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Effects of Zinc, Phosphorus and Iron on the Cadmium Uptake and Accumulation by Hydroponically Grown Tomato.

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수경 재배된 도마도(Lycopersicum esculentum Mill)에 의한 Cd의 흡수, 축적과 이에 미치는 Zn, Fe 및 인산의 효과

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ABSTRACT

Effects of Zn, P and Fe on Cd uptake and accumulations by tomato (Lycopersicum esculentum Mill) and also their interactions on the uptake of Zn,Fe, Mn, P and Cd were investigated using batch type solution culture technique. Experiment 1 was a factorial scheme with 3 levels of Zn (0, 0.5, 2.5 ppm) and 3 levels of Cd (0, 0.2, 1.0 ppm). At 1.0 ppm Cd, significant yield reduction of dry matter and visual toxicity symptoms (yellowing and necrosis) of Cd was observed for all zinc levels. At this Cd level, increasing Zn treatment from 0 to 2.5 ppm increased Cd concentration from 199 to 235 ppm in leaves and from 124 to 145 ppm in stems. Similarly, Cd treatment did not suppress Zn uptake in leaves, and rather significantly increased in stems. Fe concentrations in leaves and stems were significantly reduced due to Cd treatment while Mn were increased by both Zn and Cd treatment. The results of experiment 2 with 3 levels of P (0.5, 2.0, 4.0m Mol) and 3 levels of Cd (0, 1.0, 2.0 ppm) in a factorial scheme also showed a growth reduction and visual toxic symptons from 1.0 ppm Cd level. Increasing P treatment tend to increase Cd concentrations in leaves and stems although it was not statistically significant. Increasing P concentration due to Cd treatment could be the "concentration" effect as a result of reduced growth, while there was significant decrease in Fe concentration due to Cd treatment in spite of possible "concentration" effect. Mn concentration was increased at 1.0 ppm Cd level and then dropped at 2.0

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ppm Cd level. Zu concentration in leaves and stems showed significant increase as Cd treatment increased as observed in experiment 1. Experiment 3 had 3 levels of Fe (0.5, 1,0, 2.0 ppm) and 3 levels of Cd (0, 0.8, 1.6 ppm) treatments in a factorial design. Significant growth reduction and visual toxic symptoms as observed in experiment 1 and 2 were also observed from 0.8 ppm Cd level. Increasing Fe treatment obviously alleviated toxic symptoms, improved growth and significantly increased dry matter yield. At 0.8 ppm Cd treatment level, increasing Fe treatment from 0.5 to 2.0 ppm significantly decreased Cd concentration from 141 to 92 ppm in leaves and from 101 to 46 ppm in stems. At 1.6 ppm Cd treatment level the decrease was from 224 to 167 ppm in leaves and from 124 to 109 ppm in stems. As in the case of experiment 1 and 2, Fe concentration in leaves and stems were reduced as Cd treatment increased to 1.6 ppm at 0.5 and 1.0 Fe treatment levels, whereas at 2.0 ppm Fe level, Cd treatment increased Fe concentration in leaves and stems showing significant interactions of Fe and Cd on Fe uptake.

Cd effect on Zn and Mn showed similar results to experiment 1 and 2 and Fe treatments reduced Zn and Mn concentrations in plant tissue. The results of 3 experiments show that P and Zn did not manifest suppressive effect on Cd uptake, Fe significantly demonstrated it. Fe also alleviated Cd toxicity symptoms significantly in terms of visual symptoms and dry matter yield. Visual toxicity symptoms were definitely related to Fe status in plant tissue as well as possible physiological effect of Cd itself, and the results suggest that Fe requirement for normal growth increase as Cd element is present in plant tissue. Zn accumulated more in stems than in leaves whereas Cd, Fe and Mn showed the opposite trend in all experiments.

