0	6.46	5.89	5.79	6.05
15	4.25	5.60	5.32	5.06
30	2.97	2.93	3.10	3.00
60	1.47	2.49	2.44	2.13
Mean	3.79	4.23	4.16	4.06

L.S.D. 5%	roots	shoots
Cd	0.11	1.15
pH	NS	0.25
Cd × pH	0.20	1.56

Table (4): Effect of Cd application and soil pH on dry weights of pea plants (g / plant) at harvesting stage.

Cd applied (mg . kg^{-1})	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	5.8	5.2	5.4	5.47
15	3.1	3.2	3.4	3.23
30	2.8	2.9	3.8	3.17
60	1.4	1.8	1.5	1.57
Mean	3.28	3.28	3.53	3.36
		Shoots		
0	19.2	17.4	18.4	18.33
15	11.6	13.9	12.8	12.77
30	9.9	9.7	9.7	9.77
60	5.7	8.6	8.5	7.60
Mean	11.6	12.4	12.35	12.12
		Seeds		
0	18.9	19.4	20.7	19.67
15	9.3	10.0	9.3	9.53
30	7.9	8.2	7.9	8.00
60	4.4	5.3	5.11	4.91
Mean	10.13	10.73	10.75	10.53

L.S.D. 5%	roots	shoots	seeds
Cd	0.07	0.34	0.45
pH	0.06	0.29	0.39
Cd × pH	0.12	0.59	0.85

weight per plant grown in soil at pH 8.2. Thus, it seems that increased soil pH reduced the toxic effect of Cd to plants only with the highest amount applied Cd. Root dry weight was more sensitive to increased Cd concentrations in soil than shoots dry weight (Table 4). Wherever, it considerably decreased with raising Cd levels, this may attributed to the disturbance of enzyme activity which resulted from the phytotoxic effects of high content of Cd in corn plants as a result of its accumulation (Youssef *et al.*, 1995).

At harvesting stage, data in Table (4) indicated that the effect of soil Cd application and soil pH on dry matter yield of pea plants. In general, dry weights of roots, shoots and seeds were significantly reduced by soil Cd application. The reduction in the dry matter yield may be a consequence of inhibited enzyme activities (Marschner, 1998). In this concern, also the basic cause of the toxicity might be due to the higher affinity of Cd for thiol groups (SH) in enzymes and other proteins (Mengel and Kirkby, 1987).

As regards to soil pH, data indicated that, increasing the soil pH significantly increased the different pea plants organs of dry matter yield.

3. Seeds yield:

Seed yield (Table 4) showed a large differences according to the Cd application into the soil. The highest yield was achieved with unamended soils. Increasing soil pH to 8.2 affect seeds yield of pea plants. The incremental addition of Cd to the soil remarkably diminished the seed yield of pea plants. In this respect, Morghan (1993) found that seed yield of several plants decreased in Cd contaminated soil.

4. Cd concentration:

Cd concentration in shoots of plants grown in untreated soil ranged from 0.49 to 0.59 mg Cd kg^{-1} dry weight (Table 5). While Cd concentration at harvest stage (Table 6) ranged from 0.29 to 0.37 mg Cd kg^{-1} dry weight which exceeded the range 0.05 – 0.20 mg Cd kg^{-1} normally accepted for plants (Kabata-Pendias and Pendias, 1992).

Although application of 15, 30 and 60 mg Cd kg^{-1} to soil increased substantially Cd

Table (5): Effect of Cd application and soil pH on Cd concentration (ppm) of pea plants at flowering stage.

Cd applied ($mg . kg^{-1}$)	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	3.21	1.30	1.00	1.84
15	41.50	37.6	19.20	32.77
30	75.40	48.2	30.70	51.43
60	104.40	58.7	36.40	66.50
Mean	56.13	36.45	21.82	38.14
		Shoots		
0	0.49	0.58	0.59	0.55
15	26.10	21.40	12.98	20.16
30	36.70	26.00	15.00	25.90
60	51.07	33.80	22.10	35.66
Mean	28.59	20.45	12.67	20.57

L.S.D. 5%	roots	shoots
Cd	3.12	1.66
pH	2.18	1.43
Cd × pH	4.89	2.87

concentration in shoots up to 35.66 mg Cd kg^{-1} dry weight, at flowering stage and up to 33.8 mg Cd kg^{-1} shoots dry weight at harvesting stage (Table 6 and Fig. 1), Cd concentration in shoots was distinctly reduced by increasing soil pH (Tables 5 and 6).

