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CADMIUM AND ZINC TOXICITY EFFECTS ON GROWTH AND MINERAL NUTRIENTS OF CARROT (*DAUCUS CAROTA*)

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Abstract

The experiment was carried out in two successive seasons of 2006 and 2007 on carrot (*Daucus carota* L. var. Nantesa superior) at the Ministry of Local Government (Al Zahra Municipality), Gaza Strip, Palestine. It aimed to study the effect of (Cd and Zn) at different rates (10, 20 and 40 µg g^{-1} Cd) and (75, 150 and 225 µg g^{-1} Zn) on carrot plants. All of the studied growth characters (fresh and dry weights of shoot and root) and some of growth analysis {leaf weight ratio (LWR), relative growth rate (RGR mg $g^{-1}d^{-1}$), the rate of production of one sub-cellular component per unit of Cd and Zn (mg/g Cd or Zn per day) and specific utilization rate (SUR mg dw mg Cd^{-1} or Zn^{-1} d^{-1}) decreased with increasing Cd either alone or combined with Zn soil addition at all levels, but it increased when Zn (at all levels) was added, with some exception. Moreover attempts were carried out to reduce the toxic effect of Cd on the plants by using different rates of Zn soil addition. The effect of Cd and Zn either alone or their combination on minerals (N, P and K) in plant (shoot and root) were studied. Increase in K, P and N concentrations was recorded by the carrot shoots and roots supplied with the all levels of Zn soil addition either alone or combined with Cd soil addition. Adding Zn alone was found to insignificantly affect growth characters, but if it was combined with Cd in different levels, it overcome to some extent the toxicity of Cd on growth characters as well as minerals concentrations.

Introduction

The multi-faceted nature of environmental and agricultural issues in Gaza Strip, Palestine, requires an interdisciplinary, integrated approach to management strategies. Both the Palestinian Ministry of Environmental affairs and Ministry of Agriculture have set research priorities based on an understanding of the complexity of Gaza environment and agriculture through many years of study. Gaza strip as one of the most densely populated areas in the world with limited and deteriorated resources is suffering from the outcome of environment quality deterioration. The situation in Gaza strip is below the desired standard and that is attributed to the absence of environmental legislation and the public awareness. Therefore, there should be combined and serious efforts on the local regional and international levels to improve and protect the environment by prevention and monitoring the environmental themes. The enormous overall population growth and consequent industrial, agricultural, energy generation and communication boom of activities have led to disturbance in environmental equilibrium dynamics. Petroleum fuel combustion is a source of heavy metals, due to fuel additives, particularly tetraethyl lead antiwar protect ants incorporated in lubricants often contain Cd, Cr, Hg and Pb (Smith *et al*., 1975).

Motto *et al*., (1970) reported that, motor oil and treated wear from vehicular tires are sources of pollution with Cd, Pb and other metals for soil and plants grown near roadsides. The industrial activities of man and uncontrolled development of large cities especially currently and in the past have resulted in the contamination of soil, water and air, where burning or combustion of fuels contributes considerable amounts of pollutants to air. The engine of a motor vehicle as the most important resource of air pollutant near the city center is on ongoing problem in the city of Gaza, where there are thousands of motor vehicles. The pollutants in the urban atmosphere are discharged from many sources the major contributors are traffic and industrial establishments (Iqbal *et al*., 2001; Yilmaz *et al*., 2006). Trace metals released in the environment may be hazardous to the natural biological system and human health, plants and soil surface, which is the major sink for airborne metal. Moreover, plants form the basis of food chains by which bio-toxic trace metals are transmitted to man (Alfani *et al*., 1996). Baccio *et al*., (2005) reported that transition metals such as zinc, which are essential micronutrients for many physiological processes, but they become toxic at high concentration levels. Accordingly, zinc is one of the most abundant trace heavy metals present in agro-ecosystems. Madhoolika & Rajesh (2006) treated carrot plant with two Cd concentrations (10 and 100 µg M) and two Zn concentrations (100 and 300 µg M) and their combination. The authors pointed out that bioaccumulation of Cd in root and leaf was greater at the low metal–application rates of Cd and Zn in combination than the higher rates. Zn was found in some cases to depress Cd uptake, indicating some kind of interaction between these metals (Oliver *et al*., 1997; Cakmak *et al*., 2000). The aims of the present contribution are to study the effect of different levels of Zn soil addition on reducing the physiological impact caused by Cd and their effects on growth analysis and characters as well as on macronutrients content of carrot plant in Gaza strip, Palestine.