INTRODUCTION

Toxicity of Cd to animals and plants and also the association of Cd with various human diseases such as hypertension, emphysema, chronic bronchitis, and kidney disease (Schroeder 1965; Friberg et al 1971; Perry 1968) has brought about considerable interest in recent years in studies of Cd levels in various phases of the environment. Food is one of the main pathways of Cd into human body (Friberg et al 1971) and one of the possible sources of Cd in food is accumulated Cd in food plants. Cd accumulation in plants were reported relatively easy and varied depending on plant species (Haghiri 1973; Page et al 1972; Turner 1973). Haghiri (1973) and Page et al (1972) also observed toxicity symptoms-yellowing and Haghiri(1973) suggested that Cd toxicity may be Cd induced Fe deficiency without presenting actual data. Chaney (1973) and Page et al (1972) suggested possible antagonistic Zn effect on Cd uptake. Lagerwerff and Biersdorf (1972) reported that Zn and Cd were competitive cations resulting in lower Zn levels where Cd is present. Contrary to their observations, increased Zn upake as a result of Cd treatment was observed by Turner (1973). and in explaining this result he suggested i) true stimulation of Zn uptake, ii) redistribution of Zn between roots and tops or iii) root damage.

The results of preliminary sand culture expiermment with Tomato (Lycopersicum esculentum Mill) having 2 levels of Cd (0, 0.5 ppm) treatment and 3 levels of Zn (0.1, 0.5, 2.5 ppm) treatment did not show any antagonistic effect of Zn on Cd uptake. They rather showed incresed Cd uptake as a result of Zn treatments and increased Zn uptake as a result of Cd treatment as observed by Turner (1973). To verify this observation further, experiment 1 was designed and conducted. Experiment 2, was designed and conducted to investigate the effect of P on Cd uptake since P has been known to repress Zn

and Fe uptake or induce Zn or Fe deficiency (Stuckenholtz et al 1966; Watanabe et al 1965). The results of two experiments indicated possible Fe-Cd interaction on their uptake and visual toxicity symptoms. Thus, experiment 3 was designed and conducted to investigate Fe-Cd interaction as described below.

MATERIALS AND METHODS

Experiment-1 (Zn-Cd interaction)

Using solution culture technique, a completely randomized factorial experiment with 3 levels of Zn (0, 0.5, 2.5 ppm) and 3 levels of Cd (0, 0.2, 1.0 ppm) with 3 replicates was conducted. As basic culture solution, Johnson's (1957) revised nutrient solution of Hoagland #2 solution was used for macronutrients. For micronutrients, 1.0 ppm Fe (as $FeSO_4+H_2SO_4$), 0.25 and 0.32 ppm Mn and Cl respectively (as $MnCl_2$), 0.1 ppm B (as H_3BO_3), 0.01 ppm Cu (as $CuSO_4 \cdot 5H_2O$), 0.01 ppm Mo (as $Na_2MoO_4 \cdot 2H_2O$) were the final concentrations in the nutrient solution.

Treatment of Zn and Cd was made with the solution of $ZnSO_4 \cdot 7H_2O$ and $CdSO_4$. Four tomato seedlings (25 days old) were transplanted to each solution culture container (3.81). Throughout the growing period, pH of nutrient solution was maintained between 4.5 and 5.

To ensure substantial initial growth, half strength basic nutrient solution with 0.05 ppm Zn and no Cd was supplied. After 2 weeks of initial growth, full treatment solutions were added for each treatment. After 8 days treatment solutions were renewed with freshly prepared treatment solution. After one week of the renewal of the culture solution, plants were harvested. Leaves and stems were separated and dried in a forced air oven at 75° C for 2 days and ground in a stainless stell Wiley mill. 0.5 gm of ground sample was digested with 15ml of acid mixture (20% $HClO_4$+80% HNO_3 by volume) on a hot plate and then diluted to an appropriate volume for the determinations of Cd, Zn, Fe, Mn with dual channel atomic absorption spectrophotometer (Jarrell Ash 810). Background correction was made for the Cd analysis using non-absorbing line. Results were subject to statistical analysis by computer.