Concerning the interaction between soil pH and Cd application into the soil, the results indicate that the application of Cd at 60 mg Cd kg^{-1} soil with pH 5.5 markedly affected the high concentration in plant shoot at flowering and harvesting stages (Tables 5 and 6). Similar results were found in roots at both flowering and harvesting stages.

It is obvious that Cd concentration was much lower in shoots than in roots. Seeds accumulated intermediate amounts of Cd taken up as compared with that estimated in root (Table 6). These results were in agreement with the findings of Yantiong Guo (1995) and Cieslinski *et al.* (1996).

It seems that Cd accumulated more rapidly in roots than shoots and seeds at both growth stages. Most of Cd in the plants accumulated in the roots. Detoxifications may be metal specific with Cd bound to sulphur containing proteins which form metabolically inactive complexes which accumulate in roots (Baker *et al.*, 1990).

5. Cd uptake:

To obtain more information regarding the actual amounts of Cd absorbed from soil and accumulated into specific plant parts, the obtained results expressed in terms of Cd uptake. The results of Tables (7 and 8) indicated that the uptake of Cd by plants increased with increasing Cd addition to the soil, because of the increasing rate of absorption Cd than the decreasing rate of accumulation of the dry matter (concentration effect). In Tables (7 and 8), it is also noticed that the Cd uptake by shoots and roots in harvesting stage was more than in shoots and roots at flowering stage.

The Cd uptake by pea plants was conclude that the Cd uptake was more in seeds than in shoots and roots at harvesting stage.

6. Cd translocation:

The variation in the ratio of Cd in the shoot as observed may also be at least partly due to

Table (6): Effect of Cd application and soil pH on Cd concentration (ppm) of pea plants at harvesting stage.

Cd applied (mg . kg^{-1})	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	1.59	0.51	0.48	0.86
15	29.94	28.3	15.3	24.3
30	50.0	35.0	20.6	35.2
60	62.8	39.4	27.3	43.2
Mean	35.95	25.80	15.90	25.89
		Shoots		
0	0.36	0.29	0.37	0.34
15	24.4	17.7	7.8	16.63
30	27.9	22.7	12.2	20.9
60	48.6	31.0	18.8	33.8
Mean	25.32	17.92	9.8	17.7
		Seeds		
0	0.39	0.33	0.29	0.34
15	37.1	27.6	13.1	25.93
30	46.7	31.5	17.6	31.93
60	57.4	35.2	20.10	37.57
Mean	35.4	23.7	12.77	23.94

L.S.D. 5%	roots	shoots	seeds
Cd	1.94	1.52	1.27
pH	1.67	1.32	1.10
Cd × pH	3.34	2.04	2.20