Materials and Methods

The experiments were carried out on an open field of the Ministry of Local Government (Al Zahra Municipality) Gaza Strip, Palestine in two successive seasons, 2006 and 2007. Plastic pots of (20 cm width and 25 cm depth were used in this experiment. Each pot was filled with 25 kg soil. 15 seeds of carrot (*Daucus carota* L. var. Nantesa superior) were put in each plastic pot. Each pot received 18 g ammonium sulfate (20.5% N), 9 g of Potassium sulfate (48% K_2SO_4) and 21.5 g of Calcium superphosphate (15.5 % P_2O_5). The fertilizers were applied to the plants as soil dressing in three doses / season. The mechanical, chemical analysis of the soil and water irrigation of plants under study were analyzed and the results are presented in (Table 1).

In the two seasons, before planting, four levels of Cd (0, 10, 20 and 40 µg g^{-1}) were added to soil as cadmium sulphate ($CdSO_4.5H_2O$). For each Cd level, pots were divided into 4 groups, the first group treated with the normal level of fertilizers as mentioned before, but without any other soil additions. The second, third and fourth groups were similar to the first one but the pots were treated with Zn as a soil addition before planting in the form of zinc oxide (ZnO) @ 0, 75, 150 and 225 µg g^{-1}. Thus, the experiment included four levels of Cd soil addition represented by the main treatments while Zn soil addition served as sub-treatment, total of 16 treatments. Each treatment included 45 plants arranged randomly in three replicates. Two samples were taken from each treatment 70 and 140 days after sowing. Fresh and dry weights of the shoot and root (g) were estimated. Growth analysis such as leaf weight ratio **(**LWR**)** and relative growth rate (RGR mg $g^{-1}d^{-1}$) were also calculated. In addition, rate of production of one sub-cellular component per unit of Cd and Zn (mg g^{-1} Cd or Zn per day) and specific utilization rate

(SUR mg dw. mg Cd^{-1} or Zn^{-1} d^{-1}) were estimated according to the methods described by Hunt (1978), using the following equations:
(LWR) = {(Lw_1÷W) + (Lw_2 ÷ W)} ÷ 2; (RGR mg g^{-1} d^{-1}) = $^{In}w_2$ - $^{In}w_1$÷T_2 - T_1
(SUR mg $mg^{-1}d^{-1}$) = ($^{W}{}_2$ - $^{W}{}_1$÷$^{T}{}_2$ - $^{T}{}_1$) × ($^{In}M_2$ – $^{In}M_1$ ÷ M_2 – M_1)
Rate of production of mg (A) g^{-1}(B) d^{-1} = ($^{A}{}_2$ - $^{A}{}_1$ ÷ $^{T}{}_2$ – $^{T}{}_1$) × ($^{In}B_2$ - $^{In}B_1$ ÷ B_2 - B_1)
B = Cd or Zn content, A = elements contents, T = Time samples, W = dry weight, M = Cd, Zn and Fe accumulations, 1 = first sample, 2 = second sample. Lw = leaves dry weight.

Macronutrients N, P and K were determined in the two samples of 70 and 140 days after sowing. For determination of total nitrogen, the modified micro-Kjeldahl apparatus of Parnas & Wagner as described by Pregl (1945) was used. Phosphorus was determined colorimetrically using the chlorostannous reduced molybdophosporic blue color method as described by Jackson (1967). Potassium was determined by using a flame photometer apparatus (CORNING, M 410). The results were statistically analyzed by using factorial experiments and the means of different treatments were compared using the least significant difference test (L.S.D) at 0.05 level of probability in the two samples as average of two successive seasons (Snedecor & Cochran, 1980).

Results and Discussion

It is clear from the results in Table 2 that Cd soil addition either alone or combined with Zn gradually and significantly decreased all of the studied growth characters (fresh and dry weights of shoots and roots). In general, the decreases due to Cd soil addition were more severely toxic in some growth parameters as compared to Cd used alone. There are many similar reports on carrot plants, rice plants, common oak and sunflower plant cv. *Helianthus annuus* (Salim *et al*., 1992**;** Lata & Johri, 1999; Bai Song *et al*., 2003; Bayctailu & Ozden, 2004; Azevedo *et al*., 2005). In this respect, Bayctailu & Ozden (2004**)** mentioned that toxic effects of Cd accumulation on *Quercus robur* su sp, *Robur* (Common Oak) and *Acre negundo (Box Elder)* were due to decrease in chlorophyll content and fluctuations in peroxidase activity. In general, it is important to mention that, in carrot plants, the decreases in shoot and root dry and fresh weights as a result of Cd soil addition were associated with pronounced decreases in shoot height and root length. This might be attributed to its effects on cell division and/or cell expansion, and may be through its effect on DNA and RNA synthesis. Furthermore, any change in the growth rate which results from increasing Cd supply must be dependent on the change in the rate of net photosynthesis that reduces the supply of carbohydrates or proteins and consequently decreases the growth of the plant. A similar findings is reported by Skorzynska & Baszynski (1995) who working on bean plant, pointed out that the application of Cd resulted in reduction of photosynthesis efficiency and transpiration.