Experiment 2 (P-Cd interaction)

After experiment 1, and using same technique as experiment 1, a completely randomized factorial experiment with 3 levels of phosphate(0.5, 2.0, 4.0m Mol) and 3 levels of Cd (0, 1.0, 2.0 ppm) with 3 replicates was conducted. Phosphate treatments were made with KH_2PO_4 and $NH_4H_2PO_4$. To balance nitrogen due to phosphate treatment with $NH_4H_2PO_4$, appropriate amount of NH_4NO_3 was used. Macronutrient content of nutrient solution was 13.5, 4.5, 4, 2, and 4m Mol of N,K, Ca, Mg and S respectively. Micronutrient content was same as experiment 1 with 0.1 ppm Zn. $CdSO_4$ was the source of Cd treatment.

Three tomato seedlings were transplanted to each solution culture container (3.81) which contained half-strength basic culture solution. 16 days after initial growth, full strength treatment solutions were applied. Each day deionized water was added to make up for the loss due to evaporation. After 13 days of growth in the treatment solution, upon observing obvious growth differences and toxic symptoms due to the treatment, plants were harvested and treated as in the case of experiment 1.

Experiment 3. (Fe-Cd interaction).

After careful examination of two experimental results which showed obvious relationships between Cd treatment and Fe uptake, this third experiment using same solution culture technique, having 3 levels of Fe (0.5, 1.0, 2.0 ppm) and 3 levels of Cd(0, 0.8, 1.6 ppm) with 3 replicates in completely randomized factorial scheme was conducted. Basic nutrient solution was exactly same as experiment 1 except 0.1 ppm Zn and 3 levels of Fe which is a treatment element. 3 tomato seedlings(25 days old) were transplanted to each solution culture container which contained half strength basic nutrient solution. After 14 days of initial growth, full strength treatment

solutions were applied. 12 days after lst full treatment, solutions were replaced with freshly prepared treatment solution. This time, the source of Fe was Fe-DTPA instead of $FeSO_4+H_2SO_4$ solution which has been used in previous experiments. A week after the renewal of treatment solution, plants were harvested and subsequently analyzed as described in experiment 1 section.

All the results data presented hereafter are average of 3 replicates.

Results

Experiment 1 (Zn-Cd interaction)

As shown in Table 1, growth reduction due to Cd (1.0 ppm) treatment was significant. At the same Zn level, increasing Cd treatemtn did not affect the concentration of leaves however, Zn concentration in stems were significantly increased. At Zn 3 treatment level, both concentration of Zn and dry weight of stem increased from Cd 1 to Cd 2 treatment level indicating no possible concentration effect, however, increase of zinc concentration from Cd 2 to Cd 3 treatment level could be due to the conoentration effect since stem yield was decreased from Cd 2 to Cd 3 treatment level.

At the same Cd level, increasing Zn treatment did not suppress the Cd concentration and total total uptake. In stem, Cd concentration was

Table 1. Yield (g/container), metal concentrations (ppm) total uptake (mg container) and results of statistical analysis for experiment-1 (Zu-Cd interaction).

Treatment (level)	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd^8	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
				[Yield]					
Zn 1	4.32	4.74	2.78	3.00	3.07	1.68	7.32	7.70	4.46
Zn 2	5.61	4.50	3.54	3.92	3.13	2.38	9.35	7.63	5.92
Zn 3	3.99	4.83	3.09	2.76	3.21	1.84	6.75	8.04	4.93
Zn		N.S.			*			*	
Cd		**			**			**	
Zn×Cd		N.S.			N.S.			N.S.	
L.S.D.	1%	.81			.65			1.42	
	5%	.59			.48			1.04	
C.V.(%)		14.3			17.3			15.2	
				[Zn]					
Zn 1	19	17	18	15	14	16	0.13	0.12	0.08
Zn 2	69	65	65	132	141	155	0.90	0.72	0.59
Zn 3	191	209	199	487	491	591	2.11	2.58	1.72
Zn		**			**			**	
Cd		N.S.			**			*	
Zn×Cd		N.S.			**			N.S.	
L.S.D.	1%	12.0			29.9			0.34	
	5%	8.7			21.8			0.25	
C.V.(%)		9.3			9.7			25.2	
				[Cd]					
Zn 1	0	57	199	0	32	124	0	0.36	0.76
Zn 2	0	68	201	0	42	140	0	0.43	1.04
Zn 3	0	67	233	0	40	145	0	0.45	1.00
Zn		N.S.			**			N.S.	
Çd		**			**			**	

