RESULTS & DISCUSSION

4. RESULTS AND DISCUSSION

4.1. Incubation experiments:

4.1.1. Effect of zinc and phosphorus application on the amount of extractable Zn and P in soil:

The effect of Zn and P applications on their availability can be deduced from data presented in Table 3 and illustrated in Figs. 1 and 2.

4.1.1.1. Extractable Zn:

It is quite clear from data presented in Table 3 and Fig. 1 that AB-DTPA extractable Zn was significantly increased upon application of Zn. However, this increase was affected as phosphorus rate increased.

The increase in the extractability of Zn was progressive with increasing the rate of applied Zn. This trend occurred with all rates of P, since there was no significant interaction. Average values of Zn extracted by AB-DTPA were 0.50, 3.70, 7.07 and 11.53 $\mu g\ g^{-1}$ when Zn was applied at the rates of 0, 5, 10 and 20 $\mu g\ g^{-1}$, respectively. **Nasef (1996), Badr (1998) and Mahmoud (2001)** found that applying zinc (regardless of the Zn form, sulfate, chloride, acetate or EDTA) to non-calcareous sand and calcareous clay loam soils increased their content of AB-DTPA extractable Zn.

Concerning the effect of phosphorus on extractability of Zn, the obtained data show that application of P caused a decrease in AB-DTPA extractable Zn. Increased rate of P application was accompanied by a decrease in extractable Zn.

Table (3): Effect of zinc and phosphorus application (proceeded by 2 months incubation) on the extractable amounts of Zn and P.

P-rate (µg g^{-1} soil) [P]	Zn-rate (µg g^{-1} soil) [Zn]				
	0	5	10	20	Mean
	AB-DTPA extractable Zn (µg g^{-1} soil)				
0	0.59	4.35	7.70	12.03	6.17
10	0.55	3.94	7.31	11.77	5.89
20	0.48	3.63	6.96	11.57	5.66
30	0.38	2.88	6.30	10.73	5.07
Mean	0.50	3.70	7.07	11.53	
LSD (0.05):	[Zn] = 0.33		[P] = 0.33		[Zn P] = NS
	$NaHCO_3$ extractable P (µg g^{-1} soil)				
0	4.24	4.40	4.44	4.52	4.40
10	9.77	9.93	10.39	11.10	10.30
20	14.77	14.83	14.97	15.20	14.94
30	18.90	19.17	19.20	19.60	19.22
Mean	11.92	12.08	12.25	12.61	
LSD (0.05):	[Zn] = NS		[P] = 0.51		[Zn P] = NS

NS = not significant.

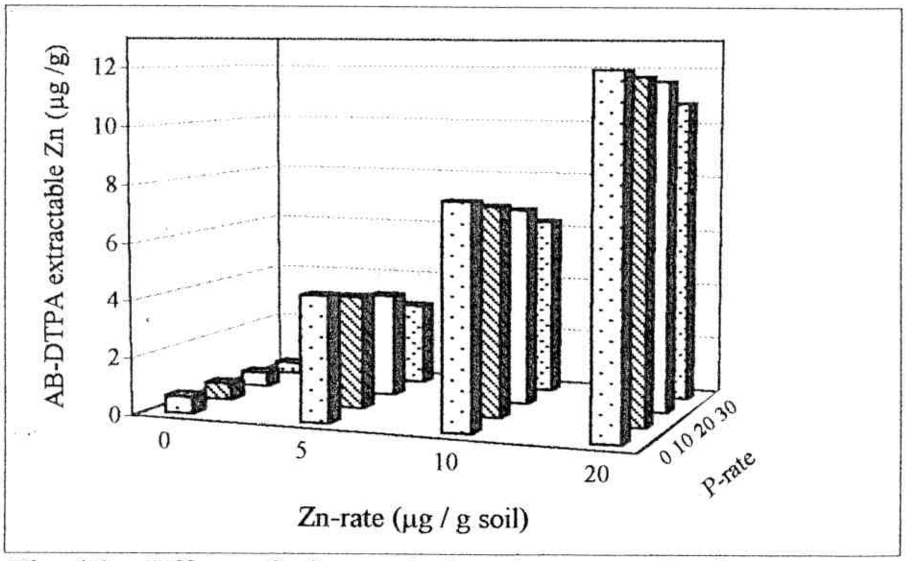


Fig. (1): Effect of zinc and phosphorus applications on AB-DTPA extractable Zn (µg / g soil).

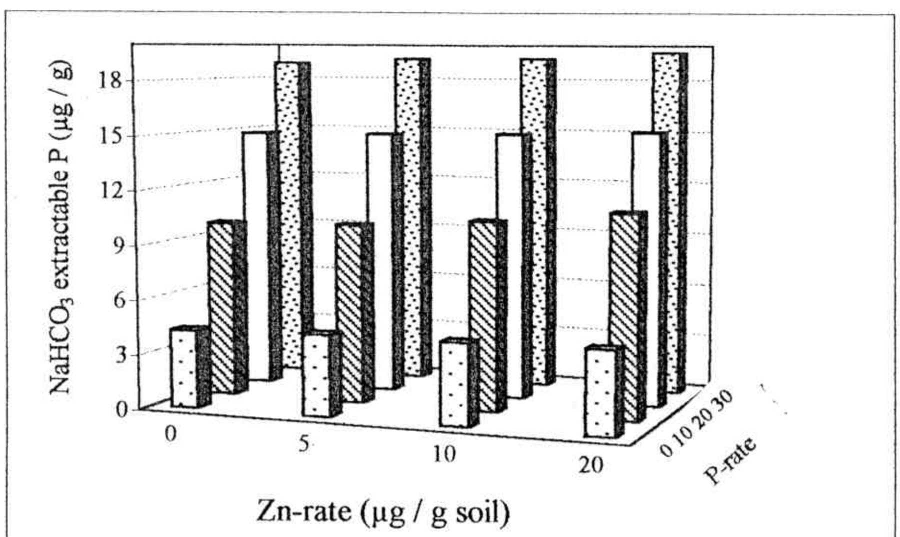


Fig. (2): Effect of zinc and phosphorus applications on $NaHCO_3$ extractable P (µg / g soil).

Application of 20 and 30 μg P g^{-1} soil led to a significant decrease in the amount of extractable Zn, but at 10 μg g^{-1} soil, the decrease was not significant as compared with no-P treatment. Mean values of Zn extracted by AB-DTPA decreased from being 6.17 μg g^{-1} in the no-P treatment to 5.89, 5.66 and 5.07 μg Zn g^{-1} for the rates of 10, 20 and 30 μg P g^{-1} treatments, respectively.

Norvell et al. (1987) and **Moraghan and Mascagni (1991)** reported that applied P tended to enhance the adsorption of Zn on soil colloids; this may lead to a low solubility of Zn in soil. **Sadik et al. (1996)** found that DTPA-extractable Zn was decreased by applying fertilizer P and this was more pronounced with time after P application and particularly in calcareous soils.

4.1.1.2. Extractable P:

With respect to the effect of added Zn on extractability of P, data presented in Table 3 and Fig. 2 reveal a slight and non-significant progressive increase in P extracted from soils. Therefore, application of Zn did not affect extractability of P. Such a pattern of response occurred whether P was concurrently applied with Zn, or not; i.e. there was no significant interaction in this respect.

Mean values of extractable P were increased from being 11.92 μg g^{-1} soil (no-Zn applied treatment), to 12.08, 12.25 and 12.61 μg P g^{-1} soil for treatments receiving 5, 10 and 20 μg Zn g^{-1} soil, respectively. Although application of Zn in the form of zinc sulphate may have caused a reduction in soil pH, such a probable reduction being very slight, particularly in the light of the rather low amount of applied Zn would not be sufficient to cause significant increase in solubility of P in the soil.

El-Sokkary et al. (1981) and **Subrahmanyam et al. (1991)** reported that application of Zn as zinc sulphate increased available P in a sandy loam soil. **Gregory and Charles (1995)** reported a slight increase in extractable P from soil fertilized with Zn fertilizer.

Application of P to the soil resulted in increased extraction of P, and such significant increase in extractable P progressed and was more obvious with increasing the rate of applied P. The mean value of extractable P from no-P application averaged 4.40 µg g^{-1}, whereas soil incubation with rates of 10, 20 and 30 µg P g^{-1} soil resulted in values averaged 10.30, 14.94 and 19.22 µg P g^{-1} soil, respectively.

4.1.2. Effect of zinc and iron application on the amount of extractable Zn and Fe:

The results presented in Table 4 and illustrated in Figs. 3 and 4 show the amounts of Zn and Fe (µg g^{-1}) extracted by AB-DTPA from the sand soil.

4.1.2.1. Extractable Zn:

Data in Table 4 and Fig. 3 indicate that application of Zn was associated with a significant increase in the amount of extracted Zn. The increases were progressive with increasing rate of applied Zn. At the rates of 5, 10 and 20 µg Zn g^{-1} soil, average amounts of AB-DTPA extractable Zn from the sand soil were 4.19, 7.56 and 13.02 µg Zn g^{-1} soil, respectively as

Table (4): Effect of zinc and iron application (proceeded by 2 months incubation) on the extractable amounts of Zn and Fe.

Fe-rate ($\mu g\ g^{-1}$ soil) [Fe]	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				
	0	5	10	20	Mean
	AB-DTPA extractable Zn ($\mu g\ g^{-1}$ soil)				
0	0.54	4.48	7.94	13.87	6.71
20	0.51	4.27	7.84	13.33	6.49
40	0.45	4.16	7.53	12.80	6.24
60	0.38	3.84	6.93	12.08	5.81
Mean	0.47	4.19	7.56	13.02	
LSD (0.05):	[Zn] = 0.29		[Fe] = 0.29		[Zn Fe] = 0.57
	AB-DTPA extractable Fe ($\mu g\ g^{-1}$ soil)				
0	3.62	3.33	2.62	2.24	2.95
20	9.72	7.97	6.91	6.67	7.82
40	14.98	11.75	10.59	8.55	11.47
60	22.04	17.30	13.59	12.41	16.34
Mean	12.59	10.09	8.43	7.47	
LSD (0.05):	[Zn] = 0.61		[Fe] = 0.61		[Zn Fe] = 1.22

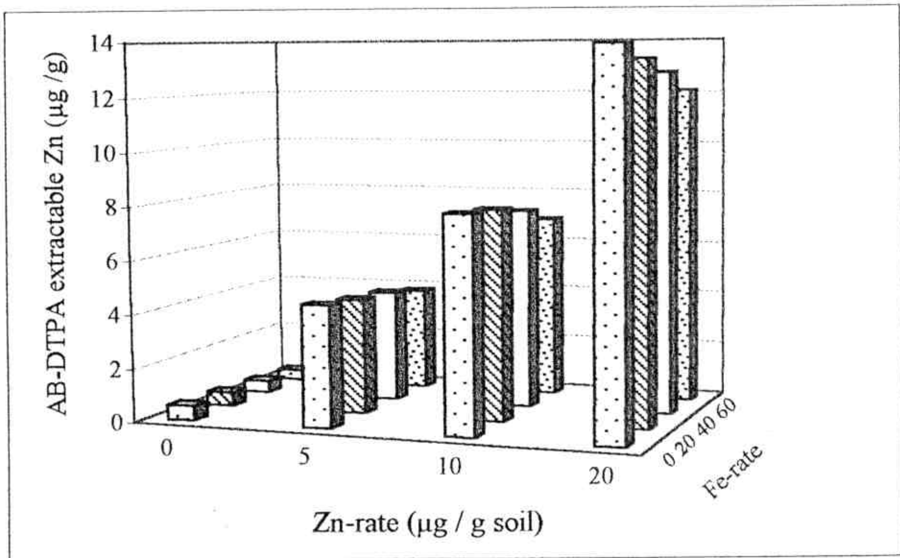


Fig. (3): Effect of zinc and iron applications on AB-DTPA extractable Zn (µg / g soil).

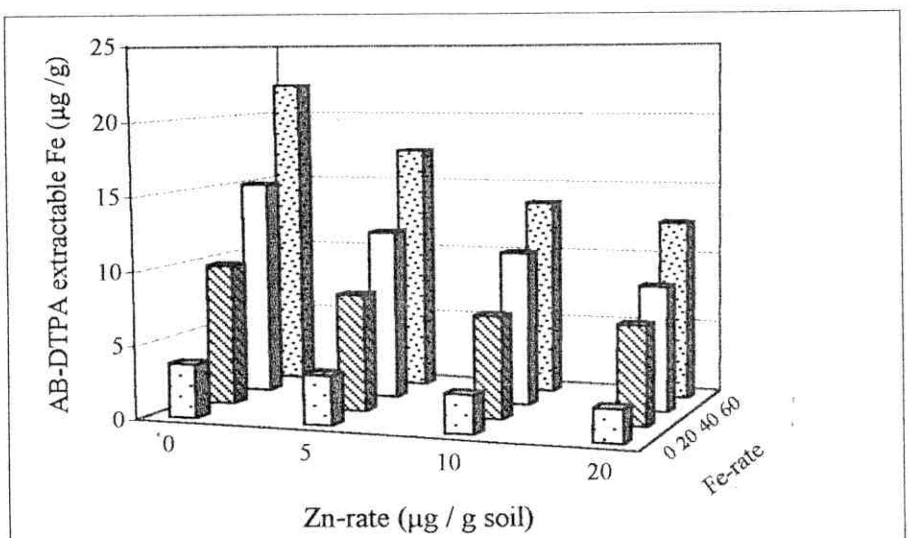


Fig. (4): Effect of zinc and iron applications on AB-DTPA extractable Fe (µg / g soil).

compared with 0.47 µg Zn g^{-1} given by the treatment which had not received Zn.

On the other hand, results reveal that AB-DTPA extractable Zn was significantly decreased upon application of Fe. The decrease progressed gradually with increasing rate of Fe application and it was more pronounced with the highest rate of Fe application. Mean value of Zn extracted from treatments not receiving Fe was 6.71 µg g^{-1} soil, decreased to 6.49, 6.24 and 5.81 µg g^{-1} in soil receiving Fe at rates of 20, 40 and 60 µg g^{-1} soil, respectively. Such a decrease in Zn indicates a decreased dissolution and extractability of Zn under the effect of increased Fe contents.

There was an interaction between Zn and Fe application with regard to Zn extractability. Under conditions of no-Zn application, there was little difference (or a slight non-significant decrease) in extracted Zn among soils receiving different rates of Fe. Under conditions of Zn application (particularly with high Zn rates), applying 60 µg Fe g^{-1} caused a considerable significant decrease in Zn extractability as compared with the rate of 40 µg g^{-1}; but no such significant decrease occurred where Zn was not added.

Dahdoh (1997) indicated that Fe and Zn ions may compete at adsorption sites of soil colloids due to their almost identical ionic radii; therefore some of the zinc ions may be displaced by iron ions and precipitate.

4.1.2.2. Extractable Fe:

Data presented in Table 4 and illustrated in Fig. 4 indicate that extractable Fe followed a trend of decrease in Fe extractability with increased application of Zn. AB-DTPA extractable Fe decreased significantly and gradually from being 12.59 µg g^{-1} soil with no-Zn applied to 10.09, 8.43 and 7.47 µg Fe g^{-1} at the Zn rates of 5, 10 and 20 µg Zn g^{-1} soil, respectively. The decrease in Fe extractability due to Zn occurred in the no-Fe treatments as well as the Fe treatments, but was most pronounced under conditions of high Fe application. **Mandal and Haldar (1980)** and **Badr (1998)** reported that application of Zn as zinc sulphate lowered the soil extractable Fe content in soils.

The. decrease in extractability of Fe due to application of Zn may reflect competition between Zn and Fe ions for chelating ligands (**Norvell, 1991).** It may also indicate a possible coating caused by the colloidal Zn sulphate on adsorbed ions of Fe and thus make it less extractable **(Subrahmanyam and Mehata, 1975)**.

Regarding the effect of Fe application on the extractable amounts of Fe, results indicate that Fe extracted by AB-DTPA was significantly and progressively increased with increasing rates of Fe application. Mean value of Fe extracted from the incubated soil with no-Fe application was 2.95 µg Fe g^{-1} soil, increased with Fe application to mean values of 7.82, 11.47 and 16.34 µg g^{-1} at rates of application of 20, 40 and 60 µg Fe g^{-1} soil, respectively.

4.1.2.3. Zn/Fe interrelationship in terms of Zn or Fe extractability:

Results show a clear antagonistic relationship between Zn and Fe. Application of Fe caused a decrease in Zn extractability, particularly when Zn was applied at 5 to 10 μg Zn g^{-1} along with Fe. However, when no Zn was concurrently applied with Fe, such effect occurred, but at a slight non-significant magnitude. A similar pattern occurred to extractable Fe under conditions of different amounts of Zn present in the soil; i.e. a decreased extractability of Fe with increased presence of Zn in soil.

These results are in agreement with those achieved by **Dahdoh (1997),** who reported that the extractable Zn increased due to application of Zn salts with no application of Fe; and that extractable Fe increased due to application of Fe salts with no application of Zn. However when both Zn and Fe salts were applied concurrently, increased presence of one nutrient caused a decreased extractability of the other. The same researcher attributed this to ionic competition between Zn and Fe ions at adsorption sites of soil colloids due to their almost identical ionic radii.

4.1.3. Effect of zinc and cadmium application on the amount of extractable Zn and Cd:

Mean values representing the effect of Zn and Cd applications to the sand soil on the amounts of extractable Zn and Cd are presented in Table 5 and illustrated in Figs. 5 and 6.

4.1.3.1. Extractable Zn:

Data presented in Table 5 and Fig. 5 show that there was an increase in the content of AB-DTPA extractable Zn due to application of Zn; extractable Zn was progressively increased with increasing the rate of applied Zn and this occurred with all Cd treatments. On the other hand, extractable Zn decreased with

Table (5): Effect of zinc and cadmium application (proceeded by 2 months incubation) on the extractable amounts of Zn and Cd.

Cd-rate ($\mu g\ g^{-1}$ soil) [Cd]	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				
	0	5	10	20	Mean
	AB-DTPA extractable Zn ($\mu g\ g^{-1}$ soil)				
0	0.53	4.42	8.12	14.70	6.94
1	0.51	4.32	7.99	14.43	6.81
2	0.49	4.24	7.65	14.03	6.60
4	0.44	3.88	7.65	13.63	6.40
Mean	0.49	4.22	7.85	14.20	
LSD (0.05):	[Zn] = 0.32		[Cd] = 0.32		[Zn Cd] = NS
	AB-DTPA extractable Cd ($\mu g\ g^{-1}$ soil)				
0	0.02	0.02	0.01	0.01	0.02
1	0.44	0.35	0.33	0.22	0.33
2	1.09	0.94	0.73	0.57	0.83
4	2.71	2.59	2.30	2.00	2.40
Mean	1.07	0.97	0.84	0.70	
LSD (0.05):	[Zn] = 0.10		[Cd] = 0.10		[Zn Cd] = 0.19

NS = not significant.

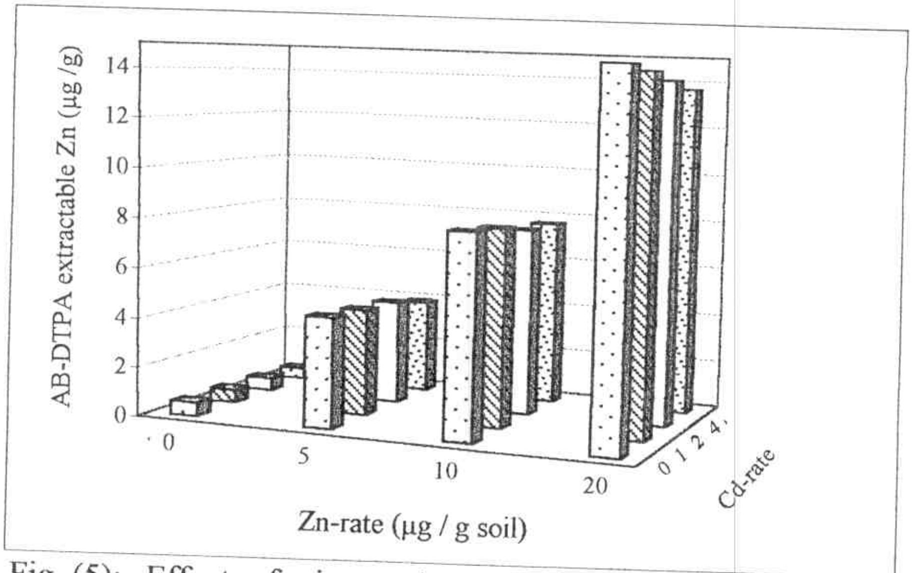


Fig. (5): Effect of zinc and cadmium applications on AB-DTPA extractable Zn (µg / g soil).

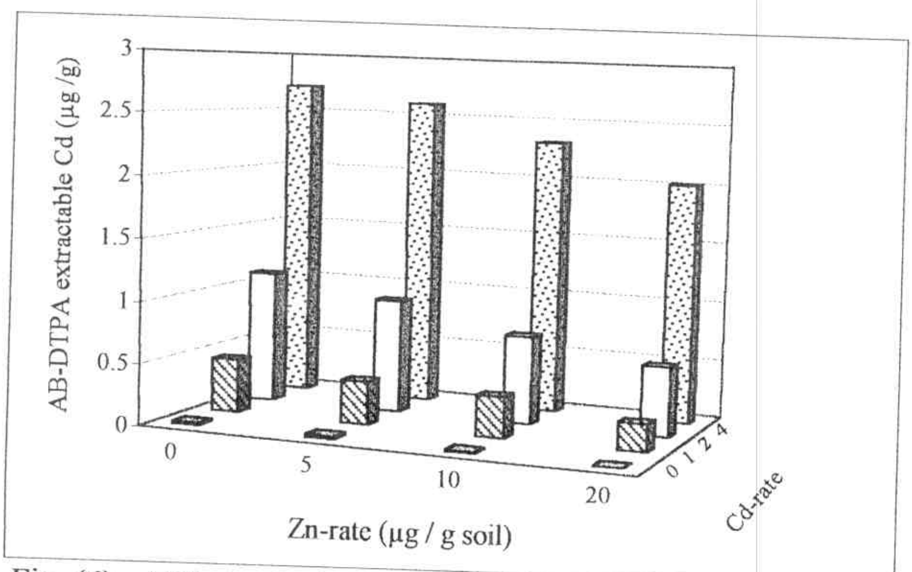


Fig. (6): Effect of zinc and cadmium applications on AB-DTPA extractable Cd (µg / g soil).

application of Cd, such a decrease was particularly pronounced with increased rates of Cd application whether or not Zn was applied. Mean value of Zn extracted from treatments which had not received Zn was 0.49 μg Zn g^{-1}, increased to 4.22, 7.85 and 14.20 μg g^{-1} due to Zn application at the rates of 5, 10 and 20 μg g^{-1} soil, respectively.

