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UPTAKE OF SOME METALS BY SORGHUM PLANTS AS AFFECTED BY CADIUM LEVEL IN THE ENVIRONMENT

A solution culture technique as well as pot experiment were carried out to examine the effect of different cadmium salts on the uptake of both cadium and zinc. The interactions of cadmium with other trace elements taken by sorghum plants grown on two different soils in Egypt were also examined. The results revealed that:

1. Cadmium salt did not affect the sorghum dry weight (at the dose of 0.5 mg/dm^3).

2. A reduction in both shoot and root sizes was observed at the dose of 100 mg of Cd/dm^3 of the nutrient solution.

3. Zinc generally affected negatively the uptake of both cadmium and iron by sorghum shoots. However, a positive effect of zinc addition was observed on the uptake of zinc, cobalt and chromium. Iron, cobalt and chromium contents were negatively affected by cadmium addition.

The uptake of zinc by sorghum plants was highly correlated with the total available amount of zinc in the soil, on one hand, and with the concentration of the zinc added, on the other hand. Cadmium uptake was best correlated with the available and total cadmium in soil.

1. INTRODUCTION

The importance of cadmium as environmental pollutant has been established, particulary in connection with human health because of its presence in water and food chain.

Although the toxicity of cadmium to plants has received recent attention, little is known about accumulation of cadmium in plants and its diverse effect on plant growth. LAGERWERFF and BIERSDROFF [12] reported that cadmium and zinc are competitive cations. However, cadmium interactions with zinc have

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shown conflicting results which may be related to plant species, source of cadmium and cadmium/zinc ratio in the soil solution or growth media [1], [8], [13], [18].

The major part of these studies has been performed by means of atomic absorption spectrophotometry (AAS) technique. However analyses of samples of low cadmium concentrations, including water sediments and plants, are often erroneous. These errors are mainly due to chemical interferences, contamination or incomplete recovery which may occur during the chemical digestion, extraction and measurement. The analytical technique of neutron activation analysis (NAA) for very valid reasons often has a number of distinct advantages in comparison with many other trace analytical techniques. Some of these favourable characteristics are highly sensitive, widely applicable, very specific and allow us to resolve problems concerning contamination problems. Applications of neutron activation analysis have been reviewed by CAMPBELL and BEWICK [4]. NAA may be a useful diagnostic tool to investigate some element interactions (i.e., cadmium and zinc, etc). In environmental studies, it is an important goal to keep better control over the movement of trace elements in a food chain. Such control may require increase or decrease in the concentration of some trace elements in food crops. This is a significant reason for studying and evaluating trace element interactions in soil–plant system which should be clearly understood and considered.

The aim of this work is to study the effect of different cadmium salts on the uptake of both cadmium and zinc and their translocation within sorghum plants grown in nutrient solution culture. Moreover, there were studied interactions of cadium with other trace elements and its effect on the uptake of other elements by sorghum plants grown on two different soils.

2. MATERIALS AND METHODS

2.1. EXPERIMENT 1

Sorghum seeds (C.V. Vulgare Pers) were germinated on filter paper in Petri dishes. Six days after germination, four seedlings were carefully transferred to pots filled with 1700 cm^3 of complete Hoagland nutrient solution of pH = 7. Nylon nets were used as a support for seedlings. The cultures were aerated by means of a pump system.

Variable cadmium salts, namely, $CdSO_4$, $CdCl_2$, $Cd(NO_3)_2$, and $Cd(C_2H_3O_2)_2$ in the concentration of 0.5 mg/dm^3, were added to each container. The entire nutrient solution in each container was replaced by fresh solution every 3 days to maintain desired metal concentration in solution. The plants were grown for 15 days, then they are removed from the solution and divided into shoots and roots.

2.2. EXPERIMENT 2

Six-days old sorghum seedlings were cultured in pots filled with 1700 cm^3 of Hoagland nutrient as mentioned earlier. Fifteen days after germination, a $Cd(NO_3)_2$ was added to the culture solution in the concentrations of 0.0, 0.1, 1.0 and 10 mg of Cd/dm^3. Fresh solution was maintained as in experiment 1. Plants were harvested at the intervals of 10, 15 and 20 days after initial addition of cadmium and divided into shoots and roots.