Treatment (level)	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
Zu×Cd		N.S.			**			N.S.	
L.S.D. 1%		16.3			4.8			.19	
5%		11.9			3.5			.14	
C.V. (%)		13.1			6.1			31.4	
[Fe]									
Zn 1	293	221	154	78	68	42	1.50	1.23	0.51
Zn 2	193	183	150	72	61	46	1.36	1.04	0.64
Zn 3	198	183	152	61	56	48	0.96	1.07	0.56
Zn		**			N.S.			N.S.	
Cd		**			**			**	
Zn×Cd		5%			N.S.			N.S.	
L.S.D. 1%		34.6			12.4			.29	
5%		25.3			9.1			.21	
C.V. (%)		13.3			15.5			21.5	
[Mn]									
Zn 1	93	115	139	41	53	52	0.52	0.69	0.47
Zn 2	84	98	135	48	50	63	0.66	0.61	0.62
Zn 3	129	138	177	64	57	67	0.69	0.85	0.67
Zn		**			**			*	
Cd		**			*			N.S.	
Zn×Cd		N.S.			N.S.			N.S.	
L.S.D. 1%		1.70			10.3			.16	
5%		12.4			7.5			.12	
C.V. (%)		10.2			13.9			18.6	

rather significantly increased. Increasing Cd treatment significantly decreased Fe concentration in stems and leaves and also total uptake. Mn concentration and uptake generally showed increasing trend as Zn and Cd treatment levels increased. Leaves and stems showed different pattern of accumulation of micronutrients rand Cd in terms of concentration. Zn accumulated more in stems than in leaves whereas Cd, Fe and Mn showed the opposite trend.

Experiment 2 (P-Cd interaction)

As shown in Table 2, significant growth reduction was observed at Cd 2 level (1.0 ppm). Cd uptake and concentration was not affectet by

Table 2. Yield (gm/container), metal concentrations (ppm), total uptake (mg/container) and results of statistical analysis for experiment 2(p-Cd internation)

Treatment	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
[Yield]									
P 1	6.09	3.64	2.62	3.20	4.07	3.85	9.28	5.74	4.08
P 2	6.77	2.61	2.32	2.10	1.33	1.64	10.84	3.94	3.71
P 3	6.46	3.35	2.34	1.47	1.38	1.28	10.30	4.99	3.62
P		N.S.			N.S.			N.S.	
Cd		**			**			**	