Concerning the effect of cadmium application on extractability of Zn, the results indicate that addition of Cd caused a decrease Zn extracted by AB-DTPA from the incubated soil. The decrease progressed with increasing the rate of applied Cd. It was particularly significant at rates exceeding 1 μg Cd g^{-1} soil. Mean value of Zn extracted from treatments which had not received Cd was 6.94 μg Zn g^{-1}, decreased to 6.81, 6.60 and 6.40 μg Zn g^{-1} at the rates of 1, 2 and 4 μg Cd g^{-1} soil, respectively.

Ramachandran and D' Souza (1997) reported that, in Cd treated soils, the amounts of available Zn were decreased.

4.1.3.2. Extractable Cd:

With respect to the effect of added Zn on extractability of Cd, data (Table 5 and Fig. 6) reveal that extractability of Cd by AB-DTPA was significantly decreased as a result of Zn application. The decrease progressed gradually with increasing Zn rate. The decrease was more pronounced under conditions of the highest rate of Zn application (20 μg Zn g^{-1} soil). The mean value of extractable Cd in soil of no-Zn application averaged 1.07 μg g^{-1}, whereas under conditions of applying 5, 10 and 20 μg Zn g^{-1} soil, mean values for extractable Cd in soil averaged 0.97, 0.84 and 0.70 μg Cd g^{-1} soil, respectively. However, decreased Cd extractability with increased Zn presence occurred only in treatments given Cd. In the treatment of no-Cd addition, increased presence of Zn showed no effect on Cd extractability. In fact, soils receiving no Cd were all of extremely low contents of Cd not exceeding 0.02 μg g^{-1}. In the treatment receiving the highest Cd rate (4 μg Cd g^{-1}), increased application of Zn caused a marked decrease in Cd; applying 20 μg Zn g^{-1} decreased Cd extractability by 26 %.

Application of Cd was associated with a significant increase in the amount of Cd extracted by AB-DTPA. The increase was progressive with increasing Cd rate of application. Mean values of extractable Cd were increased from being 0.02 μg g^{-1} soil (no-Cd applied) to 0.33, 0.83 and 2.40 μg g^{-1} for treatments receiving 1, 2 and 4 μg Cd g^{-1} soil, respectively.

Abdel-Sabour et al. (1988) and **Das and Kumar (1996)** found that the amount of extractable Cd in soil increased due to application of Cd but decreased by concurrent addition of Zn along with Cd.

4.1.3.3. Zn/Cd interrelationship in terms of Zn or Cd extractability:

Results show antagonistic relationships between Zn and Cd indicating a possible competition between these cations for adsorption sites of soil colloids (**Rajendra et al., 1996**).

4.1.4. Effect of zinc levels and $CaCO_3$ application (at different diameters) on the amount of extractable Zn:

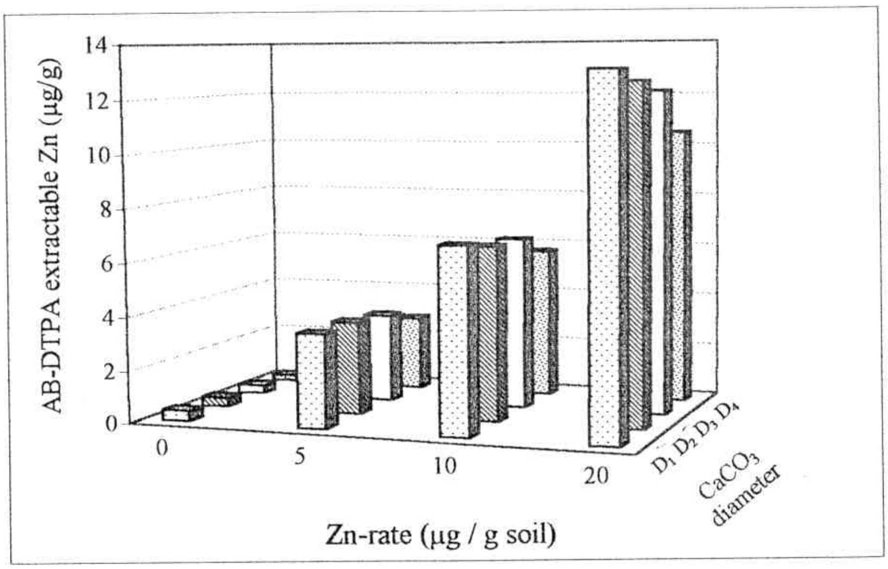
In this experiment, $CaCO_3$ was applied in the form of limestone particles of sizes ranging from < 0.25 to 2.00 mm.

Data presented in Table 6 and illustrated in Fig. 7 show that addition of zinc irrespective of presence or absence of the applied limestone, generally, raised the content of AB-DTPA extractable Zn. Zinc extractability increased progressively and significantly with increasing the rate of Zn applied solely or in combination with limestone. Mean values of extractable Zn in the soils not receiving $CaCO_3$ were 6.71 μg Zn g^{-1} as compared with 5.54 μg g^{-1} in soils receiving $CaCO_3$. This shows that applying $CaCO_3$ decreased Zn extractability by 18 %. The reduction in extractable Zn indicates a tight retention or fixation of soluble ions of Zn caused by particles of $CaCO_3$. Decreased extractability of Zn caused by $CaCO_3$ application was slight and not significant in absence of applied Zn. In presence of applied Zn such a decrease was pronounced and significant. **Norvell et al. (1987)** found that concentrations of soluble Zn^{2+} in unfertilized calcareous soils were extremely low (less than 0.70 μg g^{-1}) and were raised 7 to 14 folds by applying Zn at 5 μg g^{-1}.

Where no limestone was applied, the amount of Zn extracted from soil which had not received Zn was 0.54 μg g^{-1} as compared with 4.48, 7.94 and 13.87 μg g^{-1} extracted from soils given the rates of 5, 10 and 20 μg Zn g^{-1}, respectively. Where limestone was applied, the mean value of Zn extracted from the soils which had not received Zn was 0.32 μg Zn g^{-1}, whereas the means of extractable Zn in soils which had received Zn were 3.31, 6.43 and 12.09 μg Zn g^{-1} for treatments receiving 5, 10 and 20 μg Zn g^{-1}, respectively. Thus, although $CaCO_3$ decreased extractable Zn, addition of soluble Zn to soils was associated

Table (6): AB-DTPA extractable zinc from the incubated soil as affected by 10 % of $CaCO_3$ application (as limestone) in different diameters.

Diameter of added $CaCO_3$ [D]	AB-DTPA extractable Zn ($\mu g\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
D_1 (1.25-2.00 mm)	0.39	3.53	6.91	13.07	5.98
D_2 (0.60-1.25 mm)	0.35	3.51	6.56	12.60	5.76
D_3 (0.25-0.60 mm)	0.31	3.35	6.51	12.17	5.59
D_4 (< 0.25 mm)	0.23	2.83	5.72	10.53	4.83
Mean	0.32	3.31	6.43	12.09	5.54
LSD (0.05): [Zn] = 0.34	[D] = 0.34		[Zn D] = 0.69		
without $CaCO_3$ addition	0.54	4.48	7.94	13.87	6.71



Note: D_1 (1.25 - 2.00 mm); D_2 (0.60 - 1.25 mm); D_3 (0.25 - 0.60 mm) and D_4 (< 0.25 mm).

Fig. (7): AB-DTPA extractable Zn as affected by application of $CaCO_3$ as particles of different diameters.

with increased extractability of Zn from soil, in presence as well as in absence of $CaCO_3$.

These results stand in agreement with those obtained by **Badr (1998)** who, found that application of Zn in the form of Zn EDTA or $ZnSO_4$ resulted in an increase in the DTPA extractable Zn, although the increments of Zn due to increasing rate of the applied zinc were noticed to be reduced upon applying $CaCO_3$.

The amounts extracted were noticeably lower than the amounts applied. From about 30 to 60 % of the amounts applied were extracted by the AB-DTPA extractant. This indicates fixation or precipitation of applied soluble Zn. Such low recoveries occurred in all treatments of $CaCO_3$ addition. **Yasrebi et al. (1994)** reported a low apparent recovery of Zn fertilizers in calcareous soils and attributed this to a possible conversion of soluble Zn to insoluble Zn in a carbonate form.

Regarding the effect of $CaCO_3$ diameter on AB-DTPA extractable Zn, data reveal that the amounts of extractable Zn generally decreased with the increased fineness of $CaCO_3$ particles. Mean value of extracted Zn from soil having the coarsest particles of $CaCO_3$ i.e. diameter of 1.25-2.00 mm (D_1) was 5.98 $\mu g\ g^{-1}$. Comparable values of AB-DTPA extractable Zn for decreasing diameters of applied $CaCO_3$ particles were as follows: for 0.60-1.25 mm (D_2), 0.25-0.60 mm (D_3) and < 0.25 mm (D_4) values were 5.76, 5.59 and 4.83 $\mu g\ g^{-1}$, respectively.

There was a significant interaction between zinc addition and $CaCO_3$ particle diameter. Decreased extractability of Zn due to decreased size of $CaCO_3$ particles occurred significantly only under conditions of added Zn, especially at the highest rate. Therefore, tight retention of Zn caused by increased fineness of $CaCO_3$ was most prominent where Zn was present in the soil at rather medium to high concentrations particularly by the finest $CaCO_3$ particles.

The obvious decrease in AB-DTPA extractable Zn with increased $CaCO_3$ fineness manifests the effect of action of increased specific surface area of lime particles and consequently the ability to retain Zn tightly in higher amounts. The smallest size of $CaCO_3$ (D_4) with its apparently highest surface area would thus be the most effective in decreasing Zn extractability.

The obtained results agree with those reported by **Abd-Allah (1973)** and **Abdel-Latif et al. (1984)**, who concluded that the major factor affecting zinc availability in highly calcareous soils was the portion of $CaCO_3$ content in the fine size of $< 2\ \mu$ Ø. **Moore and Loeppert (1990)** stated that solid-phase carbonates have adsorptive surface that influences the retention and movement of Zn in soil.

4.1.5. Effect of applying $CaCO_3$ and clay contents on AB-DTPA extractable Zn:

The results presented in Table 7 and illustrated in Figs. 8 and 9 show that extractability of Zn by AB-DTPA was significantly increased as a result of application of Zn. The increases were progressive with increasing Zn rates. Data also show that this trend was true in presence as well as in absence of

Table (7): Effect of $CaCO_3$ and clay* applications on AB-DTPA Zn-extracted from soil treated with different rates of zinc.

Applied $CaCO_3$ % [L]	Applied clay* % [C]	AB-DTPA extractable Zn ($\mu g\ g^{-1}$)				
		Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
		0	5	10	20	
0	0	0.44	4.63	7.97	14.37	6.85
	5	0.45	4.45	7.67	13.83	6.60
	10	0.46	4.30	7.37	13.00	6.28
	20	0.50	4.04	7.05	12.53	6.03
	Mean	0.46	4.36	7.51	13.43	6.44
5	0	0.38	4.40	7.50	12.90	6.29
	5	0.37	4.24	7.43	12.03	6.02
	10	0.38	4.04	7.14	11.20	5.69
	20	0.40	3.92	6.95	9.91	5.29
	Mean	0.38	4.15	7.26	11.51	5.82
10	0	0.28	4.04	7.18	11.90	5.85
	5	0.26	3.85	7.01	11.40	5.63
	10	0.27	3.71	6.76	10.19	5.23
	20	0.27	3.45	6.59	8.89	4.80
	Mean	0.27	3.76	6.89	10.59	5.38
20	0	0.16	3.71	6.39	10.50	5.19
	5	0.16	3.57	6.15	8.80	4.67
	10	0.17	3.31	5.51	7.61	4.15
	20	0.20	3.24	5.14	6.00	3.64
	Mean	0.17	3.46	5.80	8.23	4.41
		Means of clay and Zn treatments				
	0	0.32	4.19	7.26	12.42	6.05
	5	0.31	4.03	7.07	11.52	5.73
	10	0.32	3.84	6.70	10.50	5.34
	20	0.34	3.66	6.43	9.33	4.94
G. mean		0.32	3.93	6.86	10.94	

LSD (0.05): [Zn] = 0.12 [L] = 0.12 [C] = 0.12
[Zn L] = NS [Zn C] = NS [L C] = 0.23
[Zn LC] = 0.47

* Applied in a form of a clay soil (22.5 % silt; 56.7 % clay).

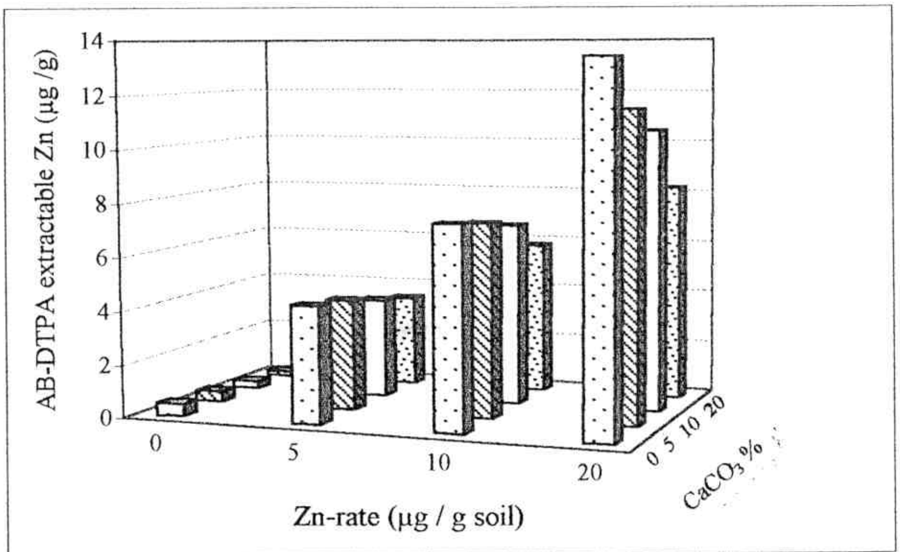


Fig. (8): Effect of zinc and $CaCO_3$ applications on AB-DTPA extractable Zn (µg / g soil).

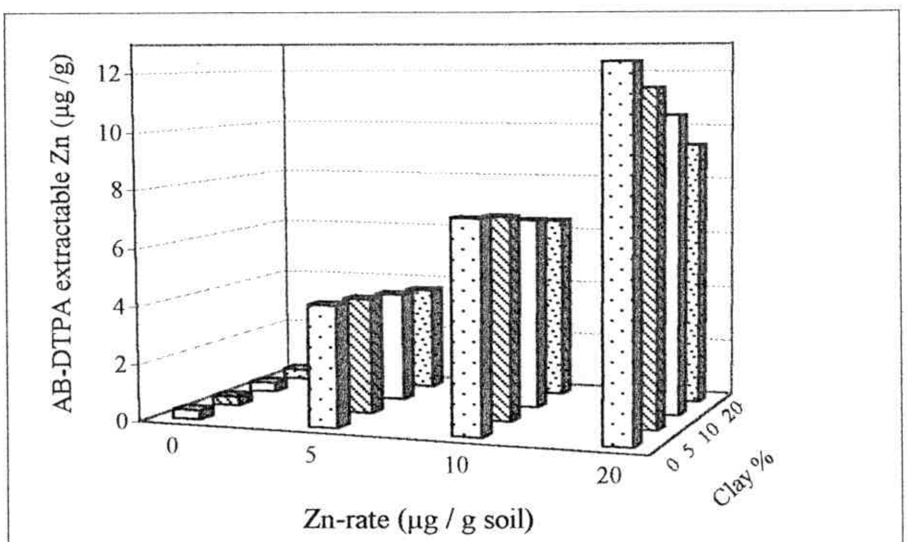


Fig. (9): Effect of zinc and clay applications on AB-DTPA extractable Zn (µg / g soil).

either $CaCO_3$, clay or both. Mean values of AB-DTPA extractable Zn were increased from being 0.32 µg g^{-1} (no-Zn treatment) to 3.93, 6.86 and 10.94 µg g^{-1} for treatments receiving 5, 10 and 20 µg Zn g^{-1} soil, respectively (means of all treatments).

Concerning the applied $CaCO_3$ (as limestone), data indicate that the main effect of $CaCO_3$ addition show a decrease in Zn extracted by AB-DTPA. However, there was an interaction caused by Zn addition. Decreased extractability of Zn caused by $CaCO_3$ addition occurred only in treatments supplied with added Zn. In treatments not receiving Zn, the effect was not significant. Therefore, involvement of added Zn sulphate with added $CaCO_3$ must have been prominent causing a decrease in Zn availability. The mean values of the AB-DTPA extractable Zn were decreased from being 6.44 µg Zn g^{-1} soil for treatment which had not received limestone to 5.82, 5.38 and 4.41 µg g^{-1} for treatments of limestone application rates of 5, 10 and 20 %, respectively. Such magnitudes of decreased extractability of Zn represent 9.6, 16.5 and 31.5 %, respectively.

Norvell et al. (1987), Moore and Loeppert (1990) and **Ibrahim et al. (1994)** reported that application of $CaCO_3$ to soils was associated with a decrease in the amounts of Zn extracted by AB-DTPA, particularly with increased application of $CaCO_3$ rates. **Yaşrebi et al. (1994)** attributed the decreased Zn extractability to strong adsorption of Zn ions on the surface of $CaCO_3$ particles as well as to a possible formation of insoluble Zn complexes.

Addition of clay (to such sand soil of the current study) resulted in a trend rather similar to that of the applied limestone; there was a decrease in Zn extractability due to application of clay and this decrease progressed with increasing the rate of applied clay. However, such a trend did not occur under conditions of no added Zn, where addition of clay had no significant effect on Zn extractability. Therefore, colloidal clay particles must have adsorbed soluble Zn ions particularly when abundant so strongly reducing their release. Decreased Zn extractability caused by increased clay addition was most prominent under conditions of high addition of Zn. Under low rate of added Zn, such a decrease occurred only with high addition of clay. The means values of extracted Zn from treatments supplied with 0, 5, 10 and 20 % clay were 6.05, 5.73, 5.34 and 4.94 μg Zn g^{-1} soil, respectively. This represents decreases of 5.3 %, 11.7 % and 18.3 % due to addition of clay at 5, 10 and 20 %, respectively.

Garate et al. (1982) reported that clay soils had higher sorption capacities for Zn than the sandy soils. **Li and Shuman (1996)** reported that the amount of desorbed Zn was low in some clayey vertisol soils than in coarse textured soils and attributed this to strong adsorption of Zn by the clay soils because of their greater reactive surface area.

There was a three-factor interaction relating Zn, clay and $CaCO_3$. The only situation where each successive addition of clay caused a successive decrease in Zn-extractability was when the rate of both added Zn and $CaCO_3$ were highest and concurrently applied. Also, this is true concerning effects of added $CaCO_3$; its effect was more obvious with highest Zn rate and highest clay rate. The decreased Zn extractability caused by increased clay addition was most prominent under conditions of 20 % $CaCO_3$ + 20 µg Zn g^{-1}. Under such a condition of highest Zn addition (i.e. 20 µg Zn g^{-1}) combined with highest $CaCO_3$ addition (i.e. 20 % $CaCO_3$); each increment of added clay caused a significant decrease in Zn extractability. Similar patterns occurred under conditions of 5 % and 10 % $CaCO_3$ (also combined with a presence of 20 µg Zn g^{-1}). Each successive addition of $CaCO_3$ caused a significant decreases in extractable Zn especially where Zn was added at its highest rate and combined with addition of clay at its highest rate.

Under other conditions, it needed high rates of added clay and $CaCO_3$ to cause a significant decrease in extractable Zn. Thus, extracted Zn decreased considerably when both $CaCO_3$ and clay were in high contents, particularly where soluble Zn was added at high rates. **Nasef (1996)** reported that soils which contained high amount of clay and $CaCO_3$ showed high capacities to adsorb zinc.

4.1.6. Effect of applying zinc, clay mineral type and content on AB-DTPA extractable zinc:

Concerning the effect of added Zn, data presented in Table 8 and Figs. 10 and 11 reveal that AB-DTPA extractable Zn significantly increased due to application of zinc and the increase progressed with the rate of applied Zn. This trend occurred in presence of either clay mineral (montmorillonite or kaolinite) since the interaction between clay mineral type and applied Zn

Table (8): Effect of some clay minerals applied in different rates on the AB-DTPA extractable Zn from the studied soil.

Clay mineral % [M]	Rate of mineral % [R]	Zn-rate (μg g^{-1} soil) [Zn]				Mean
		0	5	10	20	
Montmorillonite	5	0.40	4.35	7.58	13.71	6.51
	10	0.33	4.08	7.08	12.63	6.03
	20	0.22	3.72	6.67	11.23	5.46
	Mean	0.32	4.05	7.11	12.52	6.00
Kaolinite	5	0.44	4.47	7.87	13.90	6.67
	10	0.40	4.27	7.65	13.20	6.38
	20	0.34	3.94	7.15	12.51	5.99
	Mean	0.39	4.23	7.56	13.20	6.35
		Means of the two clay minerals				
	5	0.42	4.41	7.72	13.81	6.59
	10	0.37	4.17	7.37	12.92	6.21
	20	0.28	3.83	6.91	11.87	5.72
G. mean		0.35	4.14	7.33	12.86	

<u>LSD (0.05):</u> [Zn] = 0.28 [M] = 0.20 [R] = 0.24
[Zn R] = 0.48 [Zn M] = NS [M R] = NS
[Zn M R] = NS

No addition of clay mineral	-	0.54	4.48	7.94	13.87	6.71

NS = not significant.