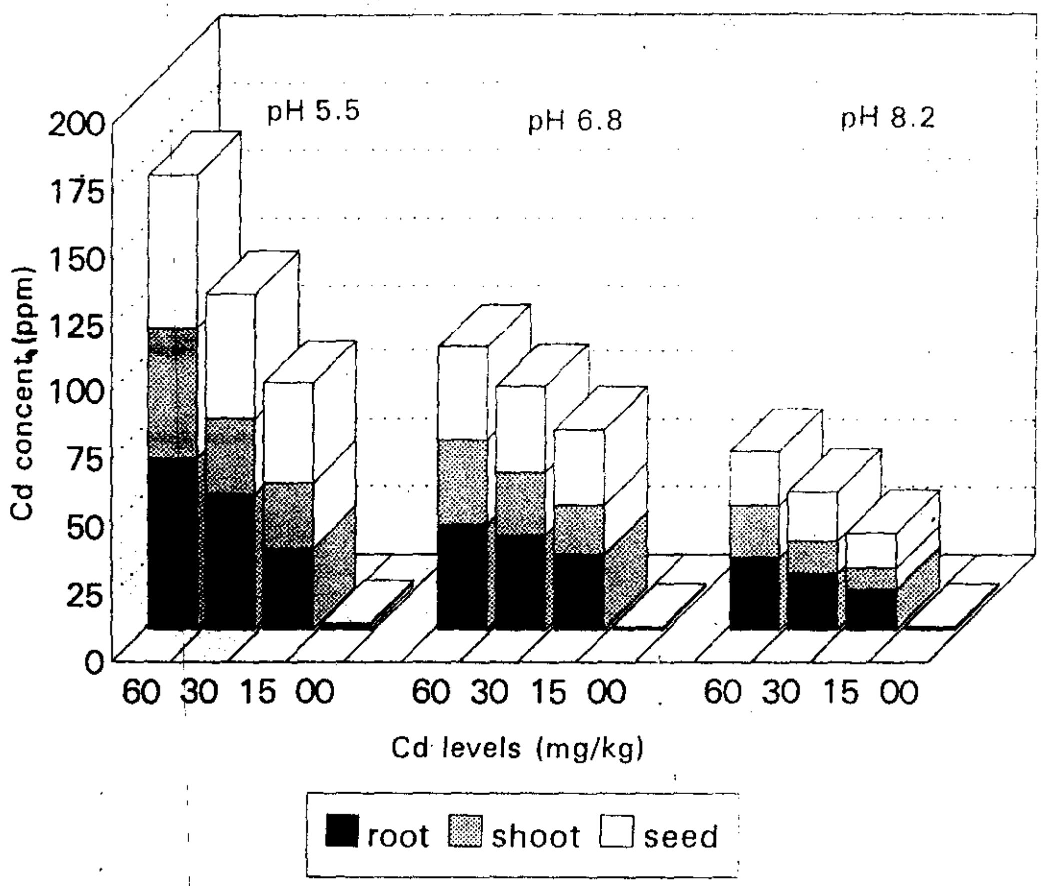

Fig (1): Cd concentration in pea roots, shoots and seeds as affected by soil Cd application and soil pH.

Table (7): Effect of Cd application and soil pH on Cd uptake (µg . g⁻¹) of pea plants at flowering stage.

Cd applied (mg . kg^{-1})	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	7.42	2.52	1.82	3.92
15	70.55	57.15	30.91	52.87
30	80.68	66.03	42.06	62.92
60	87.70	67.51	29.85	61.69
Mean	61.59	48.30	26.16	45.35
		Shoots		
0	3.17	3.42	3.42	3.34
15	110.93	119.84	69.05	99.94
30	109.00	76.18	46.50	77.23
60	75.07	84.16	53.93	71.05
Mean	74.54	70.90	43.23	72.89

L.S.D. 5%	roots	shoots
Cd	8.12	11.18
pH	10.30	12.40
Cd × pH	15.60	18.80

Table (8): Effect of Cd application and soil pH on Cd uptake (µg . g^{-1}) by pea plants at harvesting stage.

Cd applied (mg . kg^{-1})	Soil pH value			Mean
	5.5	6.8	8.2	
		Roots		
0	9.22	2.65	2.59	4.82
15	91.14	90.56	52.02	77.91
30	140.0	101.50	78.28	106.59
60	87.92	70.92	40.95	66.60
Mean	82.07	66.41	43.46	63.98
		Shoots		
0	6.91	5.05	6.81	6.26
15	283.04	246.03	99.84	209.64
30	276.21	220.19	118.34	204.91
60	277.02	266.6	159.80	234.47
Mean	210.80	184.47	96.20	163.80
		Seeds		
0	7.37	6.40	6.00	6.59
15	345.03	276.00	121.83	247.62
30	368.93	258.30	139.04	255.42
60	252.56	186.56	102.71	180.61
Mean	243.47	181.82	92.40	172.56

L.S.D. 5%	roots	shoots	seeds
Cd	8.10	16.80	18.60
pH	13.50	20.20	25.40
Cd × pH	21.60	29.40	32.90

variation in the translocation of the Cd element from roots to shoots. In order to understand this, the relative distribution of Cd in shoot / root has been calculated and presented in Table (9).