The effect of three levels of Zn (75, 150 and 225 µg g^{-1}) soil addition on the growth characters (fresh and dry weights of root and shoot) were insignificant, except fresh and dry weights of shoot in the second sample which were significantly increased relative to the control Zn-untreated plants (Table 2). Similar results were reported by Salam, (1998) on faba bean plants. On the other hand, it is important to mention that, in the first sample, high values of root fresh, dry weight and length, as well as shoots dry weight were estimated at the plants treated with the lowest Zn concentration in comparison with plants treated by the highest rate of Zn. These findings are in agreement with Rashad & Hanafy Ahmed (1997) who working on faba bean plants mentioned that Zn (50 mg L^{-1}) foliar applications significantly increase most of the study growth characters (plant height and number of leaves per plant) while the highest rate of Zn (75 mg L^{-1}) had adversely affected most of the studies of growth and yield parameters.

Table 1. Chemical properties of irrigation water and mechanical, chemical properties of the soil under study.

	Property	Value	Property	Value	Property	Value
Irrigation water	pH	7.9	Magnesium mg L^{-1}	48.1		
	EC m mho /cm	2.1	Potassium mg L^{-1}	3.0		
	T.D.S mg L^{-1}	1413.0	Sodium mg L^{-1}	273.6		
	Chloride mg L^{-1}	462.6	Total alkalinity mg L^{-1}	210.0		
	Sulfate mg L^{-1}	142.4	HCO_3 mg L^{-1}	256.2		
	Nitrate mg L^{-1}	50.0	CO_3 mg L^{-1}	0.0		
	Calcium mg L^{-1}	106.7	Hardness mg L^{-1} as $CaCO_3$	465.2		
Soil	**Property**	**Value**	**Property**	**Value**	**Property**	**Value**
	Sand %	82.0	E.C mmho/c	0.579	K meq L^{-1}	6.50
	Clay %	11.0	NO_3 mg L^{-1}	106.1	Fe µg g^{-1}	80.90
	Silt %	7.0	CO_3 meq L^{-1}	0.0	Zn µg g^{-1}	52.40
	S.P %	19.3	HCO_3 meq L^{-1}	3.0	Pb µg g^{-1}	22.00
	pH	7.8	Ca+Mg meq L^{-1}	10.4	Cd µg g^{-1}	0.02

Table 2. Fresh and dry weight (g) of carrot root and shoot as the average of the two seasons in the two samples (70 and 140 days after sowing) as affected by different levels of Cd and Zn soil addition.

Plant age (days)	Treatment	Control	Zn1	Zn2	Zn3	Mean Cd	Control	Zn1	Zn2	Zn3	Mean Cd
		Fresh weight (g)									
70	Control	3.73	3.99	3.25	2.90	3.46	4.75	4.34	4.95	4.05	4.52
	Cd1	2.35	2.74	2.72	2.36	2.54	3.15	3.65	3.89	3.34	3.50
	Cd2	2.46	2.76	2.70	2.74	2.67	3.21	3.65	3.41	2.59	3.21
	Cd3	1.78	1.62	1.76	2.04	1.80	2.50	2.53	2.92	3.13	2.77
	Mean Zn	2.58	2.75	2.61	2.52		3.40	3.54	3.79	3.28	
	L.S.D 0.05	Cd = 1.24(S) Zn = 1.24(NS) Cd* Zn =1.86(S)					Cd = 1.47 (S) Zn = 1.47N(S) Cd*Zn = 2.20(S)				
140	Control	44.18	43.18	38.27	32.25	39.47	12.24	9.50	11.80	9.60	10.80
	Cd1	28.45	34.72	35.80	30.12	32.27	7.50	8.70	11.40	11.60	9.80
	Cd2	26.43	37.00	36.47	37.90	34.45	5.89	10.00	8.70	9.00	8.40
	Cd3	19.89	29.65	29.50	29.65	27.17	7.98	8.80	9.00	9.50	8.80
	Mean Zn	29.70	36.10	35.00	32.50		8.40	9.30	10.30	10.00	
	L.S.D 0.05	Cd = 6.50(S) Zn = 6.50(NS) Cd*Zn = 9.75(S)					Cd = 1.76(S) Zn = 1.88 (S) Cd*Zn = 2.82(S)				
		Dry weight (g)									
70	Control	0.475	0.438	0.376	0.366	0.414	0.526	0.500	0.466	0.480	0.493
	Cd1	0.267	0.337	0.354	0.278	0.309	0.364	0.408	0.455	0.404	0.408
	Cd2	0.235	0.258	0.274	0.288	0.264	0.350	0.423	0.406	0.327	0.376
	Cd3	0.212	0.213	0.204	0.240	0.217	0.292	0.311	0.358	0.352	0.328
	Mean Zn	0.297	0.311	0.302	0.293		0.383	0.410	0.421	0.390	
	L.S.D 0.05	Cd=0.122(S) Zn=0.122(NS)Cd*Zn= 0.183(S)					Cd=0.099(S) Zn=0.099(NS)Cd*Zn = 0.148(S)				
140	Control	4.58	4.31	4.27	3.38	4.44	1.41	1.36	1.34	1.12	1.31
	Cd1	2.75	3.58	3.49	3.15	3.24	0.90	1.21	1.16	1.17	1.11
	Cd2	2.47	3.29	3.39	3.43	3.14	0.80	1.36	1.04	1.21	1.10
	Cd3	2.00	2.98	3.00	3.09	2.77	0.85	1.02	1.12	1.01	1.00
	Mean Zn	2.95	3.54	3.53	3.26		0.99	1.24	1.17	1.13	
	L.S.D 0.05	Cd = 0.950(S) Zn=0.950(NS) Cd*Zn =1.42(S)					Cd = 0.21(S) Zn= 0.21(S) Cd*Zn = 0.31(S)				