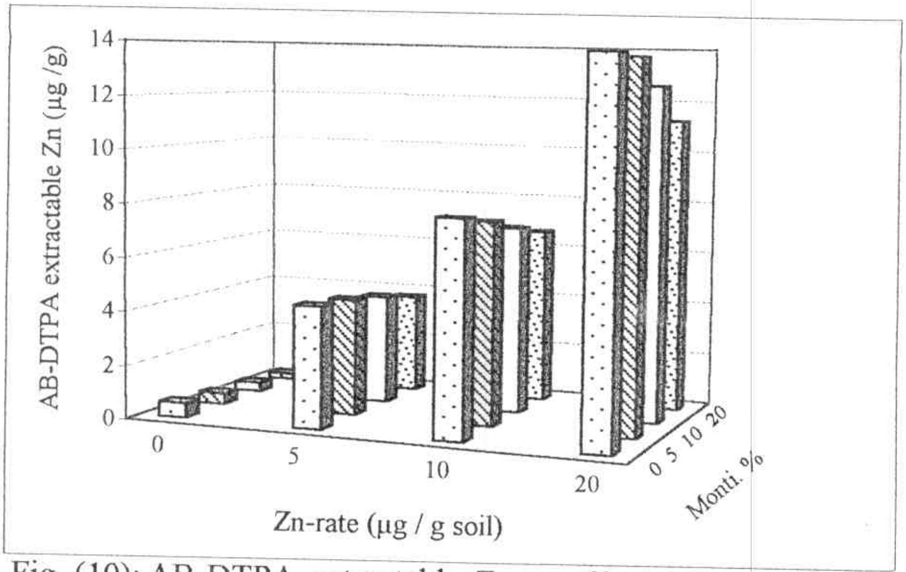


Fig. (10): AB-DTPA extractable Zn as affected by application of montimorilonite mineral.

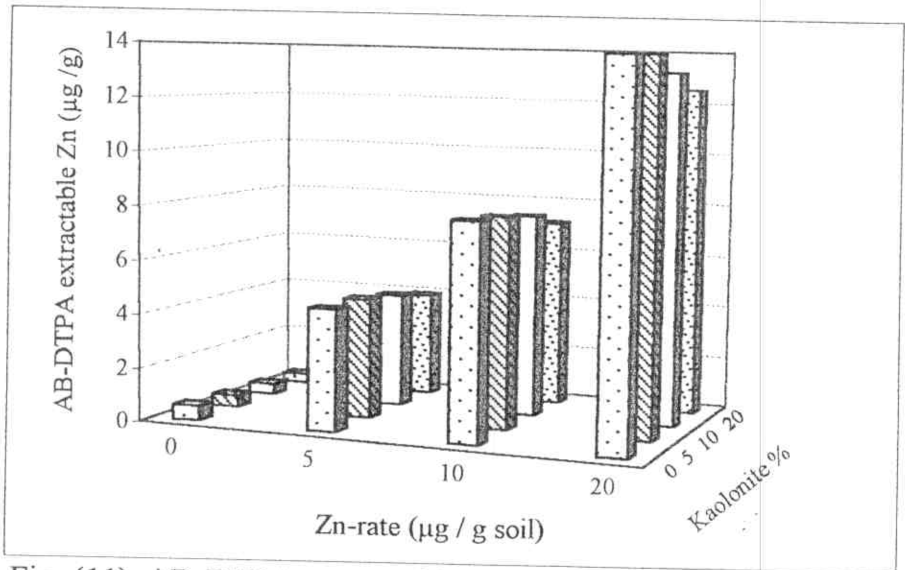


Fig. (11): AB-DTPA extractable Zn as affected by application of kaolinite mineral.

was not significant. Mean values for AB-DTPA extractable Zn for treatments receiving 0, 5, 10 and 20 µg Zn g^{-1} were 0.35, 4.14, 7.33 and 12.86 µg Zn g^{-1} soil, respectively.

Application of either clay mineral (of montmorillonite or kaolinite) resulted in a significant decrease in the amount of extractable Zn. The decrease was progressive with increasing the rate of clay mineral application only under conditions of added Zn; since such a progressive decrease was not significant where no Zn was added. This trend was prominent at the highest Zn rate. Under conditions of such highest rate of Zn (i.e. 20 µg Zn g^{-1}) increasing the rate of clay mineral addition from 5 % to 10 % was accompanied by a significant decrease in Zn extractability and a comparable significant decrease occurred when the rate was increased from 10 to 20 %. However, under conditions of Zn addition at rates of 5 or 10 µg g^{-1} the decreased Zn extractability was slight and non-significant. Therefore, for a progressive decrease of Zn extractability caused by increased presence of clay mineral, there should be high contents of Zn in the soil. The average value of extractable Zn from treatments given no-clay mineral was 6.71 µg g^{-1}; for treatments given clay minerals, mean values were 6.59, 6.21 and 5.72 µg Zn g^{-1} soil in soils receiving 5, 10 and 20 % clay minerals, respectively (means of the two clay minerals). Such a decrease is a clear indication of the effect of the increase in colloidal particles, which have a considerable role in Zn retention (**Shuman, 1988**). There were less amounts of Zn extracted from the montmorillonite treatments than from the kaolinite ones, thus confirming the effect of the type of colloid on Zn retention.

The amounts of extractable Zn as affected by montmorillonite mineral application at rates of 5, 10 and 20 % represented 97.0, 89.9 and 81.4 %, respectively, of the amount extracted from treatments given no-clay mineral. The corresponding percentages for kaolinite mineral treatments were 99.4, 95.1 and 89.3 %, respectively.

The above-mentioned results indicate that applying clay mineral (montmorillonite or kaolinite) was associated with a decrease in soil content of AB-DTPA extractable Zn. Montmorillonite mineral showed greater capacity to retain Zn than kaolinite. Zinc ion can enter some layers of lattice silicate structure (such as montmorillonite) and becomes immobile **(Kabata-Pendias and Pendias, 1992)**. **Nasef (1996)** found that clay minerals have abilities to adsorb Zn in this order: montmorillonite > attapolgite > kaolinite.

The current findings are in agreement with those obtained by **Pardo (2000)**, who found that a montmorillonitic silt loam soil of high cation exchange capacity, sorbed more Zn than a kaolinitic clay soil of low cation exchange capacity.

4.2. The greenhouse experiments:

4.2.1. Effect of applying zinc and phosphorus on plant growth, Zn and P in wheat plant:

4.2.1.1. Dry matter yield:

Data presented in Table 9 and Fig. 12 show the effect of applying Zn and P on dry matter yield of wheat.

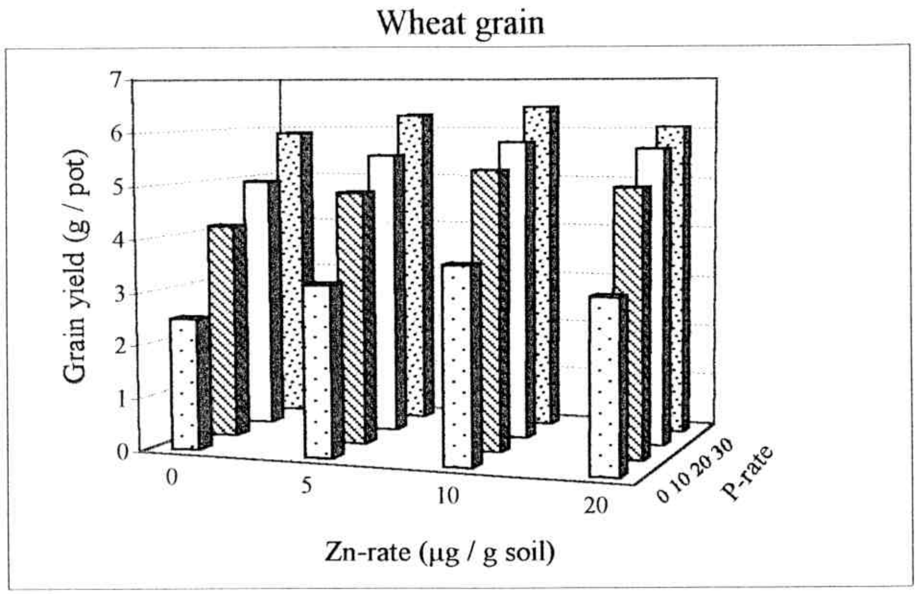
Applying Zn led to a significant increase in grain and straw yields; and the increase was progressive with increasing rates of applied Zn up to 10 µg g^{-1} soil after which a decrease occurred at 20 µg Zn g^{-1} soil as compared with 10 µg Zn g^{-1} soil. Mean values of the percentage increase of the dry weight of grains (over the treatments not given Zn) were 13.6, 21.6 and 14.3 % due to application of Zn at the rates of 5, 10 and 20 µg g^{-1} soil, respectively. With straw, the corresponding percentage increases were 9.1, 16.1 and 12.5 % for the above-mentioned rates of Zn, respectively. The results clearly show that the positive response to Zn application concerning percentage increase in dry weight production was more pronounced on grains than on straw and that the rate 10 µg Zn g^{-1} soil proved the most appropriate rate in production of grains and straw yields. These results are similar to those achieved by **Halder and Mandal (1981),** who found that application of Zn at the rates up to 10 µg Zn g^{-1} soil increased grain and straw yields of rice and that the rate of 10 µg g^{-1} soil gave the highest yield.

Regarding the effect of phosphorus application, results show that the yields of grains and straw were significantly increased with application of P. The increase was progressive

Table (9): Effect of zinc and phosphorus treatments on the dry matter yield of wheat plants.

P-rate ($\mu g\ g^{-1}$ soil) [P]	Dry matter yield (g/pot)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	2.47	3.21	3.66	3.18	3.13
10	4.12	4.83	5.30	5.01	4.81
20	4.93	5.48	5.77	5.66	5.46
30	5.87	6.25	6.43	6.04	6.15
Mean	4.35	4.94	5.29	4.97	
LSD (0.05):	[Zn] = 0.36		[P] = 0.36		[Zn P] = NS
	Straw				
0	4.75	5.52	6.25	5.84	5.59
10	6.65	7.49	8.38	8.28	7.70
20	8.55	9.22	9.55	9.24	9.14
30	9.91	10.37	10.48	10.23	10.25
Mean	7.47	8.15	8.67	8.40	
LSD (0.05):	[Zn] = 0.43		[P] = 0.43		[Zn P] = NS

NS = not significant.



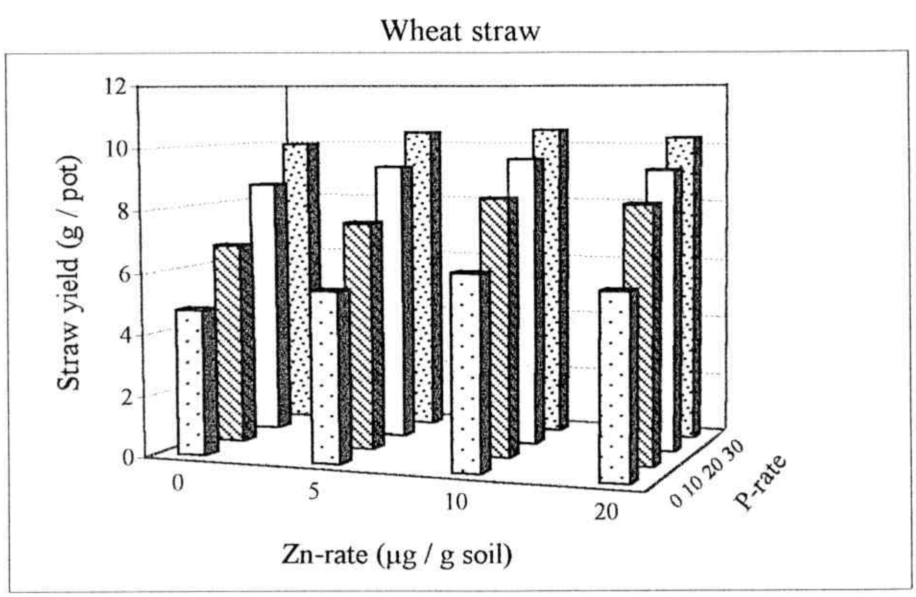


Fig. (12): Effect of zinc and phosphorus applications on the dry matter yield of wheat plants (g/pot).

with increasing the rates of applied P up to the highest rate of 30 μg P g^{-1} soil. Application of P at the rates of 10, 20 and 30 μg P g^{-1} soil resulted in percentage increases in yield of grains over that obtained with no-P application; the increases were equivalent to 53.7, 74.4 and 96.5 % for each of the above-mentioned P-rates, respectively. In case of straw, the corresponding values were 37.7, 63.5 and 83.4 %, respectively. Statistical analysis of data shows that there were no significant interactions between Zn and P on grains or straw production indicating that the pattern of response to Zn rates was not affected by P rates and *vice versa*.

Generally, it is obvious from the aforementioned data that yields of wheat grains and straw were more affected by P application than by Zn since the magnitude of response to P was between about 38 % to 97 % compared with 9 % to 22 % due to Zn application. This reflects the vital importance of P as a macronutrient in plant nutrition for plants grown on sandy soils.

These results agree with those of **Reddy and Yadav (1994)**, who found that grain and straw yields of wheat plants grown on a calcareous soil were increased with increasing levels of P and Zn. **Sharma and Bapat (2000)** reported that yields of grains and straw of wheat increased by 12.9 and 11.4 %, respectively upon application of 10 kg Zn/ha, and 48.0 % and 42.6 %, respectively upon application of 35 kg P/ ha.

4.2.1.2. Zinc in plant:

Data presented in Tables 10 and 11 and illustrated graphically in Figs. 13 and 14 show Zn concentration and Zn uptake by wheat grains and straw as affected by zinc and phosphorus applications.

I. Zinc concentration: (Table 10 and Fig. 13)

Applying Zn to the soil significantly increased Zn concentration in both grains and straw of wheat plants. The increase progressed with increasing the rate of applied Zn.

The mean value of Zn concentration in grains of wheat plants receiving no-Zn was 16.0 $\mu g\ g^{-1}$, increasing significantly to 21.0, 30.6 and 45.8 μg Zn g^{-1} when the rates of 5, 10 and 20 μg Zn g^{-1} soil, respectively were applied. The corresponding concentrations for straw were 11.2 μg Zn g^{-1} for the no-Zn treatment, increasing to 17.6, 23.8 and 36.1 $\mu g\ g^{-1}$ for the three respective applied rates of Zn. These results are in good agreement with those obtained by **Sharma and Bapat (2000)** and **Mahmoud (2001),** who found a positive significant relation between rate of the applied Zn and its concentration in both grains and straw of wheat plants grown on a sand soil as well as plants grown on a calcareous soil.

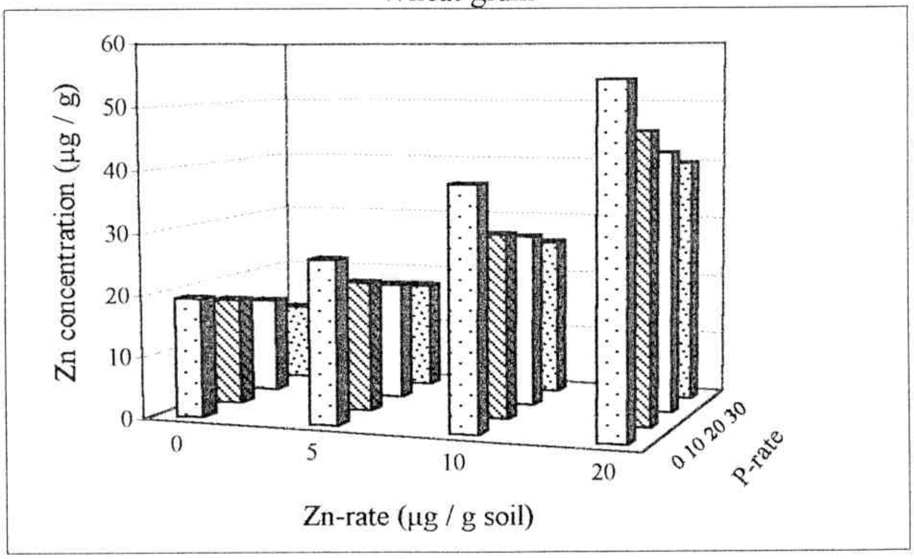
Applying P was associated with decreased Zn concentration in both components of wheat plants; and the decrease progressed gradually with increasing rates of P application. The relative decrease of Zn concentration in grains and straw was more pronounced upon applying the lowest rate of P (i.e. 10 μg P g^{-1} soil). Mean value of Zn concentration in grains decreased from 34.6 $\mu g\ g^{-1}$ in the no-P treatment to 28.6, 26.2 and 23.9 $\mu g\ g^{-1}$ for the rates of 10, 20 and 30 μg P g^{-1} soil, respectively. In case of straw, the corresponding values were

Table (10): Effect of zinc and phosphorus treatments on Zn concentration in wheat plants.

P-rate ($\mu g\ g^{-1}$) [P]	Zn concentration ($\mu g\ g^{-1}$) Zn-rate ($\mu g\ g^{-1}$ soil) [Zn] 0	5	10	20	Mean
	Grains				
0	19.1	26.3	38.6	54.5	34.6
10	17.2	21.1	29.7	46.4	28.6
20	15.4	19.1	28.1	42.4	26.2
30	12.5	17.4	25.8	39.9	23.9
Mean	16.0	21.0	30.6	45.8	
LSD (0.05):	[Zn] = 1.7		[P] = 1.7	[Zn P] = 3.3	
	Straw				
0	12.2	22.1	28.1	40.0	25.6
10	11.6	17.4	24.1	37.7	22.7
20	11.2	16.5	22.0	34.0	20.9
30	9.7	14.3	21.1	32.7	19.5
Mean	11.2	17.6	23.8	36.1	
LSD (0.05):	[Zn] = 2.3		[P] = 2.3	[Zn P] = NS	

NS = not significant.

Wheat grain



Wheat straw

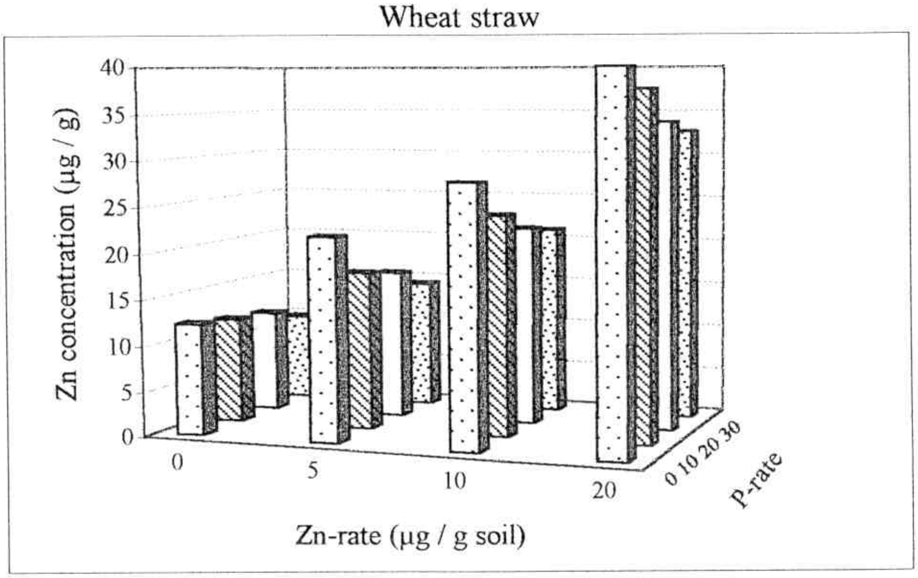


Fig. (13): Effect of zinc and phosphorus applications on Zn concentration in wheat plants (µg / pot).

25.6 μg Zn g^{-1} for the no-P treatment and 22.7, 20.9 and 19.5 μg Zn g^{-1} for the three applied P rates, respectively.

Statistical analysis shows a significant interaction between Zn and P on Zn concentration concerning grains but not concerning straw. Under conditions of a very high presence of Zn (i.e. 20 μg Zn g^{-1}), the addition of 10 μg P g^{-1} and the increase from 10 to 20 μg P g^{-1} were associated with a progressive decrease in Zn concentration in grains. However, under conditions of no-addition of Zn or addition of up to 10 μg Zn g^{-1}, the decreased Zn concentration due to applying 20 μg P in comparison with 10 μg P was not significant. Besides, applying 10 μg P caused a slight but not significant decrease in Zn concentration where no-Zn was applied.

The pattern of response concerning Zn concentration in wheat plants as affected by P application was contrary to the pattern of response concerning the weight of wheat plants as affected by P application. Increased application of P caused a progressive increase in wheat growth, but a progressive decrease in Zn concentration in plants. This is a clear case of a "dilution effect"; the positive response of increased growth of plant parts was so considerable that it led to a decrease in Zn concentration (and probably other nutrients).

These results agree with those reported by **Reddy and Yadav (1994),** who found that increasing P rates increased grains and straw yields of wheat accompanied by decreased Zn concentration in those plant parts.

Yang et al. (1999) suggested a mechanism of phosphorus-zinc antagonistic interaction in maize and wheat causing a decrease in physiological availability and activation of Zn as a result of P application.

Sharma and Bapat (2000) reported a decrease in concentration of zinc in various parts of the wheat plant with increasing levels of P application.

II. Zinc uptake: (Table 11 and Fig. 14)

Uptake of Zn by both grains and straw of wheat plants increased significantly with application of Zn, the increase progressed with increasing the rate of applied Zn. The response with regard to straw occurred in presence as well as in absence of phosphorus i.e. there was no significant interaction between P application and Zn application indicating that the pattern of response to Zn remained the same whether in absence of applied P or in presence of any of the applied rates of P. In the case of grains, there was a significant interaction. However, such interaction was reflected in the response to P addition rather than the response to Zn addition.