The results indicate that the application of Cd at high rates markedly affected the translocation of Cd from roots to shoots (shoot/root) in pea plants as compared with low rates. Cd movement from pea roots to shoots was very limited despite a high concentration in soil and, subsequently, in roots at both growth stages (Tables 5 and 6). This supports findings suggesting that an internal detoxification system can reduce plant Cd translocation which renders Cd less toxic to plant, grown in contaminated soils (Baker *et al.*, 1990).

The mobility of Cd has been reported to increase with soil acidity (Nouri and Reddy, 1995 and Reddy *et al.* 1995). On the other hand, there is evidence that Cd differ in their mobility in the soil. Even a minor decrease in the pH has been shown to increase the leaching of Cd significantly from both metal-polluted and unpolluted layers (Reddy *et al.*, 1995). In this connection, Grunhage and Jager (1985) reported that Cd translocation from roots to shoots increased in acidic soil (pH 4).

In conclusion, evidence has been presented to show the effect of both Cd concentration in soil and soil pH on pea plant productivity and Cd accumulation in plant tissue and seeds. Moreover, plant response to soil Cd was found to be soil pH-dependent. Dry weight of shoots was the best indicator of the toxic effect of Cd on pea plant growth, although the highest Cd concentrations were found in root tissue. Cadmium concentration in roots was directly related to the DTPA-extractable Cd concentration in soil. The relatively low Cd concentration in upper parts of the pea plants indicated the plant's internal detoxification system may have limited translocation of Cd from roots. This suggest that under elevated soil Cd concentration, pea plants were stimulated to activate Cd binding sites in their roots. Growing economic crops, particularly those are used for human foods, in Cd contaminated areas showed be avoided.

Table (9): Effect of Cd application and soil pH on the translocation of cadmium content (shoots / roots) at harvesting stage.

Cd applied ($mg . kg^{-1}$)	Soil pH value			Mean
	5.5	6.8	8.2	
0	0.75	1.91	2.63	1.30
15	3.11	2.72	1.92	2.69
30	1.97	2.17	1.51	1.92
60	3.15	3.76	3.90	3.52
Mean	2.57	2.78	2.21	–

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تأثير إضافة الكادميوم إلى التربة ورقم حموضة التربة على النمو وتراكم الكادميوم فى الجذور والمجموع الخضرى والبذور فى نباتات البسلة

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أجريت تجارب أصص تحت ظروف الصوبة لدراسة تأثير إضافة الكادميوم بتركيزات (صفر ، ١٥ ، ٣٠ ، ٦٠ ملليجرام لكل كيلوجرام تربة) على صورة كبريتات كادميوم وكذلك ٣ مستويات من رقم حموضة التربة وهى (٥,٥ ، ٦,٨ ، ٨,٢) والتداخل الموجود بين هذين العاملين على نمو نبات البسلة وتوزيع وتراكم الكادميوم فى أنسجة نباتات البسلة . وكانت أهم النتائج المتحصل عليها هى : وجد أن المعاملة بالكادميوم ورقم الحموضة فى التربة لهما تأثير معنوى على نمو النبات وتركيز الكادميوم فى التربة وتراكم الكادميوم فى النبات . أن تراكم الكادميوم كان أعلى فى المجموع الجذرى بالمقارنة بأجزاء النبات الأخرى . أدى زيادة تركيز الكادميوم فى التربة إلى نقص المادة الجافة للنبات وأن النقص فى المجموع الخضرى كان أكبر من الجذور . أدى إنخفاض pH الأرض إلى زيادة معنوية فى تركيز وإمتصاص الكادميوم فى أجزاء النبات المختلفة عن النباتات النامية فى الوسط القلوى . وقد إزداد أن إنتقال الكادميوم من الجذور إلى المجموع الخضرى مع إنخفاض pH الأرض .