Zn1 = 75 µg g^{-1}, Zn2 = 150 µg g^{-1} , Zn3 = 225 µg g^{-1}; Cd1 = 10 µg g^{-1} , Cd2 = 20 µg g^{-1},Cd3 = 40 µg g^{-1}
Least significance difference (L.S.D.) values at 0.05 level of probability; (S) means significantly different at 0.05 level of probability, (NS) means not significantly different

The results in Table 3 indicated that no constant trend could be detected on N% in both shoot and root. However significant decreases were detected by the shoot and root of carrot plant supplied with Cd soil addition, with some exceptions. Increasing of Cd soil addition decreased nitrate uptake, nitrate concentration, nitrate reductase activity as well as nitrate translocation to the shoot plants (Korshunoval *et al*., 1999**;** Hernadez *et al*., 1997). Furthermore, from the previous results it could be suggested that the several detrimental effects attributed to Cd addition to soil on all of the studied growth characters and yield of carrot plants might be directly or indirectly affected due to decreases in nitrogen concentration which may negatively affect net photosynthesis, chlorophyll and protein synthesis as well as essential nutrients contents. Moreover, it is clear that significant increases of N% were detected in the shoot and root of carrot plant supplied with any of the three rates of Zn soil addition alone when compared with control. These findings are in agreement with Abd El Reheem *et al*., (1992)**;** Hegazy *et al*., (1993) on faba bean plants. In addition, El Baz (2003) found that foliar sprays of both zinc and boron alone or in combination increased the concentration of N, K, Mn, Zn and B in Balady Mandarin leaves of spring flush relative to the control. On the other hand, the results indicated that significant decreases in N% were obtained in carrot shoot supplied with the lowest (75 µg g^{-1}) and the intermediate (150 µg g^{-1}) rates of Zn soil addition either alone or combined with Cd in the second sample compared with the control.

Regarding the effect of Cd and Zn soil addition on P% of carrot plants the results in Table 3 indicated that in the two successive samples no constant trend could be detected in P% of both shoot and root. Significant decreases in P concentration were detected in carrot shoot supplied at lowest (10 µg g^{-1}) and at the middle (20 µg g^{-1}) rates of Cd soil addition alone or when the middle rate of Cd combined with the lowest rate of Zn in the first sample and the highest level of Zn in the second sample. On the other hand, significant increases in P% were detected in carrot roots and shoots of the plants supplied at the middle and the highest (40 µg g^{-1}) rate of Cd soil addition either alone or combined with Zn in the second sample, relative to the control untreated plant or control untreated-Cd plant. Moreover, the results in Table 3 revealed that significant increases in P% were recorded in carrot shoot supplied with the all rates of Zn soil addition in combination with Cd in the two samples. Significant increases in P% were recorded in the root supplied with the lowest (75 µg g^{-1}) and with the middle (150 µg g^{-1}) rate of Zn soil addition in combination with Cd in the second sample. No significant effect could be observed on P% by carrot roots supplied with the three different rates of Zn either alone or in combination with Cd in the first sample, compared with control untreated plants or plants treated with Cd alone. These findings are in agreement with Lagriffoul *et al*., (1998) who mentioned that maize content of P was insignificantly modified by Cd treatment. In addition, they suggested that, increasing of Cd concentrations, P contents increased only in leaves.