Plant samples from experiments 1 and 2 were ashed and then digested in 6N HNO_3 according to MORTVEDT [14]. Cadmium and zinc concentrations were determined using atomic absorption spectroscopy (Varian AA-475).

2.3. EXPERIMENT 3

Further experiment was carried out for two surface soil samples, and chemical characteristics of these soils were determined (table 1). One kilogram of each soil was placed in plastic pots. Soil in each pot was fertilized with nitrogen and phosphorus before establishing the culture. The soil was also enriched with zinc (as $ZnSO_4$) and cadmium (as $CdSO_4$) in the concentrations of 0.5 and 10 mg of zinc/kg of soil

Table 1

Some physical and chemical characteristics of the soils tested

Type of soil	pH	% of organic matter	% of clay	Toatal trace elements (mg/dm^3)			Extractable* (mg/dm^3)		
				Cd	Zn	Fe	Cd	Zn	Fe
Sandy soil	7.8	0.09	5.5	1.2	20	1,052	0.05	1.74	8
Sandy clay loam	7.1	5.78	31.7	1.9	195	24,787	0.20	13.40	192
Clay loam	7.7	4.31	42.7	2.7	123	36,739	0.18	2.39	63

* metal concentrations as water extracts from soil.

and 1 mg of cadmium/kg of soil, respectively. Each experiment was performed in three replications after mixing the soil in each pot to ensure good distribution of cadmium and zinc applied. Ten sorghum seeds (Vulgare Pers) were planted, and the later thinned out to 5 plants per pot. Soil moisture was maintained at 70% of the water-holding capacity. Sorghum shoots were harvested after 6 weeks, dried at 70°C and ground. Each sample of a known weight was wrapped up in thin aluminum foil. Two aluminum foils were tested, one containing standard material of a known weight (NBS) with a known amount of the elements studied, and the other was empty and served as a standard sample. All samples were placed together in aluminum can and irradiated in the research reactor for 48 h (neutron flux 10^{12} $n/cm^2/s$). After irradiation, the can was left for cooling. After two weeks, concentrations of the elements of interest in the samples and the standard sample were measured for 15 min using a multichannel analyzer connected with Ge(Li) detector. The concentration of the element tested can be calculated from the formula:

$$\frac{M_x}{M_{st}} = \frac{A_x}{A_{st}}$$

where:

M_x and M_{st} – concentration of the element in the sample tested and the standard, respectively,

A_x and A_{st} – activity of the sample tested and the standard, respectively.

3. RESULTS AND DISCUSSION

3.1. EFFECT OF DIFFERENT CADMIUM SALTS ON THE UPTAKE OF CADMIUM AND ZINC BY SORGHUM PLANTS

Results obtained (figure 1A) showed that the applied cadmium salts, namely, $CdCl_2$, $Cd(NO_3)_2$, $CdSO_4$ and $Cd(CH_3CO)_2$, did not affect significantly the sorghum dry weight. However, a slight increase in the dry weight of sorghum shoots was observed when $Cd(NO_3)_2$ was added.

Different cadmium salts affected considerably the cadmium content in sorghum (figure 1B). The highest cadmium content was observed after enrichment of the medium with $CdSO_4$ and $CdCl_2$. The results were in conformity with those obtained by STREET et al. [19].

The uptake of zinc by sorghum plants (figure 1C) showed great variety depending on the composition of anions in the solution. The highest zinc content was obtained when $Cd(NO_3)_2$ was added. As expected, the accumulation of zinc by the plant roots was significantly higher than that by shoots. However, plant shoots accumulated high zinc concentrations when the medium is supplemented by $CdSO_4$.