Mean values of Zn uptake by grains increased from 67 μg pot^{-1} with no-Zn applied to 100, 156 and 221 μg Zn pot^{-1} for the rates of 5, 10 and 20 μg Zn g^{-1} soil, respectively. The corresponding values of Zn uptake in straw were 81 μg pot^{-1} for the no-Zn treatment and 138, 202 and 297 μg pot^{-1} for the 5, 10 and 20 μg Zn g^{-1} treatments, respectively.

With regard to the effect of P application on Zn uptake by grains and straw, the data indicate that the main effect of application of P resulted in a significant increase in Zn uptake, and increasing the rate of applied P was not associated with a progressive increase in Zn uptake except where Zn was present

Table (11): Effect of zinc and phosphorus treatments on Zn uptake by wheat plants.

P-rate ($\mu g\ g^{-1}$) [P]	Zn uptake ($\mu g\ pot^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	47	84	142	173	112
10	70	101	157	233	140
20	76	104	162	240	146
30	73	109	165	241	147
Mean	67	100	156	221	
<u>LSD (0.05):</u>	[Zn] = 7		[P] = 7	[Zn P] = 15	
	Straw				
0	58	121	175	234	147
10	76	129	201	311	180
20	95	151	210	313	192
30	96	149	221	332	199
Mean	81	138	202	297	
<u>LSD (0.05):</u>	[Zn] = 14		[P] = 14	[Zn P] = NS	

NS = not significant.

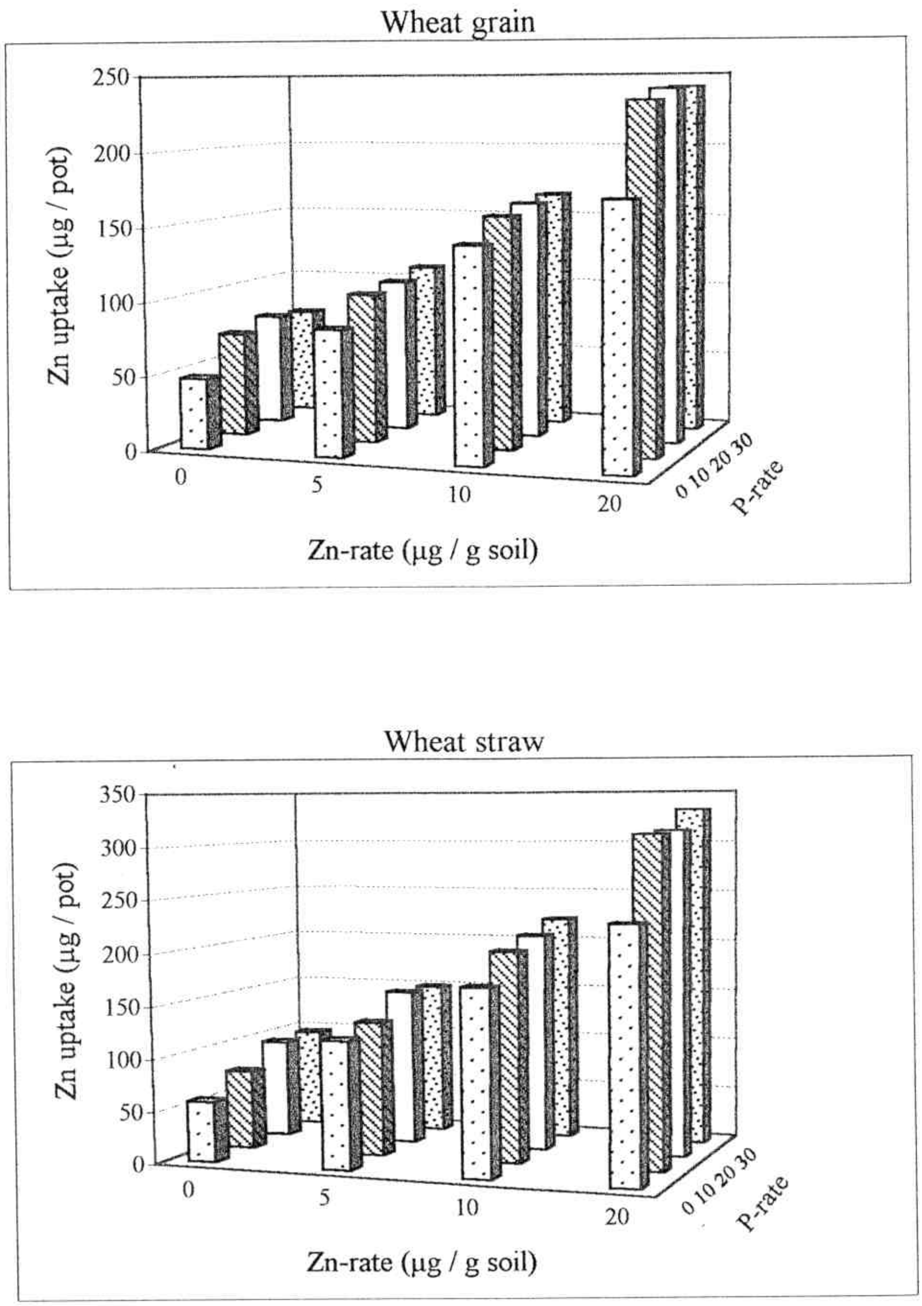


Fig. (14): Effect of zinc and phosphorus applications on Zn uptake by wheat plants (µg / pot).

in the highest dose. Regarding Zn uptake in straw, P application resulted in increased Zn uptake with no significant differences between the rates 10 to 30 μg P g^{-1} soil.

Mean values of Zn uptake by grains as affected by P rates were: 112, 140, 146 and 147 μg pot^{-1} for the rates of 0, 10, 20 and 30 μg P g^{-1} soil, respectively. The corresponding values for Zn uptake in straw were 147, 180, 192 and 199 μg pot^{-1} for the same P treatments, respectively.

The obtained results are in accordance with those reported by **Sadik et al. (1996)** who, applied up to 150 μg P g^{-1} and **Eskandar (1997),** who applied up to 60 μg P g^{-1} and found pronounced increase in Zn uptake by Sudan grass plants grown on clay and loamy sand soils.

4.2.1.3. Phosphorus in plant:

Data presented in Tables 12 and 13 and Figs. 15 and 16 illustrate P concentration and uptake by wheat grains and straw as affected by zinc and phosphorus applications.

I. Phosphorus concentration: (Table 12 and Fig. 15)

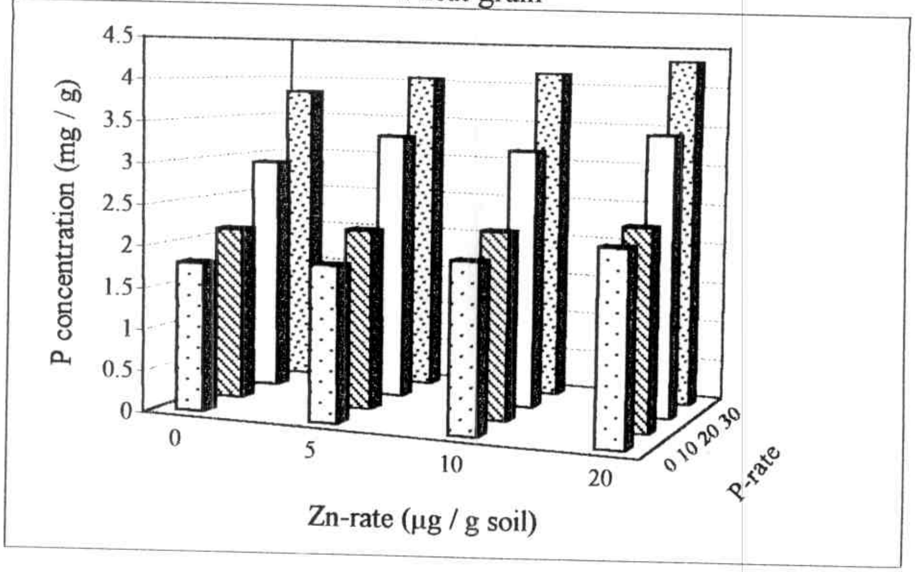
Applying Zn resulted in an increase in P concentration in grains and straw of wheat plants, except at the rate of 10 μg g^{-1} for grains and 20 μg g^{-1} for straw where the increases were not significant. Mean values of P concentration in grains increased from 2.65 mg P g^{-1} in the no-Zn treatments to 2.84, 2.90 and 3.10 mg P g^{-1} for treatments receiving 5, 10 and 20 μg Zn g^{-1} soil, respectively. Values for P concentration in straw were 1.76 mg g^{-1} for the no-Zn treatment and 1.92, 2.08 and 2.18 mg P g^{-1} for treatments receiving 5, 10 and 20 μg Zn g^{-1}, respectively.

Table (12): Effect of zinc and phosphorus treatments on P concentration in wheat plants.

P-rate ($\mu g\ g^{-1}$) [P]	P concentration ($mg\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	1.79	1.86	2.01	2.26	1.98
10	2.11	2.18	2.26	2.40	2.24
20	2.90	3.30	3.18	3.43	3.20
30	3.80	4.03	4.13	4.32	4.07
Mean	2.65	2.84	2.90	3.10	
LSD (0.05):	[Zn] = 0.14		[P] = 0.14	[Zn P] = NS	
	Straw				
0	1.20	1.27	1.37	1.38	1.30
10	1.31	1.40	1.55	1.60	1.47
20	1.97	2.17	2.37	2.53	2.26
30	2.57	2.83	3.04	3.21	2.91
Mean	1.76	1.92	2.08	2.18	
LSD (0.05):	[Zn] = 0.11		[P] = 0.11	[Zn P] = NS	

NS = not significant.

Wheat grain



Wheat straw

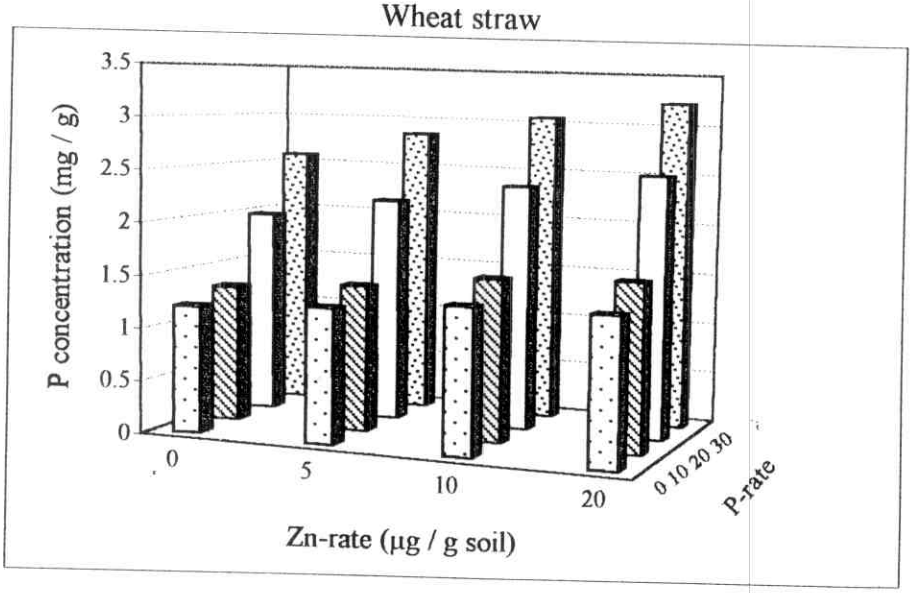


Fig. (15): Effect of zinc and phosphorus applications on P concentration in wheat plants (mg / g).

These results agree with those obtained by **Farid (1995),** who found that application of Zn to a calcareous soil led to an increase in P concentration of plant and that increasing Zn rate was accompanied by a progressive increase in P-concentration.

Applying P resulted in an increased P-concentration in plants; increased application rates of P resulted in progressive increase in P concentration. This occurred in grains as well as straw. Mean values of P concentration for treatments receiving 0, 10, 20 and 30 µg P g^{-1} soil were 1.98, 2.24, 3.20 and 4.07 mg P g^{-1} grains, respectively and 1.30, 1.47, 2.26 and 2.91 mg P g^{-1} straw, respectively.

Increased P concentration caused by increased Zn application; also increased P concentration caused by increased P application occurred under all conditions, since there was no significant interaction between application of Zn or P on P-concentration.

II. Phosphorus uptake: (Table 13 and Fig. 16)

Phosphorus uptake by plant in response to Zn or P application followed a trend similar to that of P-concentration.

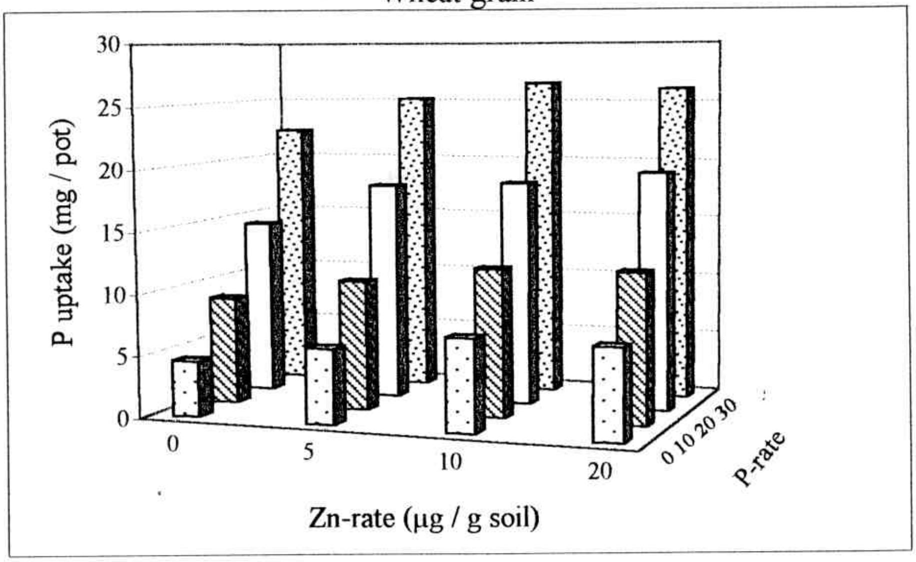
Applying Zn caused an increase in P uptake by both plant components. The increase was progressive with the increase in Zn application but only up to the rate of 10 µg Zn g^{-1} after which no difference occurred. Therefore, increasing the rate of Zn above 10 µg g^{-1} soil gave no significant effect. Increased P uptake caused by increasing application of Zn was also reported by **Sadik et al. (1996)** and **Eskandar (1997)**, who applied Zn up to 5 µg g^{-1}. Mean values of P uptake in grains of plants receiving 0, 5, 10 and 20 µg Zn g^{-1} soil were 12.42, 14.87, 16.03 and 16.17

Table (13): Effect of zinc and phosphorus treatments on P uptake by wheat plants.

P-rate ($\mu g\ g^{-1}$) [P]	P uptake ($mg\ pot^{-1}$) Zn-rate ($\mu g\ g^{-1}$ soil) [Zn] 0	5	10	20	Mean
	Grains				
0	4.41	5.94	7.33	7.19	6.22
10	8.66	10.52	11.94	12.04	10.79
20	14.34	17.89	18.33	19.38	17.49
30	22.26	25.13	26.50	26.05	24.99
Mean	12.42	14.87	16.03	16.17	
LSD (0.05):	[Zn] = 0.86		[P] = 0.86		[Zn P] = NS
	Straw				
0	5.69	7.03	8.55	8.05	7.33
10	8.75	10.45	12.96	13.27	11.36
20	16.79	20.06	22.63	23.49	20.74
30	25.45	29.33	31.86	32.87	29.88
Mean	14.17	16.72	19.00	19.42	
LSD (0.05):	[Zn] = 1.41		[P] = 1.41		[Zn P] = NS

NS = not significant.

Wheat grain



Wheat straw

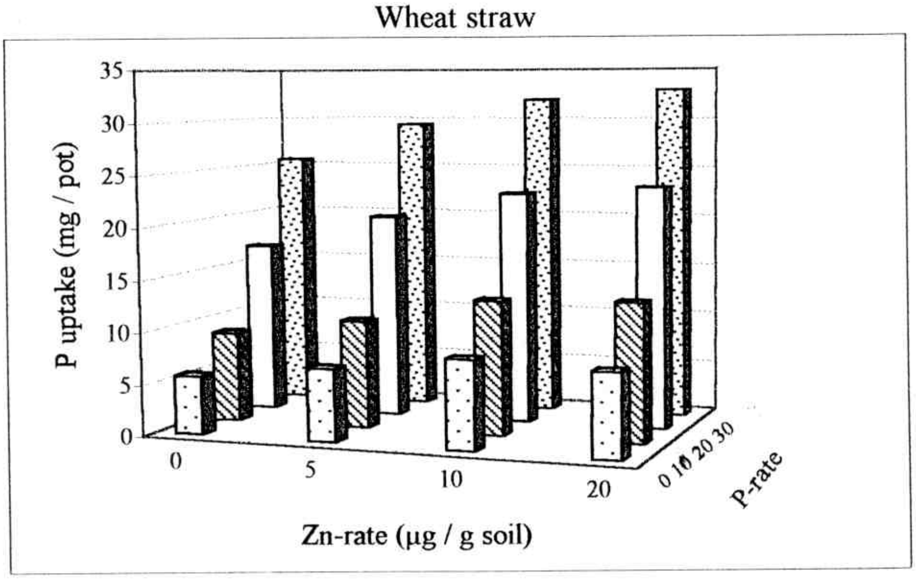


Fig. (16): Effect of zinc and phosphorus applications on P uptake by wheat plants (mg / pot).

mg P pot^{-1}, respectively. The corresponding values of P-uptake in straw were 14.17, 16.72, 19.00 and 19.42 mg P pot^{-1} for the same Zn treatments, respectively.

Applying P caused an increase in P uptake. Mean values of P uptake in grains as affected by P application were 6.22, 10.79, 17.49 and 24.99 mg pot^{-1} for the application rates of 0, 10, 20 and 30 µg P g^{-1} soil, respectively. The corresponding values for P uptake by straw were 7.33, 11.36, 20.74 and 29.88 mg P pot^{-1}, respectively. The pattern of response to Zn occurred at all P-rates; and the pattern of response to P occurred at all rates of Zn application, i.e. there was no significant interaction between Zn and P.

4.2.2. Effect of applying zinc and iron on plant growth, Zn and Fe in wheat plants:

4.2.2.1. Dry matter yield:

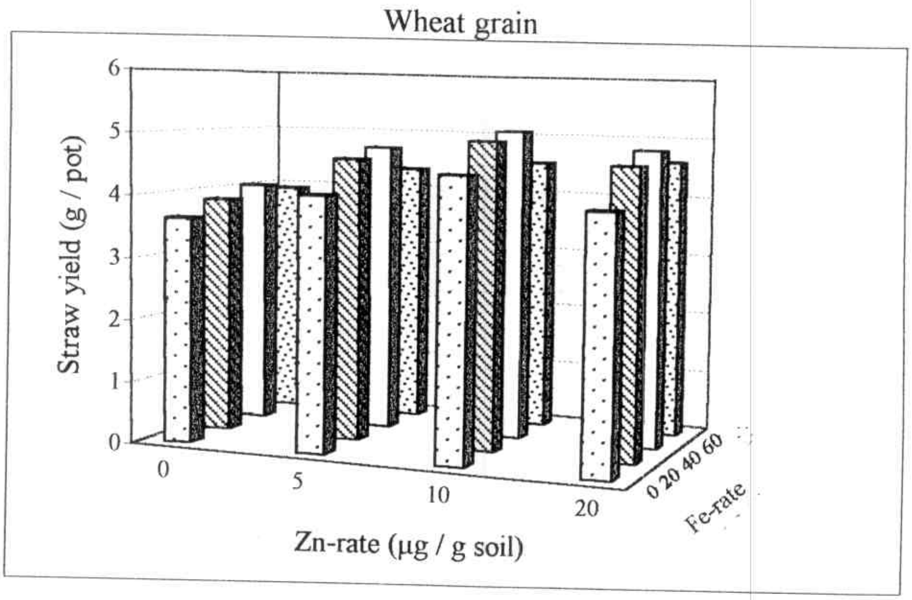
Data presented in Table 14 and illustrated in Fig. 17 show the effect of Zn and Fe on dry matter yield of wheat grains and straw.

Application of Zn enhanced the grains and straw yields. Increasing rate of Zn up to 10 µg g^{-1} soil was associated with significant increase in the dry matter yield (either grains or straw), but there was a decrease with the highest Zn-rate (20 µg Zn g^{-1} soil) as compared with the rate of 10 µg Zn g^{-1} soil and the decrease was particularly considerable and significant in the case of straw. Mean values of the percentage increase of the dry weight of grains (over the no-Zn) were 15.1, 23.4 and 17.4 % for

Table (14): Effect of zinc and iron treatments on the dry matter yield of wheat plants.

Fe-rate (µg g^{-1} soil) [Fe]	Dry matter yield (g/pot)				
	Zn-rate (µg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	3.63	4.07	4.47	4.02	4.05
20	3.85	4.59	4.95	4.63	4.50
40	4.02	4.74	5.08	4.83	4.67
60	3.91	4.33	4.51	4.59	4.33
Mean	3.85	4.43	4.75	4.52	
LSD (0.05):	[Zn] = 0.34		[Fe] = 0.34		[Zn Fe] = NS
	Straw				
0	6.90	7.23	7.93	7.18	7.31
20	7.08	7.95	8.82	7.84	7.92
40	7.45	8.20	9.34	7.93	8.23
60	7.23	7.70	8.23	8.48	7.91
Mean	7.16	7.77	8.58	7.86	
LSD (0.05):	[Zn] = 0.43		[Fe] = 0.43		[Zn Fe] = NS

NS = not significant.