Data in Table 3 indicated that, no constant trend could be detected on K% in the roots and shoots of the plants supplied with the different rates of Cd or Zn as soil addition either alone or in combination. In this respect, significant increases in K% were detected in the first sample in the root of the plants supplied with three different rates of Cd soil addition either alone or in combination with Zn and in the shoot of the plants supplied with the three different rates of Cd alone in the second sample with some exceptions compared with control. On the other hand, the results indicated that decreases in K% were detected by carrot shoots supplied with the three different rates of Cd soil addition either alone or in combination with Zn in the first sample with some exceptions, relative to the control Cd-untreated plant. Similar findings have been reported by Rudio *et al*., (1994) who mentioned that rice cv. *Baha* plant accumulated large quantities of Cd and Ni when growing for 10 days in nutrient solution containing these heavy metals also induced a decrease in K, Ca and Mg content in the plants; particularly that Cd and Ni interfered not only with nutrient uptake but also with nutrient distribution to the different plant part. Significant increases in K% were recorded in the root and shoot of carrot plant, supplies with the three rates of Zn either alone or combined with Cd soil addition, except in the second sample of the root which was decreased in K% concentration with the three rates of Zn alone as compared with control.

Table 3. Dry weight (g) and N, P and K concentration (%) of carrot root and shoot in the two samples (70 and 140 days after sowing) as affected by different rates of Cd and Zn soil additions, in the second season.

Plant age (days)	Treatment	Root					Shoot				
		Control	Zn1	Zn2	Zn3	Mean Cd	Control	Zn1	Zn2	Zn3	Mean Cd
		Dry weight (g)									
70	Control	0.475	0.455	0.393	0.366	0.422	0.594	0.567	0.517	0.548	0.557
	Cd1	0.253	0.337	0.342	0.269	0.300	0.420	0.530	0.537	0.431	0.480
	Cd2	0.222	0.228	0.253	0.275	0.245	0.442	0.462	0.476	0.353	0.433
	Cd3	0.210	0.228	0.191	0.228	0.214	0.374	0.360	0.436	0.415	0.396
	Mean Zn	0.290	0.312	0.295	0.285		0.458	0.480	0.491	0.437	
	L.S.D 0.05	Cd=0.123 (S) Zn=0.123 (NS) Cd* Zn=0.175(S)					Cd=0.142(S) Zn=0.142 (NS) Cd* Zn=0.202(S)				
140	Control	4.10	3.88	3.70	2.87	3.64	1.80	1.81	1.70	1.40	1.68
	Cd1	2.67	3.13	3.07	2.67	2.89	1.02	1.63	1.50	1.37	1.38
	Cd2	2.30	2.67	2.87	2.83	2.67	0.87	1.85	1.27	1.53	1.38
	Cd3	1.73	2.53	2.33	2.67	2.32	1.13	1.27	1.43	1.27	1.28
	Mean Zn	2.70	3.05	2.99	2.76		1.20	1.64	1.48	1.39	