3.2. EFFECT OF CADMIUM DOSE ON CADMIUM AND ZINC CONTENTS

Different cadmium concentrations, namely, 0.0, 0.1, 1.0 and 10.0 mg of Cd/dm^3, were used to study their effect on plant growth and uptake of cadmium and zinc. The results obtained (table 2) showed that sorghum growth was limited at the concentration of 10.0 mg of Cd/dm^3 and certain symptoms of its toxicity were manifested. There was observed a reduction in both shoots' and roots' growth due to increased cadmium concentration in the nutrient solution by about 56% in comparison with the control sample. Similar results were reported by other authors who found that toxicity caused by cadmium usually resulted in growth

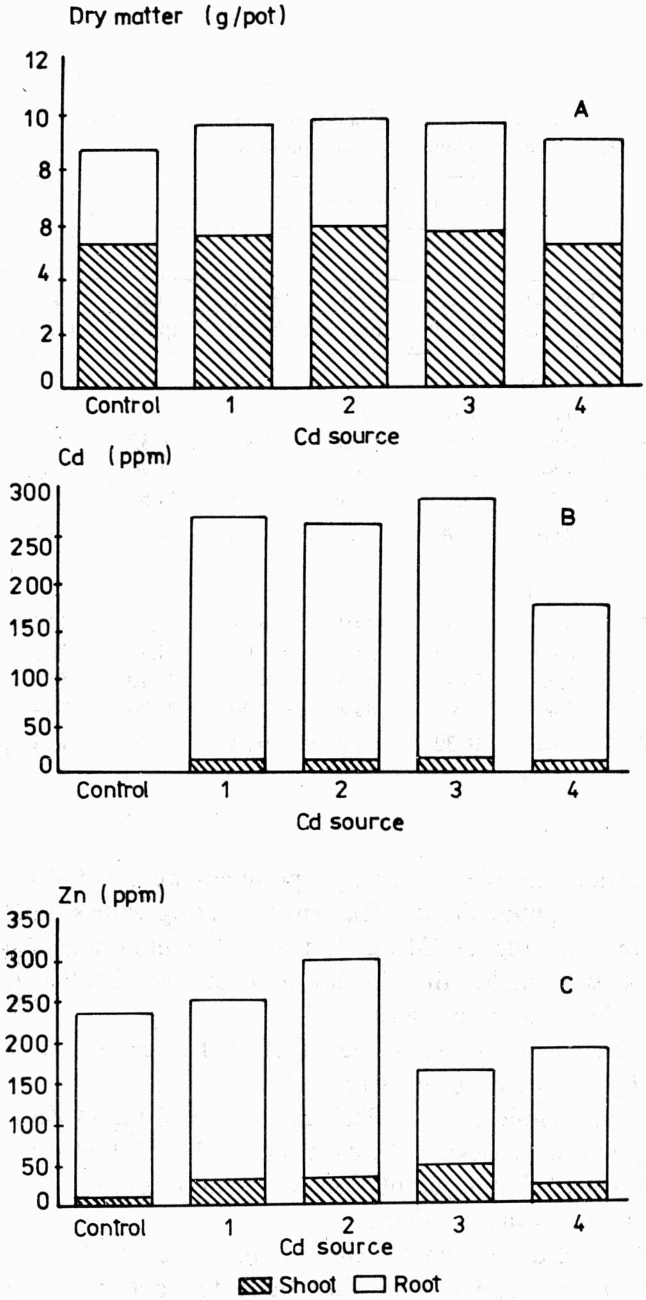

Fig. Effect of different cadmium salts on accumulation of cadmium and zinc in sorghum plants (shoot and root)

A – dry matter of sorghum plants, B – cadmium content in sorghum plants, C – zinc content in sorghum plants

Cadmium sources: *1* – $CdCl_2$, *2* – $Cd(NO_3)_2$, *3* – $CdSO_4$, *4* – $Cd(CH_3CO)_2$

reduction or poor yield (JOHN [10], BINGHAM and PAGE [3] and JOHN and VANLEARHOVEN [11]).