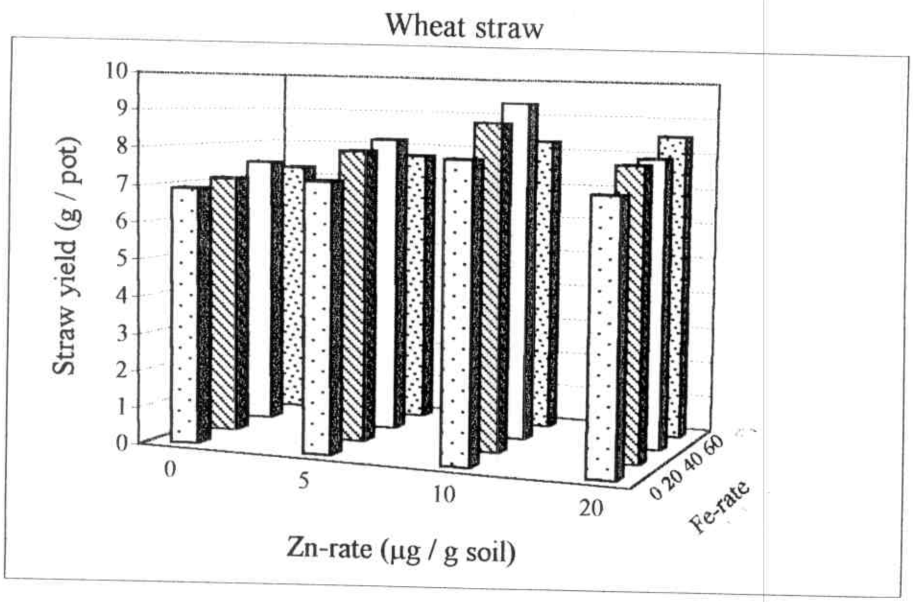


Fig. (17): Effect of zinc and iron applications on the dry matter yield of wheat plants (g / pot).

treatments receiving 5, 10 and 20 μg Zn g^{-1} soil, respectively. The comparable mean values for straw were 8.5, 19.8 and 9.8 %, respectively. These increases reflect a possible response to applied Zn in such a soil of low available Zn (see Table 1).

With regard to Fe application, data indicate applying Fe led to an increase in plant growth, but only up to the rate of 40 μg g^{-1} soil. The increase was particularly significant at the rate of 20 μg Fe g^{-1}. Increasing the rate from 20 to 40 μg Fe g^{-1} was not significant. Increasing Fe application above 40 μg g^{-1} resulted in a decrease in dry matter yields of grains as well as straw. Mean values of the percentage increase of the dry weight of grains were 11.1, 15.3 and 6.9 % as a result of applying 20, 40 and 60 μg Fe g^{-1} soil, respectively. The comparable percentage values for straw were 8.3, 12.6 and 8.2 %, respectively.

Values of the grains and straw yields of wheat plants were highest (5.08 g grains pot^{-1} and 9.34 g straw pot^{-1}) at the rate of 10 μg Zn + 40 μg Fe g^{-1} soil, and lowest (3.63 g grains pot^{-1} and 6.90 g straw pot^{-1}) where neither nutrient was applied. This stresses the importance of applying Zn along with Fe especially for plants grown in poor soils such as the sandy soil of the current study.

The obtained results agree with those of **Dahdoh (1997),** who reported that applications of Zn and Fe in the form of sulphate to a sandy soil had significant effects on increasing the yield of broad bean seeds and shoots. **Karaman et al. (1999)** reported that dry matter production of beans grown on an alluvial soil increased with addition of Fe and Zn and their highest dry matter yield was obtained from treatment of 20 μg Zn g^{-1} + 20 μg Fe g^{-1} (added as Fe-EDDHA).

4.2.2.2. Zinc in plant:

Data presented in Tables 15 and 16 and illustrated in Figs. 18 and 19 show Zn concentration and uptake by wheat grains and straw as affected by the different rates of Zn and Fe.

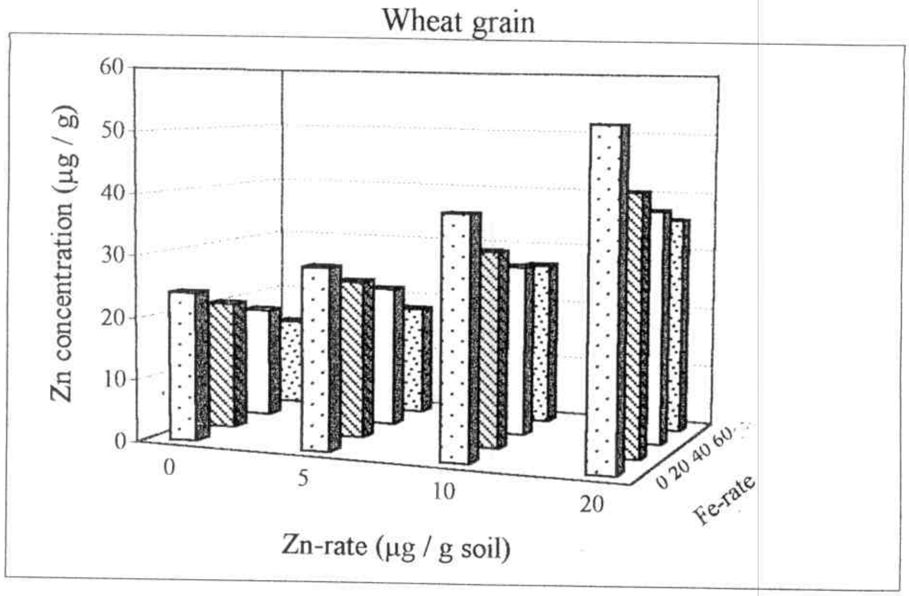
I. Zinc concentration: (Table 15 and Fig. 18)

Applying Zn to the soil resulted in increases in Zn concentration in both grains and straw of wheat plants. The increases were progressive with increasing rates of applied Zn. The mean value of Zn concentration in grains of plants receiving no-Zn was 19.3 μg g^{-1}, increasing significantly to 23.9, 31.1 and 41.9 μg Zn g^{-1} as a result of applying rates of 5, 10 and 20 μg Zn g^{-1} soil, respectively. The corresponding Zn concentrations in straw were 13.2 μg g^{-1} for the no-Zn treatment and 18.2, 25.8 and 30.6 μg g^{-1} for the three respective above-mentioned treatments of applied Zn. In this respect, there was a significant interaction between Zn and Fe concerning results of straw (but not those of grains). The progressive increase in Zn concentration due to the progressive increase in Zn application occurred only where no-Fe was applied or where the low rate of 20 μg Fe g^{-1} was applied. Under conditions of 40 or 60 μg Fe g^{-1}, such an increase was not always progressive. Under 40 μg Fe g^{-1}, the difference between no-Zn and 5 μg Zn g^{-1} was not significant, neither was that between the 10 μg Zn g^{-1} and 20 μg Zn. Under 60 μg Fe g^{-1}, the difference between the no-Zn and the 5 μg Zn g^{-1} was not significant. Therefore, presence of high contents of iron in the root media antagonized the positive effect of increased

Table (15): Effect of zinc and iron treatments on Zn concentration in wheat plants.

Fe-rate ($\mu g\ g^{-1}$) [Fe]	Zn concentration ($\mu g\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	23.9	29.0	38.4	52.5	36.0
20	20.7	25.5	31.4	41.8	29.9
40	18.1	23.0	27.8	37.9	26.7
60	14.5	18.1	26.8	35.5	23.7
Mean	19.3	23.9	31.1	41.9	
LSD (0.05):	[Zn] = 2.1		[Fe] = 2.1		[Zn Fe] = NS
	Straw				
0	15.5	24.6	32.7	42.4	28.8
20	14.1	21.3	28.2	31.5	23.8
40	12.6	15.5	22.8	25.3	19.1
60	10.5	11.3	19.3	23.0	16.0
Mean	13.2	18.2	25.8	30.6	
LSD (0.05):	[Zn] = 1.7		[Fe] = 1.7		[Zn Fe] = 3.3

NS = not significant.



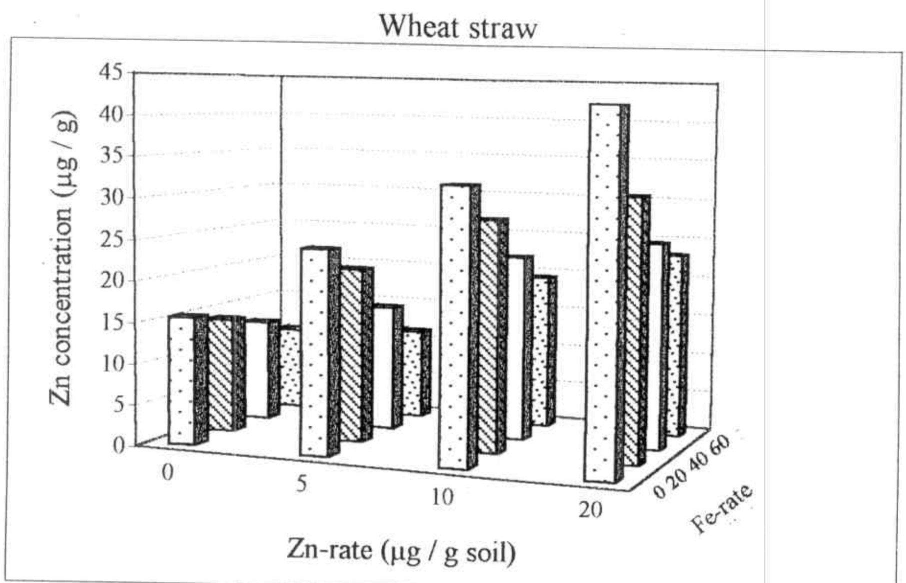


Fig. (18): Effect of zinc and iron applications on Zn concentration in wheat plants (µg / g).

increments of Zn in the media preventing persistent associated increases in Zn concentration in plants.

Applying Fe resulted in a decrease in the concentration of Zn in both grains and straw; and the decrease progressed with increasing the rate of applied Fe. The mean value of Zn concentration in grains for the no-Fe treatment was 36.0 μg Zn g^{-1}; decreasing to 29.9, 26.7 and 23.7 μg Zn g^{-1} for plants receiving 20, 40 and 60 μg Fe g^{-1} soil, respectively. The corresponding values of Zn concentration in straw were 28.8 μg g^{-1} for the no-Fe treatment; and 23.8, 19.1 and 16.0 μg g^{-1} for treatments receiving the three above-mentioned Fe rates, respectively. In this respect, there was a significant interaction between Zn and Fe concerning results of straw. The progressive decrease in Zn concentration in straw due to the progressive increase in Fe application occurred particularly under conditions of 5 or 10 μg Zn g^{-1}. Under conditions of no-Zn, the decrement was not always significant: decrements between 0 and 20 μg Fe g^{-1}, as well as between 40 and 60 μg Fe g^{-1} were not significant. Under conditions of 20 μg Zn g^{-1}, the decrement between 40 and 60 μg Fe g^{-1} was not significant.

The decreased concentration of Zn caused by increasing application of Fe was reported by **Kabata-Pendias and Pendias (1992), Farid (1995)** and **Kaya et al. (1999)**, who found that Zn concentration in tissues of tomato plants grown in nutrient solution increased to toxic levels in the high Zn treatment (5 mg/L) and application of supplementary Fe (28 mg/L for a week then 56 mg/L for another week) as a foliar spray decreased Zn concentration in the leaves and roots of tomato plants grown at this rate of Zn.

II. Zinc uptake: (Table 16 and Fig 19)

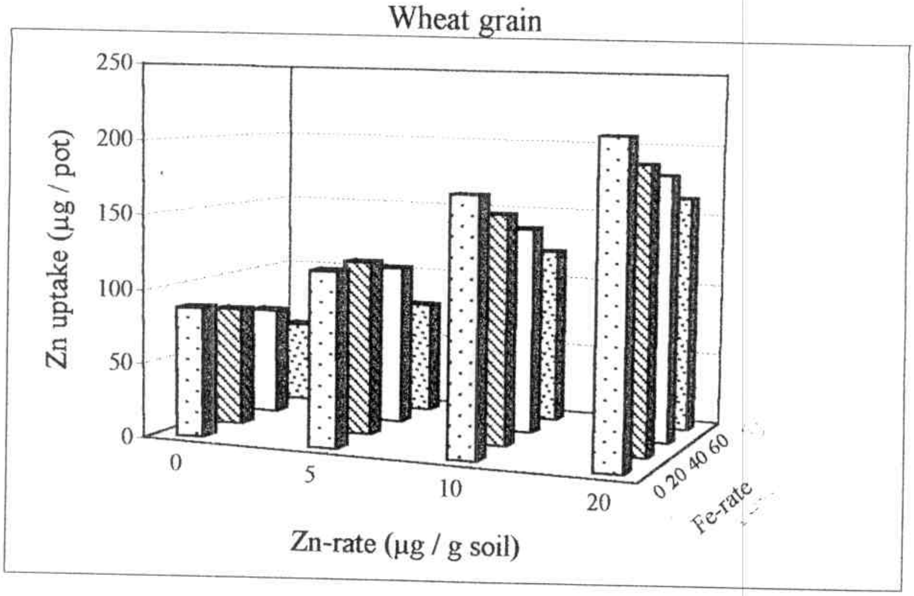
Application of Zn increased the uptake of Zn by both grains and straw of wheat plants, the increase was progressive with increased rate of Zn application. This increase was expected since application of Zn increased both dry matter yield (Table 14) and Zn concentration (Table 15). Mean value of Zn uptake by grains for the no Zn treatment was 74 µg pot^{-1}, increased significantly to 105, 147 and 187 µg pot^{-1} upon application of Zn at the rates of 5, 10 and 20 µg g^{-1} soil, respectively. Comparable mean values for Zn uptake in straw were 94, 139, 219 and 236 µg pot^{-1}, respectively. In this respect, there was a significant interaction for Zn uptake in straw. Under conditions of high Fe application (40 or 60 µg Fe g^{-1}), the increased Zn-uptake associated with the increased Zn application was not always progressive. For example under conditions of 40 µg Fe g^{-1}, increasing the rate of Zn application from 10 to 20 µg g^{-1} caused no significant change in Zn uptake by straw. Also, under conditions of 60 µg Fe g^{-1}, application of 5 µg Zn g^{-1} caused no significant change in Zn uptake. This shows the extent of Fe/Zn antagonism.

Application of Fe resulted in decreases in Zn uptake; the decrease progressed with increasing the rate of applied Fe. Mean values of Zn uptake by grains due to application of 0, 20, 40 and 60 µg Fe g^{-1} soil were 146, 136, 126 and 104 µg pot^{-1}, respectively. The corresponding values for Zn uptake in straw were 212, 190, 158 and 129 µg pot^{-1} for the aforementioned Fe

Table (16): Effect of zinc and iron treatments on Zn uptake by wheat plants.

Fe-rate ($\mu g\ g^{-1}$) [Fe]	Zn uptake ($\mu g\ pot^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	87	117	171	211	146
20	80	118	155	192	136
40	73	109	141	182	126
60	56	77	121	163	104
Mean	74	105	147	187	
LSD (0.05):	[Zn] = 8		[Fe] = 8	[Zn Fe] = NS	
	Straw				
0	107	177	259	304	212
20	99	168	248	246	190
40	94	126	212	200	158
60	76	86	158	195	129
Mean	94	139	219	236	
LSD (0.05):	[Zn] = 8		[Fe] = 8	[Zn Fe] = 16	

NS = not significant.



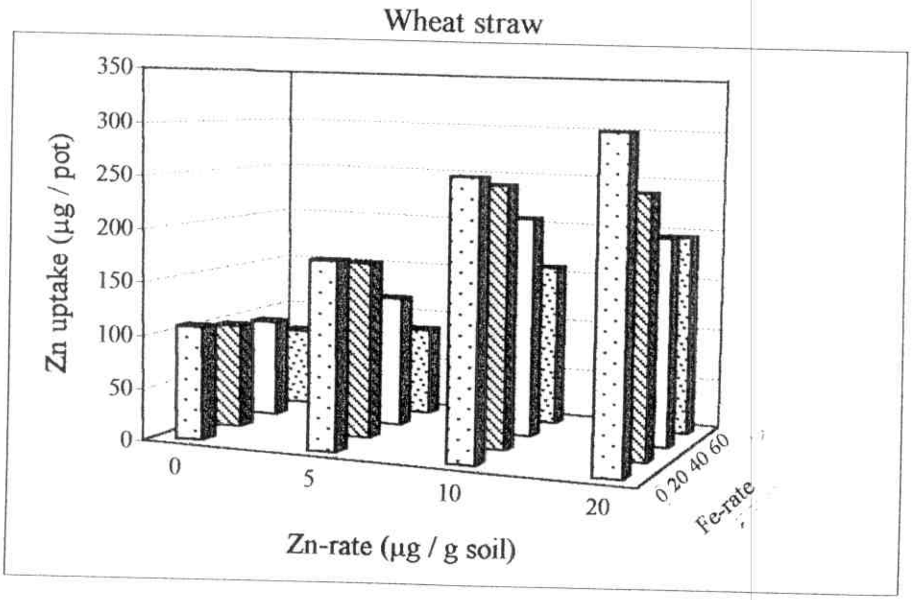


Fig. (19): Effect of zinc and iron applications on Zn uptake by wheat plants (µg / pot).

treatments, respectively. Thus Zn uptake decreased progressively (with increased application of Fe) reaching 28.8 % 39.2 % reduction in grains and straw, respectively due to adding 60 µg Fe g^{-1}. In this regard and concerning Zn-uptake in straw, the progressive decrease in Zn-uptake due to Fe application was not always the same under each condition of Zn application. While such a pattern of a progressive decrease in Zn-uptake in straw due to progressed application of Fe occurred along the entire range of 0 to 40 µg Fe g^{-1} under conditions of 20 µg Zn g^{-1}, it did not do so under other rates of Zn. Under no-Zn application, the decrease caused by 40 µg Fe g^{-1} in comparison with 20 µg Fe g^{-1} was not significant; also under conditions of 20 µg Zn g^{-1}, the decrease caused by 60 µg Fe g^{-1} in comparison with 40 µg Fe g^{-1} was not significant; but under other Zn rates such a decrease was significant.

These results are in agreement with those obtained by **Mehra and Shekhawat (1999),** who applied Fe up to 50 kg/ha in pot experiments in sandy clay loam and clay loam soils and found that Zn concentration as well as Zn uptake in wheat grains and straw consistently decreased with increasing Fe levels.

4.2.2.3. Iron in plant:

Data presented in Tables 17 and 18 and illustrated in Figs. 20 and 21 show concentration and uptake of Fe in wheat grains and straw as affected by the different rates of Zn and Fe.

I. Iron concentration: (Table 17 and Fig. 20)

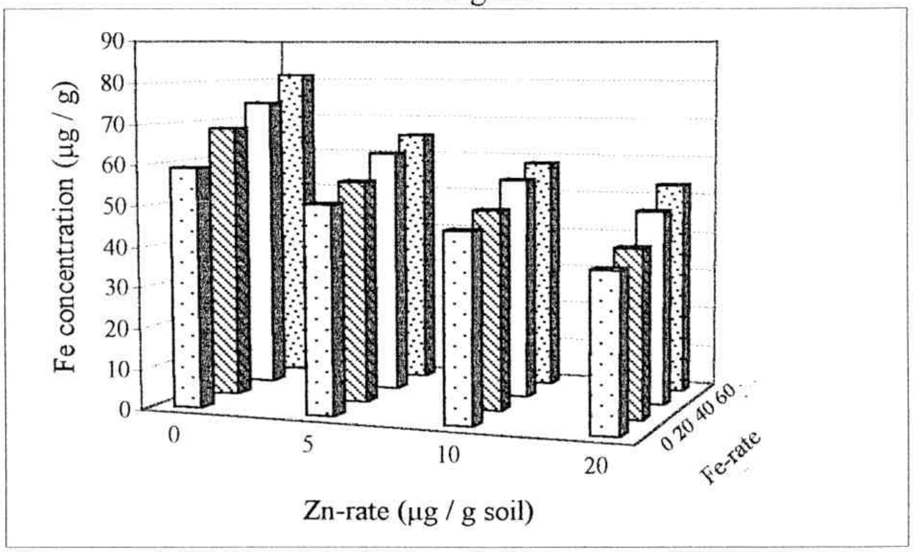
Application of Zn caused a decrease in Fe concentration in grains and straw. The decrease progressed with increasing rates of Zn application. The mean values of Fe concentration in

Table (17): Effect of zinc and iron treatments on Fe concentration in wheat plants.

Fe-rate ($\mu g\ g^{-1}$) [Fe]	Fe concentration ($\mu g\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	59	51	46	38	49
20	68	55	49	41	53
40	74	61	55	48	59
60	81	65	58	53	64
Mean	71	58	52	45	
LSD (0.05):	[Zn] = 4		[Fe] = 4	[Zn Fe] = NS	
	Straw				
0	159	142	127	108	134
20	165	147	130	115	139
40	180	157	135	125	149
60	209	183	149	140	170
Mean	178	157	135	122	
LSD (0.05):	[Zn] = 6		[Fe] = 6	[Zn Fe] = NS	

NS = not significant.

Wheat grain



Wheat straw

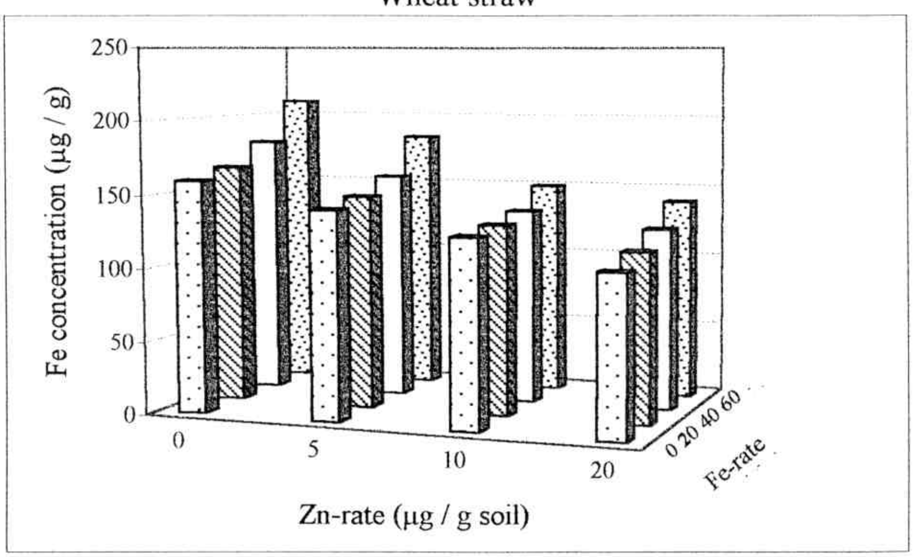


Fig. (20): Effect of zinc and iron applications on Fe concentration in wheat plants (µg / g).

wheat plants decreased from being 71 μg Fe g^{-1} grains in the no-Zn treatment to 58, 52 and 45 μg Fe g^{-1} grains due to adding 5, 10 and 20 μg Zn g^{-1} soil, respectively. For Fe concentration in straw, the mean value was 178 μg Fe g^{-1} for the no-Zn treatment as compared with 157, 135 and 122 μg g^{-1} straw for treatments receiving the aforementioned Zn-rates, respectively.