Treatment	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
P×Cd		N.S.			*			N.S.	
L.S.D.	1%	.93			.47			1.35	
	5%	.68			.33			0.99	
C.V.	(%)	17.0			15.3			15.9	
				〔CD〕					
P 1	0	132	229	0	70	162	0	0.63	0.83
P 2	0	166	237	0	114	170	0	0.58	0.79
P 3	0	153	250	0	98	160	0	0.67	0.80
p		N.S.			N.S.			N.S.	
CD		**			**			**	
P×Cd		N.S.			N.S.			N.S.	
L.S.D.	1%	23.5			24			0.15	
	5%	17.1			17.5			0.11	
C.V.		13.3			20.6			23.8	
				〔P〕					
P 1	0.62	0.86	0.81	0.66	0.84	0.96	56	49	35
P 2	0.83	1.25	0.96	0.87	1.17	1.03	91	48	37
P 3	0.88	1.24	1.15	0.80	1.13	1.12	87	60	42
P		**			**			**	
Cd		**			**			**	
P×Cd		N.S.			N.S.			N.S	
L.S.D.	1%	.19			.15			13	
	5%	.14			.11			9	
		14.7			11.9			16.9	
				〔FS〕					
P 1	132	127	75	65	54	24	1.01	0.60	0.23
P 2	110	91	78	41	30	24	0.90	0.28	0.22
P 3	110	106	76	36	52	23	0.85	0.43	0.21
P		N.S.			5%			N.S.	
CD		**			**			**	
P×Cd		N.S.			N.S.			N.S.	
L.S.D.	1%	23.6			16.8			.18	
	5%	17.3			12.3			.13	
CV	(%)	17.3			32.1			24.9	
				〔Zn〕					
P 1	38	41	62	80	78	89	.49	.31	.29
P 2	29	77	55	70	122	76	.48	.36	.23
P 3	33	51	66	75	94	89	.49	.32	.27
P		N.S.			N.S.			N.S.	
CD		**			**			**	
P×Cd		**			*			N.S.	
L.S.D.	1%	9.0			18.4			.08	
	5%	6.5			13.5			.06	
C.V.	(%)	13.2			15.8			16.5	

Treatment	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
				[Mn]					
P 1	116	133	114	38	27	13	.83	.55	.31
P 2	108	185	111	30	36	15	.85	.53	.28
P 3	118	154	132	32	42	16	.83	.58	.23
P		*			N.S.			N.S.	
Cd		**			**			**	
P×Cd		N.S.			N.S.			N.S.	
L.S.D.	1%	16.8			9.3			.008	
	5%	12.3			6.8			.006	
C.V.	(%)	32.1			24.8			26.6	

P treatments. Both concentrations and total uptake of P was affected by Cd treatments. Increasing Cd treatment increased concentrations of P in both leaves and stems. However, total uptake was decreased. Growth reduction due to Cd toxicity could give concentration effect which may result in increasing P concentration in plant. Fe concentration and uptake was significantly reduced in spite of possible concentration effect due to growth reduction.

Although total Zn uptake was decreased as Cd treatment level increased, Zn concentration in both leaves and stems increased at all P treatment levels. Total Mn uptake was all decreased as Cd treatment level increased, but its concentration increased at 1.0 ppm Cd level and then decreased at 2.0 ppm Cd level.

Experiment 3 (Fe-Cd interaction)

As shown in Table 3, yield dercrease was significant from Cd 2 treatment level (0.8 ppm), at the same time yield reduction due to Cd treatment was significantly averted as Fe treatment level increased. Total uptake of Fe was significantly reduced due to Cd treatment.

Table 3. Yield (gm/container). Metal concentrations (ppm). Total uptake of metals (mg/container), and results of statical analysis for experiment3 (pe-Cd interaction).

Treatment	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
				[Yield]					
Fe 1	10.15	2.02	1.27	7.32	1.45	1.41	17.47	3.47	2.67
Fe 2	10.53	3.20	1.77	6.77	1.98	1.53	17.30	5.18	3.31
Fe 3	10.81	4.82	2.99	6.91	3.14	2.03	17.72	7.96	5.02
Fe		**			N.S.			**	
Cd		**			**			**	
Fe×Cd		N.S.			N.S.			N.S.	
L.S.D.	1%	1.05			0.80			1.82	
	5%	0.77			0.58			1.33	
C.V.	(%)	14.7			16.2			15.0	
				[Fe]					
Fe 1	155	145	90	47	56	20	1.92	0.37	0.14
Fe 2	147	135	130	52	77	36	1.90	0.78	0.29
Fe 3	157	196	167	53	77	73	2.06	1.18	0.65
Fe		**			**			**	