On the other hand, the uptake of cadmium by plants, and thus its concentration, in both shoots and roots were significantly affected by different cadmium doses (table 2).

Table 2

Cadmium and zinc concentrations in both shoots and roots of sorghum plants grown in nutrient solutions of varying Cd doses and in different growth periods

Dose of Cd (mg/dm^3)	Days after first treatment								
	10			15			20		
	Dry wt. (g/pot)	Cd (μg/g)	Zn (μg/g)	Dry wt. (g/pot)	Cd (μg/g)	Zn (μg/g)	Dry wt. (g/pot)	Cd (μg/g)	Zn (μg/g)
				Shoot					
Control	9.80	0.22	31.5	9.60	0.03	23.5	9.40	0.10	14.2
0.1	9.90	0.74	34.7	10.50	0.52	22.0	10.40	0.32	13.7
1.0	8.00	2.84	35.6	8.50	2.58	26.7	8.50	1.76	16.2
10.0	5.20	30.10	38.3	5.50	33.50	30.6	5.50	34.50	25.8
L.S.D.	0.68	0.18	11.5	2.90	6.90	4.9	1.28	1.55	6.1
				Root					
Control	5.70	0.25	86.3	6.20	0.08	39.0	6.10	0.53	38.4
0.1	6.50	9.80	76.5	6.40	3.00	58.1	6.00	1.83	39.2
1.0	5.20	15.40	87.7	5.20	20.40	55.4	4.80	20.40	58.1
10.0	3.40	227.60	125.0	3.40	207.60	84.4	3.40	27.90	76.4
L.S.D	0.68	17.10	21.7	0.68	16.30	13.9	0.68	2.20	13.4

L.S.D. – least significant differences

The average cadmium concentrations calculated during experiment were as follows: 0.12, 0.53, 2.39 and 32.7 mg/kg of sorghum shoots. The corresponding values in the roots were 0.29, 4.88, 18.73, and 154 mg of Cd/kg. It is worth mentioning that cadmium concentrations in roots were higher than in shoots. They were 2.4, 9.2, 7.8 and 4.7 times higher in roots than those in shoots.

Further investigation was carried out to study the effect of different cadmium doses on the uptake of zinc by sorghum plants (table 2).

The average zinc contents were as follows: 23.1, 23.5, 22.8 and 31.6 mg of Zn/kg of sorghum shoots. The corresponding values for the roots were 54.6, 57.9, 60.4 and 95.4 mg of Zn/kg. These results proved that accumulation of zinc in sorghum roots is 2.36, 2. 46, 2.65 and 3 times higher than in shoots.

At the concentration of 10 mg of Cd per 1 dm^3 of the medium, zinc translocation to shoots seems to affect the plant growth, and the shoot to root ratio was significantly reduced by about 20 to 10% if compared with control treatment. Therefore, it could be stated that mechanism of zinc translocation was affected by high cadmium concentration and its absorption by plants. HAWF and SCHMID [9] indicated that high concentration of cadmium (6 mg/dm^3) interfered with zinc translocation in the plant. WALLACE et al. [22] reported that a 10^{-5} M cadmium concentration in solution culture decreased zinc accumulation in the various parts of bush beans.

It is worth mentioning that previous results are the averages of three time intervals, namely, 10, 15 and 20 days (table 2). In addition, the values of cadmium and zinc concentrations in roots and shoots are the averages based on the data for the whole experimental vegetation season.

3.3. EFFECT OF ZINC AND/OR CADMIUM ON THE UPTAKE OF SOME TRACE ELEMENTS BY SORGHUM (SHOOTS) AS DETERMINED BY NAA TECHNIQUE

Table 3 presents the effect of different zinc and/or cadmium doses on the average uptake of zinc, cadmium, iron, cobalt and chromium by sorghum plants grown on the two soils tested.

Zinc application generally had a negative effect on the uptake of both cadmium and iron by sorghum shoots. However, its positive effect on the uptake of zinc, cobalt and chromium was observed. Zinc addition inhibited the accumulation of cadmium and iron in sorghum tops which amounted to 14 and 10%, respectively, in all soils tested.