Application of Fe resulted in significant increase in Fe concentration in grains and straw, which progressed as Fe rate increased. Fe concentration for the treatments not given Fe was 49 μg g^{-1} grains; it increased significantly to reach mean values of 53, 59 and 64 μg Fe g^{-1} grains upon application of Fe at the rates of 20, 40 and 60 μg Fe g^{-1} soil, respectively. The corresponding values of straw were 134 μg Fe g^{-1} for the no-Fe treatment, and 139, 149 and 170 μg g^{-1} for the aforementioned iron rates, respectively.

These results are in agreement with those obtained by **Kabata-Pendias and Pendias (1992),** who attributed the depressing effect of Zn on Fe concentration to the competition between Zn^{2+} and Fe^{2+} in the absorption processes by plants and the interference in chelation processes during the uptake and translocation of Fe from the roots to shoots of plants.

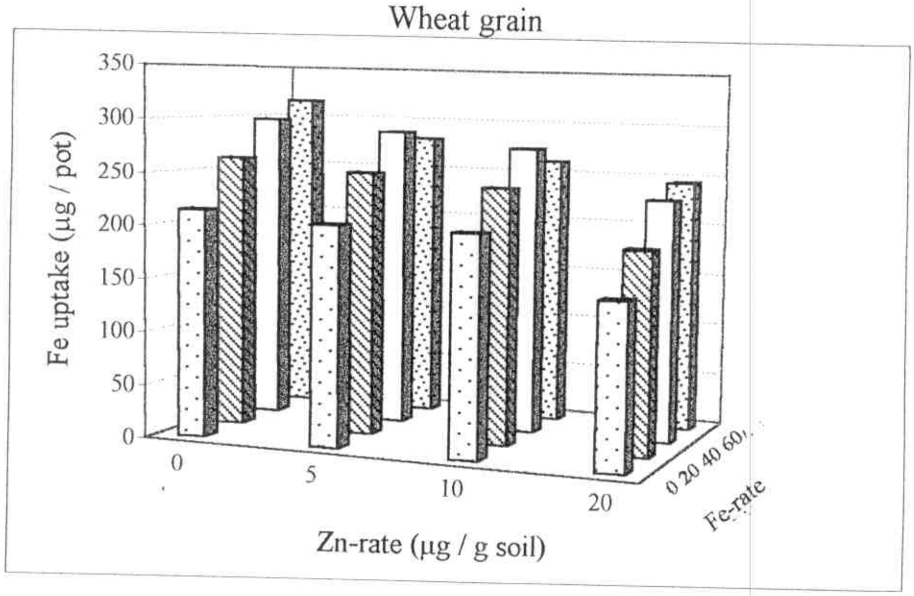
II. Iron uptake: (Table 18 and Fig. 21)

Data of Fe uptake by both grains and straw of wheat plants followed a trend rather similar to that of Fe concentration. Application of Zn resulted in a decrease in Fe uptake, and such a decrease progressed with increasing the rate of applied Zn. The highest rate of Zn application showed the most pronounced decrease in Fe uptake. Mean values of Fe uptake by grains of

Table (18): Effect of zinc and iron treatments on Fe uptake by wheat plants.

Fe-rate ($\mu g\ g^{-1}$) [Fe]	Fe uptake ($\mu g\ pot^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	214	205	204	152	194
20	261	251	241	189	236
40	297	288	276	230	273
60	315	280	261	243	275
Mean	272	256	246	203	
LSD (0.05):	[Zn] = 9		[Fe] = 9		[Zn Fe] = NS
	Straw				
0	1093	1023	1005	774	974
20	1166	1165	1142	901	1093
40	1340	1288	1258	992	1220
60	1510	1405	1220	1187	1330
Mean	1277	1221	1156	963	
LSD (0.05):	[Zn] = 43		[Fe] = 43		[Zn Fe] = 86

NS = not significant.



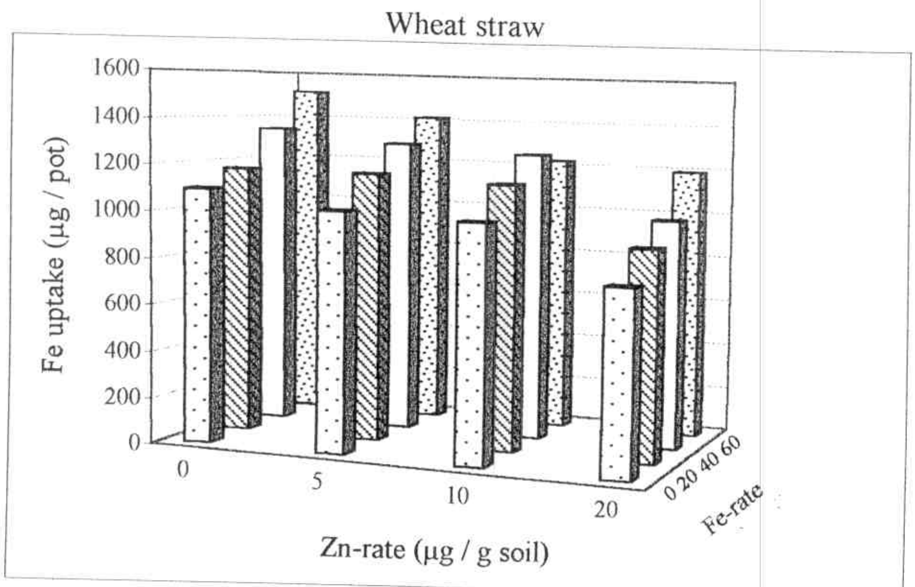


Fig. (21): Effect of zinc and iron applications on Fe uptake by wheat plants (μg / pot).

plants receiving 0, 5, 10 and 20 µg Zn g^{-1} soil, were 272, 256, 246 and 203 µg pot^{-1}, respectively. The corresponding values for Fe-uptake in straw were 1277, 1221, 1156 and 963 µg pot^{-1}, respectively.

There was a significant interaction with regard to Fe uptake in straw; the decreased Fe uptake due to application of increased rate of Zn occurred only where there was a very high addition of Fe. Under addition of 60 µg Fe g^{-1}, applying Zn decreased Fe uptake and, up to 10 µg Zn g^{-1}, every increment of applied Zn was associated with a significant decrease in Fe uptake, but the increment from 10 to 20 µg Zn g^{-1} caused a non-significant decrease. Under conditions of no-Fe or low to medium rate of 20 to 40 µg Fe g^{-1}, the decrease in Fe uptake due to Zn application was very slight and not significant. Such decreases did not continue significantly until adding the very high rate of 20 µg Zn g^{-1} when the decrease was significant. Therefore, the antagonistic effect caused by applying Zn on the uptake of Fe in plants required high applied Zn and high applied Fe in the root media.

Decreased Fe-uptake caused by Zn application reflects the antagonistic relationship of Fe and Zn manifested in the internal translocation of these elements (**Vedina and Toma, 2000**).

Application of Fe resulted in an increase in the uptake of Fe by grains. The increase was progressive with increased rate of applied Fe, but up to the 40 µg Fe g^{-1}; beyond this rate the increase was slight and non-significant. A similar trend occurred with Fe uptake by straw and the progressive increase continued up to the highest rate of applied Fe. Mean values of Fe uptake by grains were 194, 236, 273 and 275 µg pot^{-1} for the rates of 0, 20, 40 and 60 µg Fe g^{-1} soil, respectively. Comparable values for uptake by straw were 974, 1093, 1220 and 1330 µg pot^{-1}, respectively.

Therefore, application of Zn increased Zn and decreased Fe in plants (concentration and uptake). Likewise, application of Fe increased Fe and decreased Zn in plants. **Dahdoh (1997)** reported such an effect between the two elements giving antagonistic relationship regarding concentration and uptake of either element.

4.2.3. Effect of applying zinc and cadmium on plant growth, Zn and Cd in wheat plants:

4.2.3.1. Dry matter yield:

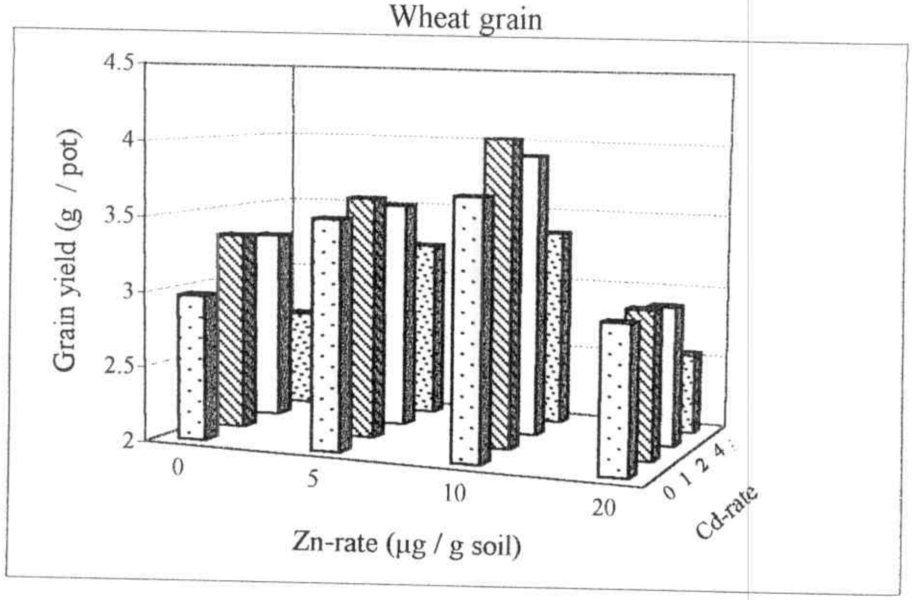
Data presented in Table 19 and Fig. 22 show the effect of Zn and Cd on dry matter yield of wheat grains and straw.

Application of Zn led to a significant increase in the dry matter yields of both wheat grains and straw. The increase was progressive with increasing rate of the applied Zn up to 10 µg g^{-1} soil after which a decrease occurred, and the decrease was so pronounced that the dry matter yield of grains or straw at the 20 µg Zn g^{-1} was lower as compared with no-Zn treatment. Such marked decrease at 20 µg Zn g^{-1} may reflect a Zn toxicity. Such a pattern was observed among all Cd-rates indicating that there was no significant interaction between Zn and Cd applications on production of wheat grains or straw.

Table (19): Effect of zinc and cadmium treatments on the dry matter yield of wheat plants.

Cd-rate ($\mu g\ g^{-1}$ soil) [Cd]	Dry matter yield (g/pot)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	2.97	3.52	3.70	2.96	3.29
1	3.33	3.62	4.05	2.98	3.50
2	3.29	3.54	3.92	2.94	3.42
4	2.66	3.22	3.35	2.54	2.94
Mean	3.06	3.48	3.76	2.85	
LSD (0.05):	[Zn] = 0.29		[Cd] = 0.29		[Zn Cd] = NS
	Straw				
0	6.73	7.41	7.63	6.91	7.17
1	7.10	7.88	8.22	7.01	7.55
2	7.07	7.69	8.00	6.13	7.22
4	6.08	7.18	7.32	5.99	6.64
Mean	6.75	7.54	7.79	6.51	
LSD (0.05):	[Zn] = 0.41		[Cd] = 0.41		[Zn Cd] = NS

NS = not significant.



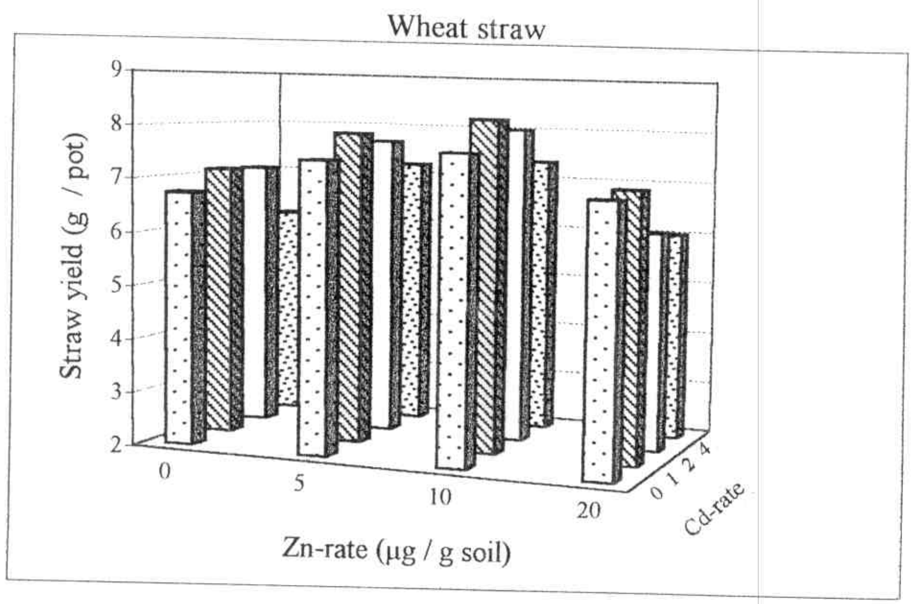


Fig. (22): Effect of zinc and cadmium treatments on the dry matter yield of wheat plants.

Mean values of the dry matter yield of grains were 3.06, 3.48, 3.76 and 2.85 g pot^{-1} due to application of Zn at the rates of 0, 5, 10 and 20 µg g^{-1} soil, respectively. With straw, the corresponding values were 6.75, 7.54, 7.79 and 6.51 g pot^{-1} for the applied rates of Zn, respectively.

The results show that application of Cd at rate of 1 µg g^{-1} soil had a positive effect on yields of both wheat components, since addition 1 µg Cd g^{-1} soil increased the dry matter yield of grains and straw by about 6.4 and 5.3 % over the treatments not given Cd. Increasing Cd application from 1 µg g^{-1} to 2 µg Cd g^{-1} soil resulted in a slight decrease and increasing it to the rate of 4 µg Cd g^{-1} resulted in a pronounced and significant decrease in the yields. The magnitudes of decrease at 2 and 4 µg Cd g^{-1} applications in dry matter of grains were 2.3 and 16.0 %, respectively as compared with that obtained from treatment which had received 1 µg g^{-1} soil. In the case of straw yield, the corresponding percentage decreases were 4.4 and 12.1 % for each of the two rates, respectively. The yield at 4 µg Cd g^{-1} was lower than the yield obtained with no-Cd applied. This indicates a toxicity of Cd at 4 µg Cd g^{-1}. At this rate, the decrease percentage averaged 10.6 % for grains and 7.4 % for straw as compared with the no-Cd treatment. **Mengel and Kirkby (1982)** indicated that Cd interfere with the work of some enzymes and may cause lethal effect on the embryos and metabolic process. Also, there could be a delay in seed germination and root growth.

The lowest yields occurred with application of the highest rates of Zn and Cd together. The highest yield occurred with 10 μg Zn g^{-1} + 1 μg Cd g^{-1} soil.

The obtained results are in partial agreement with those of **Abdel-Sabour et al. (1988),** who found that addition of 1 μg Cd g^{-1} to a silt loam soil increased dry matter yield of maize plants by 25 %; however the current results are not in agreement with those researchers since they found that increasing the rate of applied Cd to 10 μg g^{-1} soil gave an increase of 15 %. The decreased plant growth obtained by 4 μg Cd g^{-1} in the current study as opposed with the increased plant growth obtained by 10 μg Cd g^{-1} as reported by **Abdel-Sabour et al. (1988)** may be due to the differences in the two soils; the sand soil of the current study would be of less adsorption capacity as well as buffering capacity as compared with the silt loam soil.

4.2.3.2. Zinc in plant:

Data presented in Tables 20 and 21 and Figs. 23 and 24 show Zn concentration and uptake by wheat grains and straw as affected by zinc and cadmium applications.

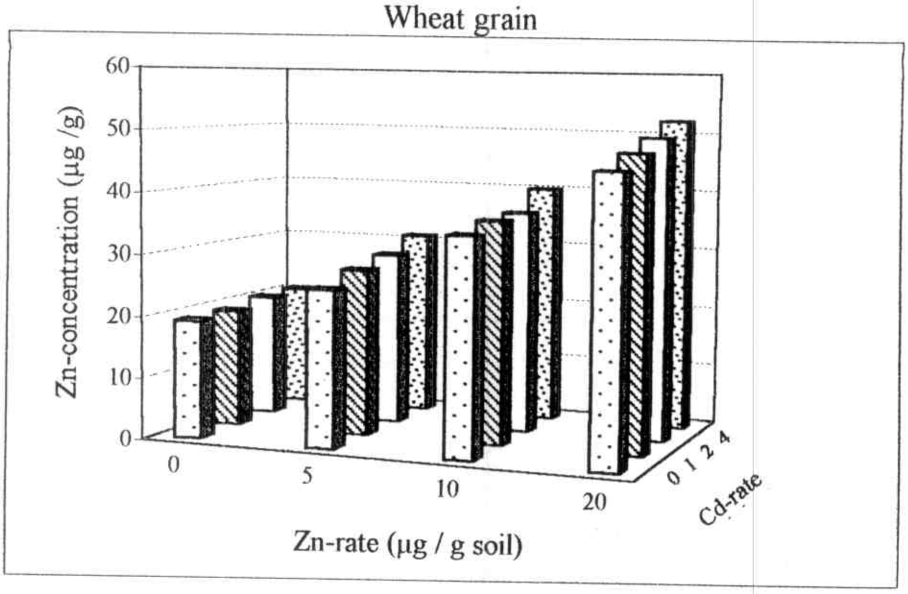
I. Zinc concentration: (Table 20 and Fig. 23)

Applying Zn significantly increased Zn concentration in both grains and straw of wheat plants. The increase progressed with increasing the rate of applied Zn. The mean value of Zn concentration in grains of wheat plants receiving no-Zn was 19.7 μg g^{-1}; it increased significantly to 27.9, 36.7 and 48.6 μg g^{-1} at the rates of 5, 10 and 20 μg Zn g^{-1} soil, respectively. The mean Zn-concentration in straw for the no-Zn treatment was 13.8 μg

Table (20): Effect of zinc and cadmium treatments on Zn concentration in wheat plants.

Cd-rate ($\mu g\ g^{-1}$) [Cd]	Zn concentration ($\mu g\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	19.1	25.3	34.7	45.3	31.1
1	19.2	27.1	36.0	47.5	32.5
2	20.1	28.4	36.4	49.5	33.6
4	20.2	30.7	39.8	51.9	35.7
Mean	19.7	27.9	36.7	48.6	
LSD (0.05):	[Zn] = 2.4		[Cd] = 2.4	[Zn Cd] = NS	
	Straw				
0	13.2	21.3	28.3	39.2	25.5
1	13.6	21.4	28.1	40.8	26.0
2	14.1	22.4	30.3	43.0	27.4
4	14.4	23.0	32.7	43.0	28.3
Mean	13.8	22.0	29.8	41.5	
LSD (0.05):	[Zn] = 1.5		[Cd] = 1.5	[Zn Cd] = NS	

NS = not significant.



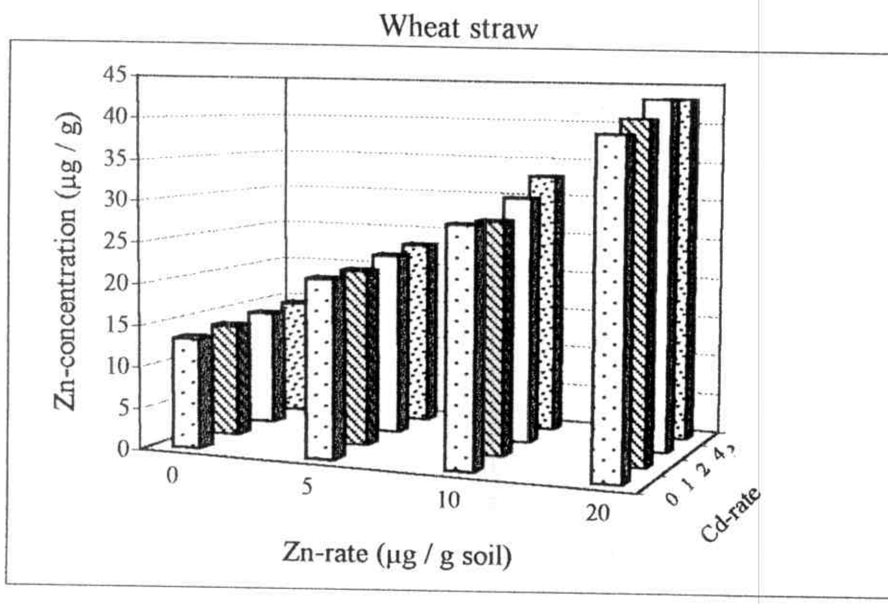


Fig. (23): Effect of zinc and cadmium treatments on Zn concentration in wheat plants.

Zn g^{-1}, increasing to 22.0, 29.8 and 41.5 µg g^{-1} for the respective three applied rates of Zn, respectively.

Application of Cd resulted in increased Zn concentration in both components of wheat plants and the increase progressed with increasing Cd rate. The mean value of Zn concentration in grains increased from 31.1 µg g^{-1} in the no-Cd treatment to 32.5, 33.6 and 35.7 µg g^{-1} for the rates of 1, 2 and 4 µg Cd g^{-1} soil, respectively. In the case of Zn concentration in straw, the mean values for the no-Cd, 1, 2 and 4 µg Cd g^{-1} were 25.5, 26.0, 27.4 and 28.3 µg g^{-1}, respectively.