	L.S.D 0.05	Cd=0.88(S) Zn=0.88 (NS) Cd* Zn= 1.25 (S)					Cd=0.266 (S) Zn= 0.266(S) Cd* Zn=0.378 (S)				
		Nitrogen concentration %									
70	Control	2.02	2.07	2.12	2.15	2.09	1.94	2.24	2.34	2.16	2.17
	Cd1	1.83	1.84	1.89	1.79	1.83	2.22	2.34	2.43	2.26	2.31
	Cd2	1.79	1.88	1.94	1.86	1.86	2.31	2.11	2.22	2.14	2.19
	Cd3	2.10	2.20	1.62	2.09	2.00	2.25	2.14	2.21	2.15	2.18
	Mean Zn	1.93	1.99	1.89	1.97		2.18	2.20	2.30	2.18	
	L.S.D 0.05	Cd=0.12 (S) Zn=0.12 (NS) Cd* Zn=0.17 (S)					Cd=0.14 (S) Zn=0.14(NS) Cd* Zn=0.19 (S)				
140	Control	2.08	2.18	2.11	2.17	2.13	2.63	2.54	2.74	3.56	2.87
	Cd1	2.21	2.18	2.17	2.27	2.20	3.05	2.64	2.48	3.30	2.86
	Cd2	2.19	4.19	2.16	2.13	2.66	2.85	2.55	3.00	2.54	2.73
	Cd3	2.05	1.93	2.23	2.18	2.09	2.74	2.48	2.33	2.86	2.60
	Mean Zn	2.13	2.62	2.16	2.18		2.81	2.55	2.64	3.06	
	L.S.D 0.05	Cd=0.14 (S) Zn=0.14 (S) Cd* Zn=0.20 (S)					Cd=0.10 (S) Zn=0.10 (S) Cd* Zn=0.15 (S)				
		Phosphorus concentration %									
70	Control	0.175	0.205	0.185	0.200	0.191	0.245	0.220	0.245	0.320	0.258
	Cd1	0.180	0.160	0.185	0.245	0.193	0.205	0.270	0.260	0.280	0.254
	Cd2	0.165	0.215	0.185	0.205	0.193	0.220	0.165	0.270	0.275	0.233
	Cd3	0.225	0.175	0.170	0.180	0.188	0.250	0.320	0.230	0.230	0.258
	Mean Zn	0.186	0.189	0.181	0.208		0.230	0.244	0.251	0.276	
	L.S.D 0.05	Cd=0.031(NS) Zn=0.031(NS) Cd* Zn=0.058(S)					Cd= 0.016(S) Zn=0.016(S) Cd* Zn=0.022 (S)				
140	Control	0.260	0.285	0.220	0.265	0.258	0.285	0.255	0.340	0.335	0.304
	Cd1	0.240	0.235	0.270	0.230	0.244	0.225	0.265	0.340	0.355	0.296
	Cd2	0.270	0.430	0.295	0.230	0.306	0.335	0.370	0.320	0.250	0.319
	Cd3	0.270	0.250	0.305	0.265	0.273	0.350	0.345	0.315	0.365	0.344
	Mean Zn	0.260	0.300	0.273	0.248		0.299	0.309	0.329	0.326	
	L.S.D 0.05	Cd=0.058 (NS) Zn=0.058 (S) Cd* Zn=0.082 (S)					Cd=0.024 (S) Zn=0.024 (S) Cd* Zn=0.034 (S)				
		Potassium concentration %									
70	Control	2.52	2.85	2.93	3.05	2.83	2.61	2.64	2.62	2.650	2.63
	Cd1	2.78	2.84	2.75	2.76	2.78	2.44	2.53	2.53	2.62	2.53
	Cd2	2.80	2.76	2.92	2.88	2.84	2.48	2.51	2.53	2.74	2.56
	Cd3	2.82	2.96	2.89	3.01	2.92	2.63	2.73	2.74	2.55	2.66
	Mean Zn	2.73	2.85	2.87	2.92		2.54	2.60	2.60	2.64	
	L.S.D 0.05	Cd=4.6 (S) Zn=4.6 (S) Cd* Zn=6.5 (S)					Cd=0.091 (S) Zn=0.091(S) Cd* Zn =0.130 (S)				
140	Control	3.47	3.44	3.22	3.25	3.34	2.84	2.91	2.86	2.91	2.88
	Cd1	3.32	3.34	3.31	3.47	3.36	2.78	3.05	3.30	3.03	3.04
	Cd2	3.33	3.28	3.35	3.32	3.32	2.95	3.16	2.84	2.94	2.97
	Cd3	3.35	3.12	5.25	3.37	3.77	2.90	2.96	2.91	2.87	2.91
	Mean Zn	3.36	3.29	3.78	3.35		2.86	3.02	2.98	2.93	
	L.S.D 0.05	Cd=7.5 (S) Zn=7.5 (S) Cd* Zn=10.7 (S)					Cd=6.0 (S) Zn=6.0 (S) Cd* Zn=8.6 (S)				