Table 3

Effect of zinc and cadmium application on the uptake of certain trace elements by sorghum (shoots)

Type of soil	Dose of Zn (mg/dm^3)	Concentrations of metals in plants (mg/dm^3)									
		Without Cd addition					With Cd addition (1 ppm)				
		Zn	Cd	Fe	Co	Cr	Zn	Cd	Fe	Co	Cr
A	*	580	2.9	1,646	0.83	7.8	653	3.8	762	0.89	9.1
	5	784	2.4	1,532	1.12	8.4	766	2.9	1	0.94	7.8
	10	806	2.5	1,476	1.40	9.2	875	2.9	726	0.95	8.0
	$\bar{X}$	723	2.6	1,551	1.12	8.5	765	3.2	842	0.93	8.3
B	*	288	2.8	1,568	0.78	7.9	282	2.8	936	0.74	8.3
	5	343	2.5	1,553	1.50	9.2	352	2.7	1,359	1.30	6.8
	10	497	2.4	1,456	1.40	9.2	478	2.4	884	1.40	7.1
	$\bar{X}$	376	2.6	1,526	1.23	8.8	371	2.6	1,059	1.15	7.4

* – control, $\bar{X}$ – average, A – sandy clay loam, B – clay loam.

These results indicated that zinc competed strongly with cadmium and iron. Many studies showed interactions between the trace elements which modify the nutrition of plants. Summarized reviews by OLSEN [15] and CHANEY and GIORDANO [6] allow us to conclude that such interaction depends mainly on soil factors (i. e., nutrient supply, degree of element mobility) and plant factors (e.g., nutrient requirements, rate of absorption and the mobility of the nutrient within the plant).

Data in table 3 showed that iron, cobalt and chromium uptake by sorghum was negatively affected by cadmium addition. The decrease in the concentrations of the three elements taken by sorghum plants grown on the sandy loam soil amounted to 46, 17 and 2%, while the corresponding values for plants from clay loam soil amounted to 31, 7 and 16%, respectively.

The effect of cadmium upon zinc uptake was negligible which is in a good agreement with the results reported by HAGHIRI [8], WALLACE et. al. [21] and ABDEL-SABOUR et al. [1]. However, these results are in disagreement with those published by LAGERWERFF and BIERSDORF [12] and ROOT et al. [17]. This inconsistency may be due to the fact that they used the solution culture technique which minimized many factors that could be harmful as it would be in the case of soil system. Also it is well known that the results of experiments, which involved high concentrations of cadmium in hydroponic solutions, may yield unreproducible results and may lead to erroneous conclusions when they are extrapolated to represent the conditions of a soil system (CATALDO and WILDUNG [5] and ABDEL-SHAFY et al. [2]). It is worth mentioning that cadmium competes with zinc in similar active sites but does not functionally substitute for zinc (VALLEE and ULMER [20]).

A slight decrease in cadmium uptake by sorghum roots due to zinc application was observed which could be ascribed to the dilution effect of relatively high concentration of zinc in the soil solution (HAGIRI [8]).

Multiple regression analysis showed that zinc uptake was highly correlated with total zinc concentration in soil, available zinc and the dose applied (table 4). Cadmium uptake was positively correlated with its available concentration ($r = 0.85$). Introduction of the value of total cadmium concentration in soil to the regression equation improved the r value ($r = 0.91$). However, taking into account the concentration of zinc applied in the equation slightly affected the r values (0.92).

Table 4

Stepwise statistical analyses of Cd and Zn in the plant with respect to their doses, total and available Zn or Cd

Uptake of Zn		Uptake of Cd	
Available Zn	0.98	Available Cd	0.73
Available Zn + total Zn	0.84	Available Cd + total Cd	0.83
Available Zn + total Zn + dose of Zn	0.79	Available Cd + total Cd + dose of Cd	0.84

PETERSON and ALLOWAY [16] extensively reviewed the cadmium behaviour in soil and plant. They stated that cadmium or any other metal amounts adsorbed by soil depended both on the soil composition and the concentration of cadmium and other cations in solution.