Singh and Nayyar (1990) reported that Cd application of up to 5 µg g^{-1} increased Zn concentration in maize plants grown on loamy sand soil, but higher rates of Cd had no further effect. **Youssef et al. (1995)** found that Zn concentration increased in maize plants grown on a clay loam soil by Cd addition for up to 20 µg g^{-1} soil.

II. Zinc uptake: (Table 21 and Fig. 24)

Applying Zn to the sand soil resulted in an increase in Zn uptake in grains and straw; the increase progressed with increasing the rate of Zn application up to the highest rate of applied Zn, however, increasing the rate from 10 to 20 µg Zn g^{-1} gave no further increase in Zn uptake in grains. The mean values of Zn uptake in grains of plants receiving 0, 5, 10 and 20 µg Zn g^{-1} soil were 60, 97, 138 and 139 µg pot^{-1}, respectively. The corresponding values of Zn uptake in straw were 93, 166, 232 and 269 µg pot^{-1}, respectively.

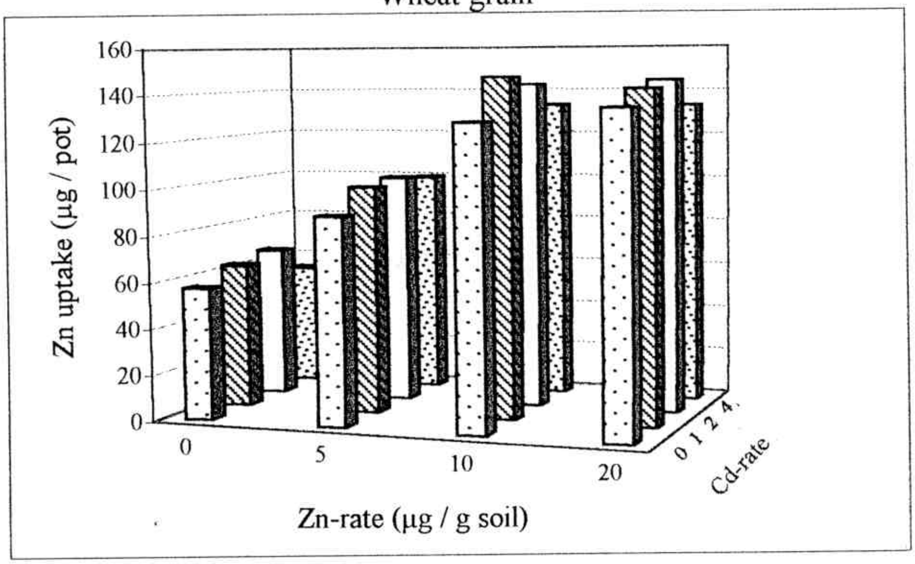
Application of Cd caused a slight and insignificant increase in Zn uptake in grains and straw of plants. Mean values

Table (21): Effect of zinc and cadmium treatments on Zn uptake by wheat plants.

Cd-rate ($\mu g\ g^{-1}$) [Cd]	Zn uptake ($\mu g\ pot^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	57	89	129	135	102
1	63	99	147	142	113
2	66	101	143	145	114
4	54	99	133	133	105
Mean	60	97	138	139	
LSD (0.05):	[Zn] = 14		[Cd] = NS		[Zn Cd] = NS
	Straw				
0	89	158	216	271	184
1	97	170	230	286	196
2	100	172	242	264	194
4	88	165	239	257	187
Mean	93	166	232	269	
LSD (0.05):	[Zn] = 14		[Cd] = NS		[Zn Cd] = NS

NS = not significant.

Wheat grain



Wheat straw

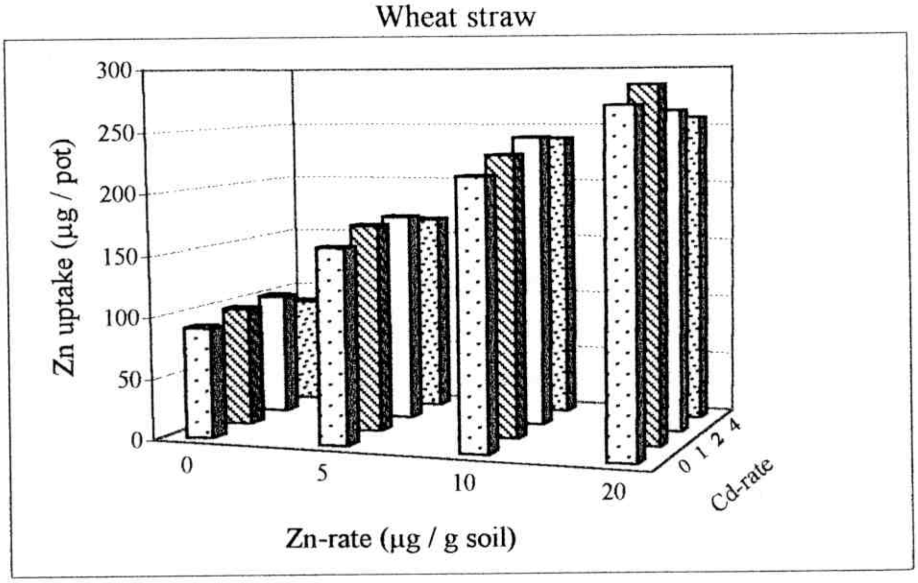


Fig. (24): Effect of zinc and cadmium treatments on Zn uptake by wheat plants.

of Zn uptake by grains were 102, 113, 114 and 105 µg pot^{-1} for the rates of 0, 1, 2 and 4 µg Cd g^{-1} soil, respectively; the corresponding values in straw were 184, 196, 194 and 187 µg pot^{-1}, respectively.

4.2.3.3. Cadmium in plant:

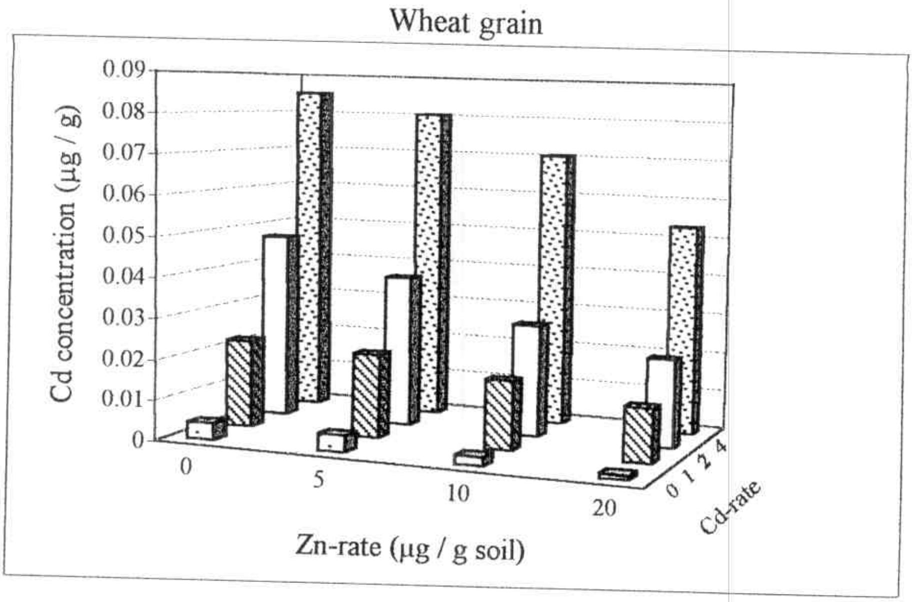
Data presented in Tables 22 and 23 and Figs. 25 and 26 illustrate Cd concentration and uptake by wheat grains and straw as affected by zinc and cadmium applications.

I. Cadmium concentration: (Table 22 and Fig. 25)

Application of Zn resulted in a decrease in Cd concentration in grains and straw of wheat plants, Cd concentration decreased significantly upon application of Zn and the decrease progressed with increasing Zn rate. The decrease was more pronounced with the highest rate of Zn application. Mean values of Cd concentration in grains of wheat plants, which received 0, 5, 10 and 20 µg Zn g^{-1} soil, were 0.039, 0.036, 0.029 and 0.022 µg g^{-1}, respectively. Comparable values for Zn concentration in straw were 0.706, 0.604, 0.548 and 0.465 µg g^{-1}, respectively. There was significant interaction between rates of Zn and Cd on concentration of Cd in grains and straw of wheat plants. The significant decrease in Cd concentration caused by Zn application did not occur where no-Cd was applied. With no-Cd application, concentration of Cd were extremely low ranging from 0.001 to 0.004 µg g^{-1} in grains and from 0.005 to 0.010 µg g^{-1} in straw, all with no significant difference between plants receiving no-Zn or those receiving Zn. The decrease was significant where Cd was applied, and it progressed decreasing with increased rates of Zn.

Table (22): Effect of zinc and cadmium treatments on Cd concentration in wheat plants.

Cd-rate ($\mu g\ g^{-1}$) [Cd]	Cd concentration ($\mu g\ g^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	0.004	0.004	0.002	0.001	0.003
1	0.022	0.021	0.017	0.013	0.018
2	0.047	0.038	0.028	0.022	0.034
4	0.085	0.080	0.070	0.053	0.072
Mean	0.039	0.036	0.029	0.022	
LSD (0.05):	[Zn]= 0.003		[Cd]= 0.003		[Zn Cd]= 0.007
	Straw				
0	0.010	0.008	0.008	0.005	0.008
1	0.380	0.340	0.287	0.187	0.298
2	0.857	0.757	0.720	0.633	0.742
4	1.577	1.310	1.177	1.033	1.274
Mean	0.706	0.604	0.548	0.465	
LSD (0.05):	[Zn]= 0.037		[Cd]= 0.037		[Zn Cd] = 0.075



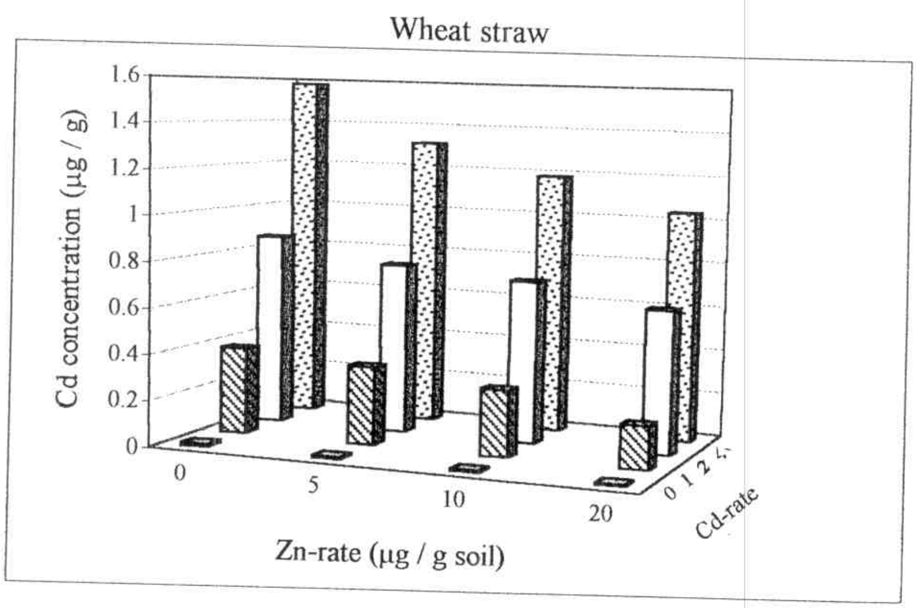


Fig. (25): Effect of zinc and cadmium treatments on the Cd concentration in wheat plants.

Application of Cd resulted in increased concentration of Cd in straw or grains. The increase was progressive with increasing the rate of applied Cd. Mean values of Cd concentration in grains increased from being 0.003 $\mu g\ g^{-1}$ in the no-Cd treatment to 0.018, 0.034 and 0.072 $\mu g\ g^{-1}$ due to adding Cd at rates of 1, 2 and 4 $\mu g\ g^{-1}$ soil, respectively. The corresponding values for straw were 0.008 $\mu g\ g^{-1}$ in the no-Cd treatment and 0.298, 0.742 and 1.274 $\mu g\ g^{-1}$ in the 1, 2 and 4 μg Cd g^{-1} rates, respectively.

Concentration of Cd in grains was very much less than that in straw (mean 0.032 $\mu g\ g^{-1}$ for grains and 0.581 $\mu g\ g^{-1}$ for straw). This shows that when Cd is in high hazardous contents in the root zone, plants accumulate Cd in straw rather than grains.

Dong and Zhang (1992) reported that excess of Cd to Zn, i.e. a high ratio of Cd: Zn with high concentration of Cd in the nutrient solution resulted in accumulation of Cd in rice plants, and that application of Zn reduced such an accumulation. **Choudhary et al. (1995)** reported that addition of Zn decreased Cd concentration in wheat plants; and that the concentration was highest in roots and lowest in grains with an order of: roots > leaves > stems > grains.

II. Cadmium uptake: (Table 23 and Fig. 26)

Addition of Zn particularly at the high rates decreased Cd uptake in grains and straw. The lowest uptake was at the highest Zn rate. Mean values of Cd uptake by grains were 0.116, 0.121, 0.106 and 0.061 μg Cd pot^{-1} for Zn rates of 0, 5, 10 and 20 μg Zn g^{-1}, respectively. The corresponding values for Cd uptake by

Table (23): Effect of zinc and cadmium treatments on Cd uptake by wheat plants.

Cd-rate ($\mu g\ g^{-1}$) [Cd]	Cd uptake ($\mu g\ pot^{-1}$)				
	Zn-rate ($\mu g\ g^{-1}$ soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	0.011	0.013	0.007	0.003	0.009
1	0.074	0.075	0.070	0.040	0.065
2	0.154	0.136	0.111	0.064	0.116
4	0.226	0.258	0.234	0.136	0.214
Mean	0.116	0.121	0.106	0.061	
LSD (0.05):	[Zn]= 0.015		[Cd]= 0.015	[Zn Cd]= 0.029	
	Straw				
0	0.07	0.06	0.06	0.03	0.06
1	2.68	2.67	2.35	1.31	2.25
2	6.06	5.81	5.76	3.88	5.38
4	9.57	9.40	8.63	6.19	8.45
Mean	4.59	4.48	4.20	2.85	
LSD (0.05):	[Zn]= 0.37		[Cd]= 0.37	[Zn Cd]= 0.74	

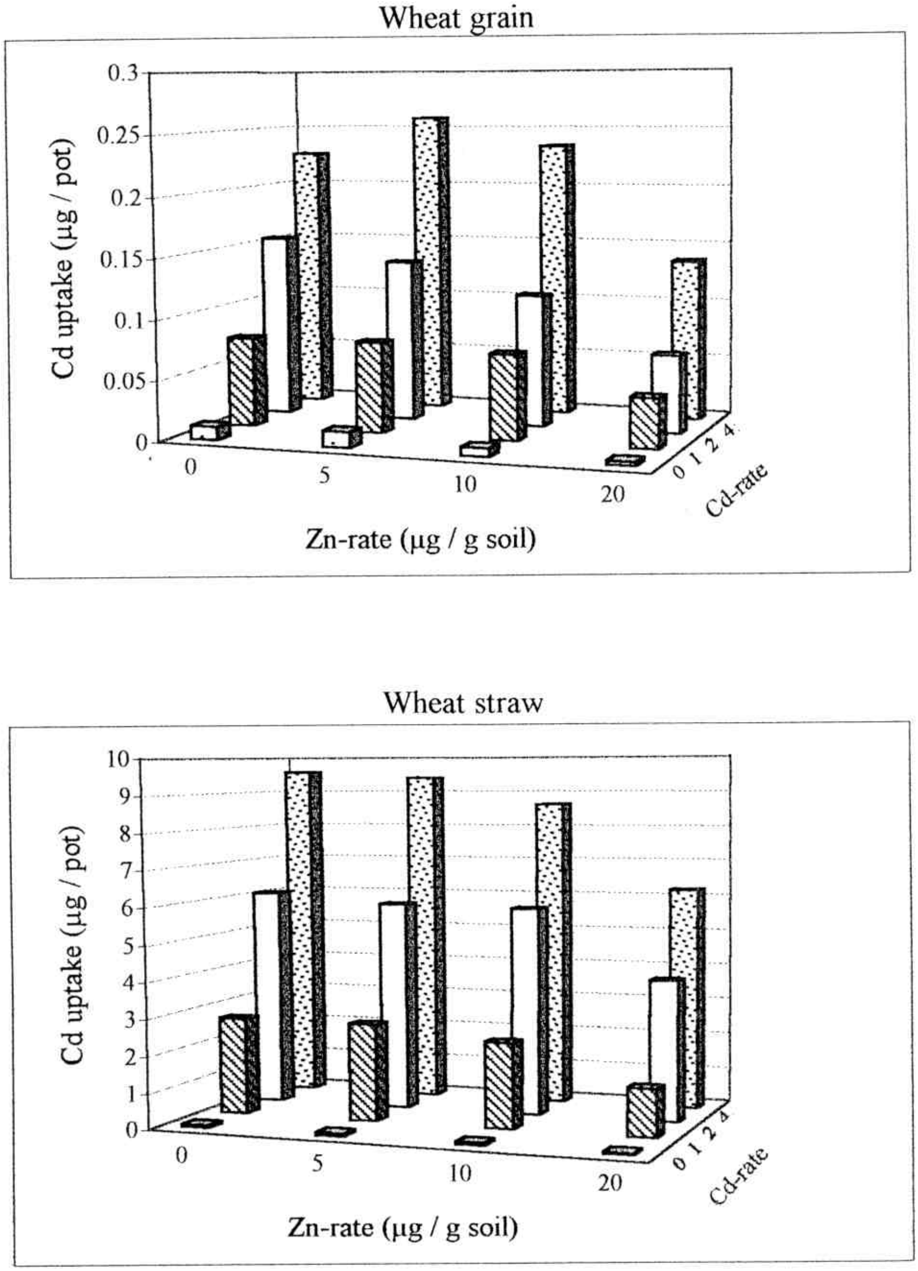


Fig. (26): Effect of zinc and cadmium treatments on Cd uptake by wheat plants.

straw were 4.59, 4.48, 4.20 and 2.85 μg pot^{-1} for the same Zn treatments, respectively.

There was a significant interaction between Zn and Cd. Application of Zn and its increased rates caused no significant change in Cd uptake by plants, which had not received Cd (since the slight decrease under such condition was not significant). Under conditions of 1 to 2 μg Cd g^{-1}, the decreased Cd uptake due to Zn addition was not significant, except at the highest Zn rate (20 μg Zn g^{-1}). Under conditions of 4 μg Cd g^{-1}, the rate of 5 μg Zn g^{-1} caused insignificant decrease, but beyond this rate decreases were progressive and significant. Therefore, the positive effect of Zn application on preventing accumulation of Cd was most prominent under conditions of high Cd in the root zone.

The magnitude of Cd uptake increase due to its progressive application was extremely high in the case of straw than in the case of grains. This illustrated the ability of plant to prevent accumulation of Cd in grains, and allows such accumulation in straw instead. Applying 1, 2 and 4 μg Cd g^{-1} resulted in uptake magnitude of Cd of nearly 7, 13 and 23 folds in grains and 37, 90 and 141 folds in straw (as compared with Cd uptake in the no-Cd treatment).

Application of Cd resulted in an increase in Cd uptake by plants; the increase was progressive with increasing rate of applied Cd. Mean values of Cd uptake by grains of plants receiving 0, 1, 2 and 4 μg Cd g^{-1} soil were 0.009, 0.065, 0.116 and 0.214 μg pot^{-1}, respectively. Comparable values for Cd uptake by straw were 0.06, 2.25, 5.38 and 8.45 μg pot^{-1}, respectively. The increased uptake of Cd due to application of Cd and the progressive nature of this increase with progressive rates of applied Cd occurred under each of the four treatments of Zn (i.e. whether Zn was applied or not). The interaction between Zn and Cd concerned the response to Zn application rather than the response to Cd application.

4.2.4. Effect of applying zinc and $CaCO_3$ "in various degrees of fineness" on wheat growth and Zn in plant:

Calcium carbonate (limestone) was applied as powdered material of particles not exceeding 2.0mm Ø. The addition rate was 10 %. Since the soil was sand in texture, there was increased retention of water. Also, with increased degree of fineness of limestone, pots showed problems of soil aeration when pots were watered. During intervals between waterings, crusts of lime were observed on the soil surface, also hardening of soil body of pots was observed. This would have a negative effect on plant growth.

4.2.4.1. Dry matter yield:

Dry matter yields of grains and straw as affected by application of Zn and $CaCO_3$ "in the form of limestone of various degrees of fineness" are presented in Table 24 and Fig. 27. The diameters of $CaCO_3$ particles indicate their degree of fineness. They were as follow; D_1 "very coarse: 1.25-2.00 mm Ø", D_2 "coarse: 0.60-1.25 mm Ø", D_3 "fine: 0.25-0.60 mm Ø, D_4

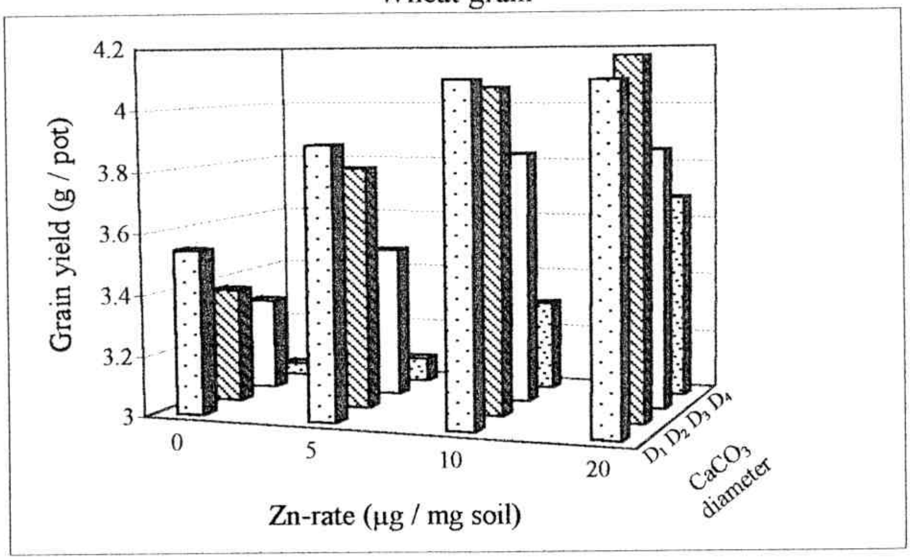
Table (24): Effect of zinc and diameters of $CaCO_3$ applications on the dry matter yield of wheat plants.