Treatment	Leaves			Stems			Total		
	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3	Cd_1	Cd_2	Cd_3
Cd		**			**			**	
Fe×Cd		**			**			*	
L.S.D.	1%	12.3			6.2			0.20	
	5%	8.9			4.5			0.14	
C.v.	(%)	5.9			8.3			14.2	
				[Cd]					
Fe 1	0	141	224	0	101	124	0	0.43	0.47
Fe 2	0	123	208	0	71	148	0	0.53	0.59
Fe 3	0	92	167	0	46	109	0	0.58	0.72
Fe		**			**			**	
Cd		**			**			**	
Fe×Cd		**			**			N.S.	
L.S.D.	1%	12.9			10.4			0.11	
	5%	9.4			7.6			0.08	
C.V.	(%)	9.0			11.5			21.9	
				[Zn]					
Fe 1	42	115	159	81	143	100	1.02	0.44	0.34
Fe 2	49	85	90	72	103	86	0.98	0.48	0.28
Fe 3	58	57	58	71	76	83	1.10	0.51	0.34
Fe		**			*			N.S.	
Cd		**			*			**	
Fe×Cd		**			N.S.			N.S.	
L.S.D	1%	27.1			31.8			0.15	
	5%	19.8			23.2			0.11	
C.V.	(%)	25.2			25.8			17.7	
				[Mn]					
	129	267	199	44	68	14	1.63	0.64	0.27
	124	173	181	45	34	26	1.60	0.61	0.36
	106	131	166	41	27	37	1.42	0.71	0.57
Fe		1%			5%			N.S.	
Cd		1%			1%			1%	
Fe×Cd		1%			1%			1%	
L.S.D.	1%	29.3			7.0			0.10	
	5%	21.4			5.1			0.08	
C.V.	(%)	13.2			13.8			8.9	

Increasing Fe treatment increased Fe concentration significantly Cd_2 and Cd_3 levels and this trend was similar to dry yield increase due to Fe treatment. Fe concentrations at low Fe treatment levels did show decrease at Cd_3 treatment level as in the case of experiment 1 and 2, however at high Fe treatment level Fe concentration was increased as Cd treatment increased. Increasing Fe treatment consistently decreased Cd concentration both in leaves and stems significantly at all Cd treatment levels, although total uptake of Cd was rather increased. This increase in total uptake was definitely due to the dry yield increase as a result of Fe treatment. Increasing Fe treatment did not affect Zn concentration at Cd_1 level (0 ppm) significantly whereas at Cd_1 and Cd_2 levels, increasing Fe significantly decreased Zn concentration in both leaves and

stems indicating Fe-Cd interaction on Zn concentration in plant tissue. Total Zn uptake however was all decreased significantly as Cd treatment level incresed due to reduced growth. Total uptake of Mn was also reduced due to reduced dry matter yield, whereas concentration in leaves and stems showed complicated Fe-Cd interaction. At Fe_1 treatment level(0.5 ppm Fe) Mn concentration in leaves and stems increased as Cd treatment increased from 0 to 0.8 ppm and then dropped a little at 1.6 ppm Cd level. At Fe2, and Fe 3 treatment levels, Mn concentration in leaves steadiliy increased as Cd treatment level increased from 0 to 1.6 ppm whereas it showed opposite trend in stems at Fe_2 level.

At Cd_1 level (0 ppm) increasing Fe did no reduce Mn concentration in both leaves and stems whereas at Cd_1 and Cd_2 treatment level, increasing Fe treatment significantly reduced Mn concentration in leaves. In stems however, Cd_2 and Cd_3 showed exactly opposite trend to each other indicating complicated interaction in terms of treatment concentration of Cd and Fe in nutrient solution.