Zn1 = 75 µg g^{-1}, Zn2 = 150 µg g^{-1}, Zn3 = 225 µg g^{-1}; Cd1 = 10 µg g^{-1} , Cd2 = 20 µg g^{-1}, Cd3 = 40 µg g^{-1}

Least significance difference (L.S.D.) values at 0.05 level of probability; (S) means significantly different at 0.05 level of probability, (NS) means not significantly different.

Table 4. Leaf weight ratio (LWR) and relative growth rate (RGR mg $g^{-1}d^{-1}$) as the average of two successive seasons and specific utilization rate (SUR mg dw. mg Cd^{-1} or Zn^{-1} d^{1}) and rate of production (mg Zn or Fe g Cd^{-1} d^{-1} & mg Cd or Fe g $Zn^{-1}d^{-1}$) in the second season of carrot plant as affected by different rates of Cd and Zn soil additions.

Treatment	Cadmium effect					Zinc effect				
	Control	Zn1	Zn2	Zn3	Mean Cd	Control	Zn1	Zn2	Zn3	Mean Cd
	LWR					RGR mg g^{-1} d^{-1}				
Control	0.394	0.388	0.395	0.411	0.397	25.6	26..0	27.1	23.9	25.7
Cd1	0.412	0.400	0.406	0.431	0.412	25.1	27.0	25.0	26.3	25.8
Cd2	0.422	0.457	0.416	0.396	0.423	24.7	27.0	26.7	28.8	26.9
Cd3	0.439	0.424	0.455	0.421	0.435	24.9	29.0	28.5	27.6	27.5
Mean Zn	0.417	0.420	0.418	0.415		25.1	27.0	26.8	26.7	
	(SUR) mg mg^{-1} Cd^{-1}d^{-1}					(SUR) mg m g^{-1} Zn^{-1} d^{-1}				
Control	19.24	11.53	15.78	13.25	14.95	0.385	0.251	0.219	0.178	0.258
Cd1	4.06	3.88	3.79	4.13	3.96	0.439	0.233	0.207	0.215	0.273
Cd2	3.25	3.78	3.69	3.95	3.67	0.447	0.266	0.224	0.236	0.293
Cd3	3.06	3.55	3.51	3.51	3.41	0.514	0.271	0.239	0.240	0.316
Mean Zn	7.41	5.68	6.69	6.21		0.446	0.255	0.222	0.217	
	mg Zn g^{-1} Cd d^{-1}					mg Cd g^{-1} Zn d^{-1}				
Control	1742.4	1671.4	2590.8	2237.5	2060.5	0.463	0.464	0.407	0.356	0.423
Cd1	329.2	572.3	584.9	642.1	532.1	3.508	1.862	1.696	1.740	2.202
Cd2	254.6	588.0	590.5	614.8	512.0	3.863	2.285	1.969	2.031	2.537
Cd3	210.3	505.1	505.9	507.8	432.3	4.443	2.444	1.993	2.119	2.750
Mean Zn	634.1	834.2	1068.0	1000.6		3.069	1.764	1.516	1.562	
	mg Fe g^{-1} Cd d^{-1}					mg Fe g^{-1} Zn d^{-1}				
Control	2895.1	1703.8	2118.7	1765.8	2120.8	57.92	37.13	29.44	23.68	37.04
Cd1	470.4	547.0	570.0	609.8	549.3	50.83	32.90	31.18	31.74	36.66
Cd2	330.1	513.9	440.5	465.1	437.4	45.37	36.21	26.75	27.78	34.03
Cd3	366.4	497.3	509.7	517.4	472.7	61.46	37.98	34.69	35.37	42.37
Mean Zn	1015.5	815.5	909.7	839.5		53.90	36.06	30.51	29.64	

Zn1 = 75 µg g^{-1}, Zn2 = 150 µg g^{-1} , Zn3 = 225 µg g^{-1}; Cd1 = 10 µg g^{-1} , Cd2 = 20 µg g^{-1},Cd3 = 40 µg g^{-1}

Data in Table 4 revealed that, gradual increases in the mean values of the leaf weight ratio LWR were found in the plants treated with the three doses of Cd soil addition either alone or combined with Zn soil addition as the average of the two seasons when compared with control Cd-untreated plant. Thus, in this respect, it can be suggested that, the depressing effect of Cd supplies either alone or combined with Zn was more severe on root growth relative to its effect on the shoot growth. A similar finding is reported by Nagoor & Vyas (1997) on wheat. El Enany & Abd Alla (1995) and Mahmood *et al*., (2009) mentioned that the roots of faba bean and wheat respectively accumulated Cd at higher levels than shoots, indicating that the roots acted as barrier restricting Cd transport. A similar finding is reported by Liu *et al*., (2006) who found that the Cd levels in roots and shoots of cultivars of maize (*Zea mays* L.) increased significantly with increasing Cd concentration. In addition, Cd were concentrated mainly in the roots, and small amounts of Cd were transferred to the shoots. Similarly, Cd treatments affected the seed germination, root, shoot length and seedlings dry biomass of *Albizia lebbeck* L. (Farooqi *et al*., 2009). Moreover, the results in Table 4 revealed that the Zn soil addition either alone or combined with Cd tended to increase the leaf weight ratio in all levels except, at the lowest level of Zn, and when the highest level of Zn addition combined with the middle and the highest level of Cd soil addition. Regarding the relative growth rate between the two successive samples as the average of the two seasons, it is clear that, gradual decreases in RGR value were recorded with increasing Cd soil addition alone. However, a reverse trend was detected when Cd soil addition combined with any of the three doses of Zn soil addition or the mean values of these treatments. These results supported the assumption that Zn application can overcome, to some extent, the toxic effect of Cd in plants. Zn and Cd have many physical and chemical similarities as they belong to group II of the periodic table. They are usually found together in the ores and compete with each other for various ligands. Moreover, the biochemical mechanisms of Cd-Zn interaction are unknown, but various cellular and sub-cellular processes like the ratio of Cd to Zn in tissues, induction of synthesis of different types of metallothionein, binding characteristics of metallothionein, alteration of absorption and tissue distribution of one metal by another, and competition at the level of Zn containing metalloenzymes are known to be involved in the interactions (Das *et al*., 1997).