Basing on the results obtained, it can be concluded that different cadmium salts have no effect on the sorghum dry weight. However, a decrease in a dry weight of both shoots and roots was observed at 100 mg of Cd/dm^3 of the nutrient solution. On the other hand, zinc application had a negative effect on both cadmium and iron contents taken by sorghum shoots. However, a positive effect of zinc on the uptake of zinc, cobalt and chromium was observed. The uptake of iron, cobalt and chromium was negatively affected by the cadmium addition. Furthermore, the uptake of zinc by sorghum plants was highly correlated with the total available amount of zinc in the soils studied, on one hand, and with the concentration of the zinc added, on the other hand. Cadmium uptake was best correlated with the available and total cadmium concentrations in the soil.

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WPŁYW POZIOMU KADMU W ŚRODOWISKU NA ABSORPCJĘ WYBRANYCH METALI PRZEZ ROŚLINY *SORGHUM*

Zbadano wpływ różnych soli kadmu na absorpcję kadmu i cynku przez rośliny. Eksperymenty przeprowadzono dla hodowli w roztworze i hodowli wazonowych. Określono również wzajemne oddziaływanie pomiędzy kadmem a innym śladowymi pierwiastkami pobieranymi przez rośliny typu *Sorghum*. Rośliny hodowano na dwóch różnych glebach w Egipcie. Otrzymane rezultaty wykazały, że:

1. Dawka soli kadmu w ilości 0.5 mg/dm^3 nie wpływała na suchą masę roślin.

2. Dawka soli kadmu w ilości 100 mg/dm^3 w pożywce powodowała zmniejszenie rozmiarów pędów i korzeni roślin.

3. Dodanie cynku do pożywki najczęściej wpływało ujemnie na absorpcję kadmu i żelaza przez pędy roślin. Zaobserwowano natomiast dodatni wpływ cynku na absorpcję kobaltu i chromu, podobnie jak i cynku. Dodanie kadmu do pożywki wpływało ujemnie na pobieranie żelaza, kobaltu i chromu przez rośliny.

Stwierdzono, że absorpcja cynku przez *Sorghum* w znacznej mierze zależy od całkowitej ilości cynku dostępnego w glebie oraz od stężenia cynku dodawanego do pożywki, podczas gdy absorpcja kadmu jest uzależniona przede wszystkim od stężenia dostępnego w glebie kadmu.

ВЛИЯНИЕ УРОВНЯ КАДМИЯ В СРЕДЕ НА АБСОРБЦИЮ ИЗБРАННЫХ МЕТАЛЛОВ РАСТЕНИЯМИ *SORGHUM*

Исследовано влияние разных солей кадмия на абсорбцию кадмия и цинка растениями. Эксперименты вели для культур в растворе и культур, разводимых в вазонах. Определено также взаимодействие между кадмием и другими микроэлементами, получаемыми растениями типа

Sorghum. Растения разводили на двух разных почвах в Египете. Полученные результаты обнаружили, что:

1. Доза соли кадмия количеством в 0,5 мг/дм^3 не имела влияния на сухую массу растения *Sorghum.*

2. Доза соли кадмия количеством в 100 мг/дм^3 в питательной среде вызывала уменьшение размеров ростков и корней растений.

3. Добавление к питательной среде цинка влияло чаще всего отрицательно на сорбцию Cd и Fe ростками растений. Зато наблюдалось положительное влияние наличия цинка на абсорбцию Co и Cr, а также Zn. В свою очередь, добавление кадмия к питательной среде оказало отрицательное влияние на поглощение Fe, Co и Cr растениями.

Было установлено, что абсорбция цинка растениями *Sorghum* в значительной степени зависит ит полного количества цинка, доступного в почве, а также от концентрации цинка, добавленного к питательным средам. Абсорбция кадмия растениями, в свою очередь, зависит прежде всего от количества кадмия, доступного в почве.