DISCUSSION

Visual sysmptoms of Cd toxicity were positively identified at about 1.0 ppm Cd level as observed by Haghiri (1973) and Page et al (1972) except in experiment 3 where there was no apparent visual symptoms even at 2.0 ppm Cd level as Fe treatment increased to 2.0 ppm. In experiment 3, Cd_2 and Cd_3 treatment levels showed yellowing of upper leaves for all Fe treatment levels just before the renewal of full treatment nutrient solution. As treatment solution was replaced with freshly prepared solution, growth differences due to Fe treatments became more apparent and yellowing of upper leaves completely disappeared at 2.0 ppm Fe treatment. This observation and yield data suggest that one of the causes of visual sysmptoms could be the concentration of Fe in plant tissue as in the case of experiment 1 and 2 where there was decrease in Fe concentration due to Cd treatment as reported by Haghiri (1973). The results on tissue concentration of Zn and Cd did not suggest any antagonistic effect between Cd and Zu. This is contrary to what Chaney(1973) suggested and Lagerwerff and Biersdorf (1972) and Root et al (1975) observed. Increasing Cd treatment rather increased Zn concentration in plant tissue as observed by Turner (1973) and Haghiri (1974). Haghiri (1974) suggested this might be due to concentration effect as a result of reduced growth. Increasing P treatment tend to increase Cd concentration in plant tissue although it was not significant. The same trend was extensively examined and reported by Miller et al (1976) who observed high correlation between soil available P and Cd accumulation. Increasing P treatment.

Also reduced Fe concentration and uptake which agree with the report by Brown et al (1959) and Watanabe et al (1965). This result with reduced Fe uptake by Cd treatment might have intensified visual toxic symptoms(yellowing of upper leaves) as observed in experiment 2.

Fe treatment positively reduced Cd and Zu concentrations in plant tissue and alleviated somewhat Cd toxicity in terms of visual symptoms and dry matter yield. Similar antagonistic relationship between Zn and Fe was observed by Brown and Tiffin (1952) and Chapman et al (1940).

Root et al (1976) however observed increased Fe uptake as Cd concentration in leaves increased. They examined Fe/Zn ratio vs. Cd concentration in corn roots and shoots and found positive linear relationship (Root $r=0.89$, Shoots $r=0.65$). However, three experiments conducted in this report the opposite trend was observed (see Table 4). In experiment 1, the magnitude of Fe/Zn ratio differ widely depending on Zn level of nutrient solution. Only at high Fe treatment in experiment 3, data showed slight increase in Fe/Zn ratio at Cd 2 level. This suggests that Fe/Zn ratio could also show widely different

Table 4. Fe/Zn ratio in leaves and stems

Treatment	Leaves			Stems		
	Cd 1	Cd 2	Cd 3	Cd 1	Cd 2	Cd 3
Experiment-1. (Zn-Cd interaction)						
Zn 1	15.4	13.0	8.5	5.2	4.9	2.6
Zn 2	2.8	2.8	2.3	0.55	0.43	0.30
Zn 3	1.00	0.90	0.76	0.12	0.11	0.08
Experiment-2. (P-Cd interaction)						
P 1	3.5	3.1	1.2	0.81	0.69	0.27
P 2	3.8	1.2	1.4	0.59	0.25	0.32
P 3	3.3	2.1	1.2	0.48	0.55	0.26
Experiment-3. (Fe-Cd interaction)						
Fe 1	3.7	1.3	0.57	0.58	0.39	0.20
Fe 2	3.0	2.3	1.4	0.72	0.75	0.42
Fe 3	2.7	3.5	2.3	0.75	1.02	0.88

trend depending on the Fe treatment level in the nutrient solution. They used triple strength Fe of Hoagland solution which gives more than 3 ppm Fe in culture solution. This could be one of the reasons they obtained different relationship of Fe/Zn ratio vs. Cd concentation from those of this report. Another reason may be different plant species since the magnitude of Cd uptake was highly varied. (Page et al 1972). Results of experiment 3 suggest that some Fe in plant tissue may be inactivated when Cd ion is present, thus total Fe requirement in such condition for normal growth could become higher. Increasing Fe treatment level amy have met this requirement both by reducing Cd uptake and increasing Fe uptake as evidenced by dry yield increase and disappearing of toxic symptoms. Attempts to elucidate Cd toxicity with resulting micronutrient balance due to Cd treatment has not been made since the results of these experiments showed direct and indirect effect of Cd, Zn, P and Fe treatment on uptake and concentrations of micronutrients as well as severe growth reduction due to Cd toxicity which may result in additional "concentrated" or "diluted" effects of these elements in plant tissue (Olsen 1972).