The relative growth rates were increased with increasing Zn soil addition either alone or combined with any of the three levels of Cd except in the plants treated with the highest level of Zn soil addition alone which had the lowest value (Table 4). This might be attributed to a high metabolic activity of the plant by Zn due to an increase in photosynthesis or a decrease in respiration rate that increase rate of dry matter production in the two parts of the plant. On the other hand, the highest value of (RGR mg $g^{-1}d^{-1}$) was recorded in the plants treated with the lowest level of Zn combined with the highest rate of Cd when compared with the plants not supplied with either Zn or Cd soil addition. In this respect, it may be suggested that the inhibiting effects of the high levels of Zn soil addition or all levels of Cd soil addition alone on plant growth and dry matter accumulation can be overcome to some extent by adding these two metals to plants. It may be concluded that the effect of these two ions in combination was different when Cd concentration in soil 40 µg g^{-1} and Zn 75 µg g^{-1} in contrast with the individual effects of every metal alone. These findings are in agreement, with the threshold dose of toxic metals (Cd and Zn) when applied in combination was generally lower than that of metals given singly (Smilde *et al*., 1982).

Generally it is important to mention that in carrot plants, the decreases in shoot or root dry and fresh weights as a result of Cd soil addition were associated with pronounced decreases in shoot height and root length. This might be attributed to its effects on cell division and or cell expansion which may be through its effect on DNA and RNA synthesis. In addition, Abo Kassem *et al*., (1997) suggested that, the root and shoot dry weight and the relative growth rate on wheat were significantly reduced by 5 and 10 mM Cd and the application of Cd resulted in reduction of photosynthesis and transpiration.

The gradual decreases in the specific utilization rate were found in the plants treated with the three doses of Cd soil addition either alone or combined with any of the three dose of Zn soil addition when compared with control-Cd untreated plants**.** In this respect, it can be assumed that Cd supply might affect photosynthetic activity or respiration rate or both, leading to a decrease in dry matter production per unit Cd concentration in the plant. The uptake and physiological effects of Cd on spinach were related to mineral accumulation and associated with continuous reduction of spinach organ growth, in terms of leaf number, whole plant leaf area, and fresh and dry weights of roots and shoots (El Nabarawy, 2002)**.** Regarding the rate of production of mg (Zn & Fe) g $Cd^{-1}d^{-1}$, the data indicated that the plants treated with the three different rates of Cd alone or combined with Zn soil addition were gradual, and pronounced decreased when compared with control Cd-untreated plant. It can be assumed that the increasing of Cd supply might have affected absorption and translocation of elements on plant. Gradual decreases in the specific utilization rate was observed for the plants treated with the three doses of Zn soil addition either alone or combined with any of the three doses of Cd soil addition, relative to the control (Table 4**).** In this respect, it might be suggested that the favorable effect of Zn soil application either alone or combined with Cd soil addition on plant growth as well as the detrimental effect of high Zn soil addition might be attributed to its effect on enzymatic systems responsible for the biosynthesis of amino acid, protein, chlorophyll and photosynthesis. Zn is an essential component of a number of enzymes such as dehydrogenases, proteinases, phosphohydrolases and peptidases (Singh, 1981). On the other hand, high value of specific utilization rate were observed in the plants treated with any of the three levels of Cd. Moreover, low values were found in the plants treated with any of the three levels of Cd combined with the highest level of Zn (Table 4). Such decreases might be attributed to the inhibiting effect of high doses of elements on the metabolic activity of the growth.

The rate of production of mg (Cd & Fe) g Zn^{-1} d^{1} was decreased by the plants treated with any of the three rate of Zn either alone or combined with Cd soil addition relative to the control Cd-untreated plant. In this respect, it can be assumed that increasing Zn supply might decrease accumulations of elements in plants thought combination between Zn and the other elements uptake or translocation of plant (Table 4). The availability of Cd as mentioned earlier has been found to be affected by the presence of other cations and anions in soils, particularly Zn and Cu which decreased the availability of Cd in soils. The application of Zn on soils decreases the concentration of Cd and subsequently decrease the content and uptake of Cd by the plants which also suggest antagonistic relationship between them (Das, 2000).

In conclusion, the mean values of fresh and dry weights of roots, shoots and whole plants were significantly decreased by using an increasing Cd soil addition either alone or combined with Zn. In contrast, the effects of three different levels of Zn on the fresh and dry weights were insignificant, except for fresh and dry weights of shoot in the second sample which were significantly increased. Cd appears to be more severely toxic to carrot plants compared with Zn (at tenfold concentrations). Generally, the harmful effects of Cd soil additions on carrot plants can be overcome to some extent by using Zn. Zinc application may reduce to some extent toxic effect of Cd on shoot growth than its effect on root growth. Increases in K, P and N concentrations were recorded by the carrot shoots and roots treated with all levels of Zn soil addition either alone or combined with Cd soil addition. The inhibiting effects of Cd soil addition on plant growth and dry matter accumulation can be overcome to some extent by adding Zn soil addition, thus it may be concluded that the effect of these two ions in combination was different from their individual effects.

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