LITERATURE CITED

1. Brown, J. C., R. S. Holmes, and L. O. Tiffin. 1959. Hypothesis concerning iron chlorosis. Soil Sci. Soc. Amer. Proc. **23**: 231-134.
2. Brown, J. C. and L. O. Tiffin. 1962. Zinc deficiency and iron chlorosis dependent on the plant species and nutrient element balance in Tulare clay. Agron. J. **54**: 356-358.
3. Chaney, R. L. 1973. Crop and fodd chain effects of toxic elements in sludges and effluents. U. S. EPA, U. S. Dept. of Agric., Universities Workshop, Champaign-Urbana, Ill.
4. Chapman, H. D., G. F. Liebig, Jr., and A. P. Vanselow. 1940. Some nutritional relationships as revealed by a study of mineral deficiency and excess symptoms on citrus. Soil Sci. Soc. Amer. Proc. **4**: 196-200.
5. Friberg, L., M. Piscator, and G. Bordberg. 1971. Cadmium in the environment. Chemical Rubber Co. Press. Cleveland, Ohio, p. 166.
6. Haghiri, F. 1973. Cadmium uptake by plants. J. Environ. Quality **2**: 93-96.
7. Haghiri, F. 1974. Plant uptake of Cadmium as influenced by cation exchange capacity,

organic matter, zinc and soil temperature. J. Environ. Quality 3: 180-183.

8. Lagerwerff, J. V. and G. T. Biersdorf. 1972. Interaction of Zinc with uptake and translocation of cadmium in radish. Proceedings of the 5th annula conference on trace substances and environmental health. Univ. of Missouri, Columbia Mo. p. 515-522.
9. Miller, J. E., J. J. Hassett, and D. E. Koeppe. 1976. Uptake of Cadmiums by soybeans as influenced by soil cation exchange capacity, pH and available phosphorus. J. Environ. Quality 5: 157-160.
10. Olsen, S. R. 1972. Micronutrient interactions. In Micronutrients in agriculture. Mortvedt, J. J. (ed.). p. 243-264. Soil Sci. Soc. Amer, Inc. Madison, Wisc.
11. Page, A. L., F. T. Bingham, and C. Nelson 1972. Cadmium adsorption and growth of various plant species as influenced by solution cadmium concentration. J. Environ. Quality 1: 288-291.
12. Perry, H. M. Jr. 1968. Hypertension and trace metals, with particular emphasis on Cadmium. Proceedings of the 2nd annual conference on trace substances and environmental health, Univ. of Missouri, Columbia, Mo. p.101-125.
13. Root, R. A., R. J. Miller, and D. E. Koeppe. 1975. Uptake of Cadmiumits toxicity, and effect on the iron ratio in Hydroponically Grown corn. J. Environ. Quality 4: 473-476.
14. Schroeder, H. A. 1965. Cadmium as a factor in hypertension. Jour. of Chronic Disease 18: 647.
15. Stuckenholtz, D. D., R. J. Olsen, G. Gogan, and R. A. Olsen. 1966. On the mechanism of phosphorus-zinc interaction in corn nutrition. Soil Sci. Soc. Amer. Proc. 30: 759-763.
16. Turner, M. A. 1973. Effect of Cadmium treatment on cadmium and Zinc uptake by selected vegetable species. J. Environ. Quality 2: 118-119.
17. Watanabe, F. S., W. L. Lindsay and S. R. Olsen. 1965. Nutrient balance involving phosphorus, iron and zinc. Soil Sic. Soc. Amer. Proc. 29: 562-565.