$CaCO_3$ diameter (mm)* [D]	Dry matter yield (g/pot)				
	Zn-rate (µg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grains				
D_1	3.54	3.89	4.10	4.10	3.91
D_2	3.38	3.80	4.07	4.17	3.86
D_3	3.31	3.50	3.84	3.86	3.63
D_4	3.04	3.08	3.30	3.68	3.28
Mean	3.32	3.57	3.83	3.95	3.67
LSD (0.05):	Zn] = 0.25		[D] = 0.25	[Zn D] = NS	
With no-$CaCO_3$	3.72	3.99	4.34	4.08	4.03
	Straw				
D_1	7.08	7.20	7.56	7.63	7.37
D_2	6.90	7.14	7.34	7.50	7.22
D_3	6.36	6.81	7.47	7.30	6.98
D_4	5.71	5.89	6.18	6.98	6.19
Mean	6.51	6.76	7.14	7.35	6.94
LSD (0.05):	[Zn] = 0.35		[D] = 0.35	[Zn D] = NS	
With no-$CaCO_3$	7.12	7.36	7.85	7.55	7.47

NS = not significant.

* D_1, D_2, D_3 and D_4 are diameters of $CaCO_3$ particles of 1.25-2.00, 0.60-1.25, 0.25-0.60 and < 0.25 mm; application rate of $CaCO_3$ = 10 % w/w to soil.

Wheat grain



Wheat straw

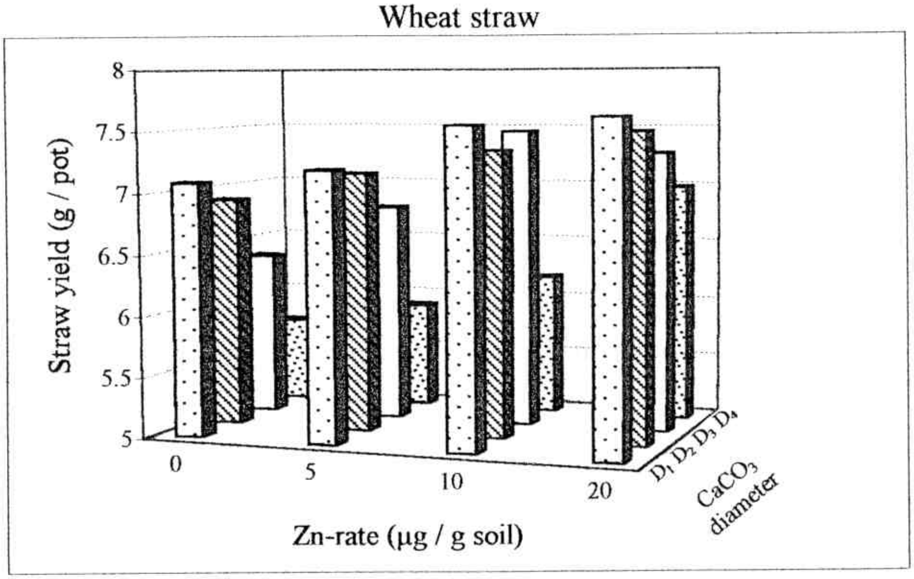


Fig. (27): Effect of zinc and diameter of $CaCO_3$ treatments on the dry matter yield of wheat plants.

"very fine: < 0.25 mm Ø". The rate of $CaCO_3$ application was 10 %.

Application of Zn increased yields of grains and straw; the increases were progressive with increasing rate of applied Zn. The response to application of Zn occurred in presence as well as in absence of $CaCO_3$. The mean values of grain yield due to addition of 0, 5, 10 and 20 µg Zn g^{-1} soil were 3.72, 3.99, 4.34 and 4.08 g pot^{-1}, respectively for treatments not receiving $CaCO_3$. Mean values for treatments receiving $CaCO_3$ were 3.32, 3.57, 3.83 and 3.95 g pot^{-1}, respectively. Corresponding straw yields were 7.12, 7.36, 7.85 and 7.55 g pot^{-1} (with no-$CaCO_3$), and 6.51, 6.76, 7.14 and 7.35 g pot^{-1} (with $CaCO_3$) for the same Zn treatments, respectively. Percentage increases of the dry weight (for the no-$CaCO_3$ and $CaCO_3$ treatments) due to Zn application and as a result of applying 5, 10 and 20 µg Zn g^{-1} soil were in the same respective order as follows: for grains: 7.4, 16.2 and 14.2 %; for straw: 3.5, 10.0 and 9.3 %, respectively. **Soliman (1980)** found that growth of wheat plant grown on a sandy loam soil was stimulated by increasing Zn application. **Badr (1998)** reported an increase in the growth of barley plants grown on a calcareous soil due to Zn application up to 20 µg Zn g^{-1} soil.

Application of $CaCO_3$ (in the form of limestone particles) resulted in a decrease of yields averaging 8.9 % for grains and 7.1 % for straw. The decrease was progressive with the decrease in the diameter of $CaCO_3$. Percentage decrease in grain yield due to $CaCO_3$ application as particles of very coarse, coarse, fine and very fine particles were 3.0, 4.2, 9.9 and 18.6 % for each size category, respectively. Corresponding percentage decreases regarding straw yields were 1.3, 3.3, 6.6 and 17.1 %, respectively. Therefore with increased fineness of $CaCO_3$ in soil, decreased plant growth due to presence of $CaCO_3$ becomes more considerable. It is shown in these data that the magnitude of fineness of $CaCO_3$ resulted in nearly a similar magnitude of yield reduction. For example, the reduction by one half of particle size from D_1 to D_2 (i.e. from the very coarse "1.25-2.00 mm" to the coarse "0.60-1.25 mm") was associated with a yield reduction at D_2 = twice the reduction which was caused by D_1.

Results of the current study illustrate the increased negative effectiveness of fine $CaCO_3$ particles creating more reactive surface area of such particles, which causes decreased availability of some soil nutrients, particularly P and Zn. These findings are in agreement with those achieved by **Moore and Loeppert (1990) and Fahmy (1995)**, who reported negative effect of $CaCO_3$ on availability of Zn in calcareous soils.

The negative effect of $CaCO_3$ on the dry matter yield was reported by **Fahmy (1995),** who found that yield of barley plant was inversely proportional to the soil content of $CaCO_3$. **Eskandar (2001)** attributed the decrease in the yield of sorghum shoots caused by $CaCO_3$ addition to soil to the alkaline pH resulting from the hydrolysis of $CaCO_3$ ($CaCO_3 + HOH \rightarrow Ca^{+2} + HCO_3^- + OH^-$) with HCO_3 ions transforming into CO_3 ions. Alkaline pH along with presence of carbonate ions would lead to precipitation of nutrients such as P, Zn, Fe and Mn, therefore decreasing plant growth.

Abdel-Latif et al. (1984) reported that the dry matter yield of maize plants grown in calcareous soils decreased with the increase of their contents of $CaCO_3$ of the < 0.002-mm size.

There was no significant interaction between Zn and $CaCO_3$ fineness application; i.e. the pattern of increased yield with increased application of Zn took place in presence as well as in absence of $CaCO_3$. Also decreased yield caused by application of $CaCO_3$ and the severity of each decrease with increased fineness of $CaCO_3$ particles occurred in presence as well as absence of Zn. Increased fineness of $CaCO_3$ in such a coarse sandy soils showed some adverse water-relationships as mentioned in 4.2.4.

4.2.4.2. Zinc in plant:

Data presented in Tables 25 and 26 and Figs. 28 and 29 show Zn concentration and uptake by wheat plants as affected by addition of Zn and addition of limestone particles of various degrees of fineness.

I. Zinc concentration: (Table 25 and Fig. 28)

The obtained data show that applying Zn increased Zn concentration in grains and straw; the increases were progressive with increasing rate of applied Zn. The response to application of Zn occurred in presence as well as in absence of limestone particles. The mean values of Zn concentration in grains due to addition of 0, 5, 10 and 20 μg Zn g^{-1} soil, and under condition of no added $CaCO_3$ were 22.6, 28.7, 38.4 and 50.7 μg g^{-1}, respectively. The corresponding mean values under conditions of $CaCO_3$ addition were 13.0, 22.1, 32.6 and 41.0 μg Zn g^{-1}, for

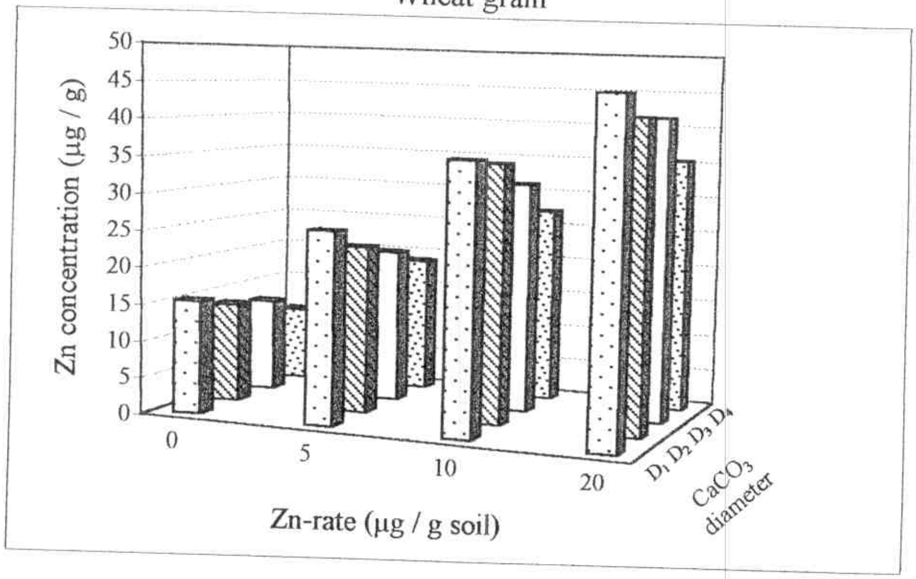
Table (25): Effect of zinc and diameters of $CaCO_3$ applied on Zn concentration in wheat plants.

$CaCO_3$ Diameter (mm)* [D]	Zn concentration (µg g^{-1})				
	Zn-rate (µg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grain				
D_1	15.3	25.9	36.1	45.3	30.7
D_2	13.6	22.8	35.2	42.0	28.4
D_3	12.8	21.1	31.8	41.6	26.8
D_4	10.3	18.8	27.3	35.3	22.9
Mean	13.0	22.1	32.6	41.0	27.2
LSD (0.05):	[Zn] = 1.3	[D] = 1.3	[Zn D] = NS		
With no-$CaCO_3$	22.6	28.7	38.4	50.7	35.1
	Straw				
D_1	12.9	17.2	28.7	36.8	23.9
D_2	11.3	16.8	25.6	34.4	22.0
D_3	10.8	15.2	21.5	31.9	19.9
D_4	10.6	14.8	18.8	28.1	18.1
Mean	11.4	16.0	23.6	32.8	21.0
LSD (0.05):	[Zn] = 1.7	[D] = 1.7	[Zn D] = 3.3		
With no-$CaCO_3$	16.1	23.7	31.1	41.6	28.1

NS = not significant.

* D_1, D_2, D_3 and D_4 are diameters of $CaCO_3$ particles of 1.25-2.00, 0.60-1.25, 0.25-0.60 and < 0.25 mm; application rate of $CaCO_3$ = 10 % w/w to soil.

Wheat grain



Wheat straw

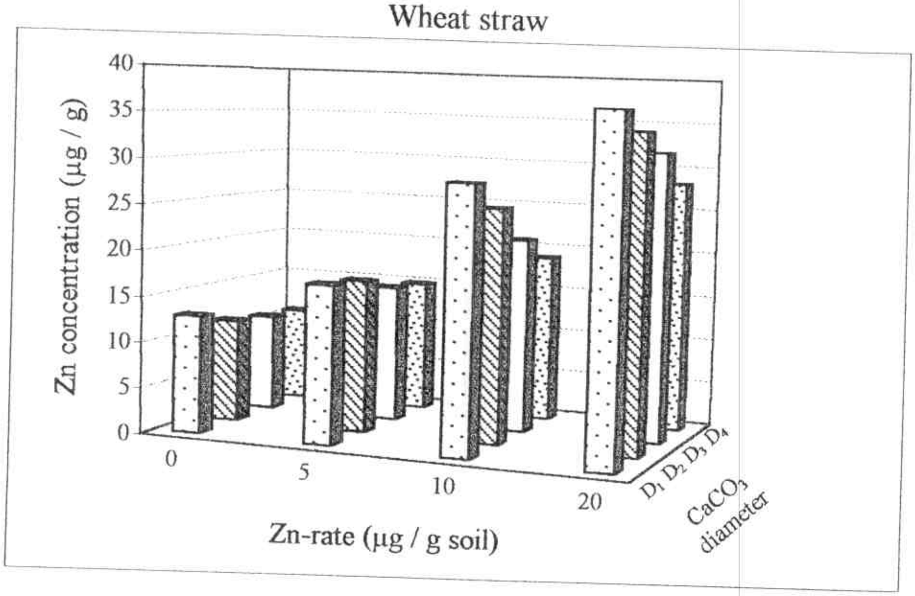


Fig. (28): Effect of zinc and diameter of $CaCO_3$ treatments on Zn concentration in wheat plants.

each of the above-mentioned Zn rate, respectively. Corresponding Zn concentrations in straw were 16.1, 23.7, 31.1 and 41.6 µg Zn g^{-1} (with no-$CaCO_3$), and 11.4, 16.0, 23.6 and 32.8 µg g^{-1} (with $CaCO_3$) for the same Zn rates, respectively. In this connection, **Soliman (1980)** found that Zn application increased Zn content of wheat plant grown in pots of sandy loam soil, but the response was less pronounced in presence of $CaCO_3$ particularly when it increased.

Application of $CaCO_3$ resulted in a decrease of Zn concentration averaging 23 % for grains and 25 % for straw. The decrease in Zn concentration was progressive with the decrease in the diameter of $CaCO_3$. The mean values of Zn concentration in grains due to $CaCO_3$ application in diameters of D_1, D_2, D_3 and D_4 were 30.7, 28.4, 26.8 and 22.9 µg Zn g^{-1}, respectively. The corresponding values regarding Zn concentration in straw were 23.9, 22.0, 19.9 and 18.1 µg g^{-1}, respectively.

Statistical analysis shows a significant interaction between the degree of $CaCO_3$ fineness and the rate of Zn addition with regard to Zn concentration in straw. Under conditions of no Zn or the lowest rate of Zn, the effect of increased fineness of $CaCO_3$ was not significant. Under conditions of the high rates of Zn, the negative effect of increased fineness of $CaCO_3$ was very much prominent and significant. Therefore, under no-Zn or the lowest rate of added Zn (5 µg g^{-1}), $CaCO_3$ application as very coarse, coarse, fine and very fine particles was of equal effect concerning Zn concentration in straw; and that under condition of high Zn rates, increased fineness of $CaCO_3$ was associated with marked decrease in Zn concentration.

Abdel-Latif et al. (1984) found that Zn concentration in maize plants grown on calcareous soils having equal contents of $CaCO_3$ decreased as the fine particle size of $CaCO_3$ was increased especially with sizes below 2 μ Ø.

II. Zinc uptake: (Table 26 and Fig. 29)

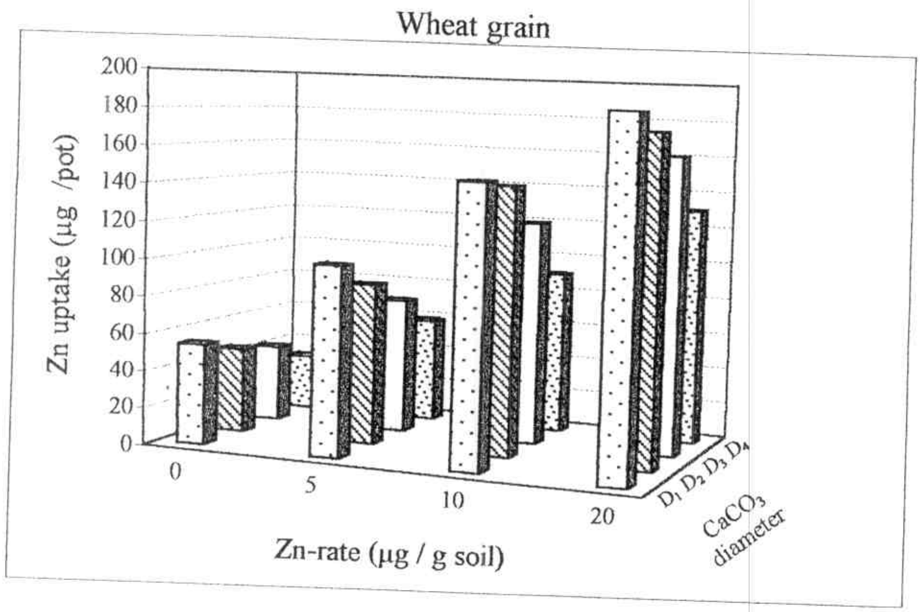
The obtained data show that Zn uptake by grains and straw of wheat followed a trend which was rather similar to that of plant growth and Zn concentration since Zn addition caused an increase in the yield as well as Zn concentration and consequently increase in Zn uptake. This response to application of Zn occurred in presence as well as in absence of limestone particles. The mean values of Zn uptake in grains due to addition of 0, 5, 10 and 20 μg Zn g^{-1} soil were 84, 115, 167 and 207 μg pot^{-1}, respectively for treatments not receiving limestone. Corresponding mean values due to addition of each Zn rates for treatments receiving limestone were 43, 80, 126 and 163 μg Zn pot^{-1}, respectively. Corresponding Zn uptake in straw were 115, 174, 244 and 314 μg Zn pot^{-1} (with no-$CaCO_3$), and 75, 109, 170 and 242 μg pot^{-1} (with $CaCO_3$) for the same Zn rates, respectively. In this respect, there was a significant interaction between Zn and the magnitude of fineness of $CaCO_3$ concerning straw (but not grains). Increased Zn uptake with increased Zn application occurred where $CaCO_3$ was very coarse, coarse or fine, i.e. up to D_3. Under conditions of very fine $CaCO_3$, increased uptake due to adding 5 μg Zn g^{-1} was not significant.

Table (26): Effect of zinc and diameters of $CaCO_3$ applied on Zn uptake by wheat plants.

$CaCO_3$ Diameter (mm)* [D]	Zn uptake (µg pot^{-1})				
	Zn-rate (µg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grain				
D_1	54	101	148	186	122
D_2	46	87	144	175	113
D_3	42	74	122	161	100
D_4	31	58	90	130	77
Mean	43	80	126	163	103
LSD (0.05):	[Zn] = 10		[D] = 10	[Zn D] = NS	
With no-$CaCO_3$	84	115	167	207	143
	Straw				
D_1	91	124	217	280	178
D_2	78	120	189	259	161
D_3	68	104	160	233	141
D_4	61	88	116	196	115
Mean	75	109	170	242	149
LSD (0.05):	[Zn] = 14		[D] = 14	[Zn D] = 28	
With no-$CaCO_3$	115	174	244	314	212

NS = not significant.

* D_1, D_2, D_3 and D_4 are diameters of $CaCO_3$ particles of 1.25-2.00, 0.60-1.25, 0.25-0.60 and < 0.25 mm; application rate of $CaCO_3$ = 10 % w/w to soil.



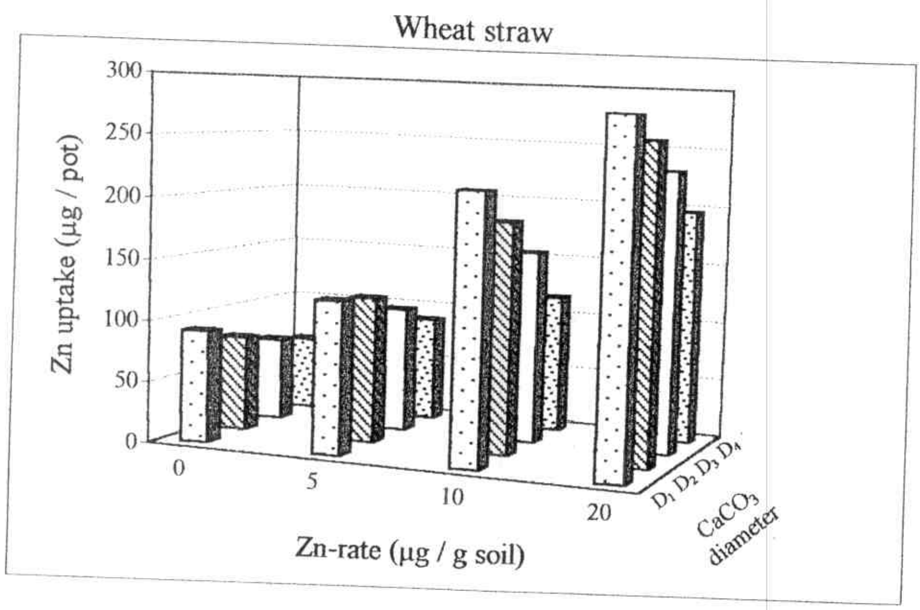


Fig. (29): Effect of zinc and diameter of $CaCO_3$ treatments on Zn uptake by wheat plants.

Thus, very fine $CaCO_3$ caused no response to the 5 μg Zn g^{-1} soil indicating possible fixation of Zn by fine $CaCO_3$.

Application of $CaCO_3$ resulted in a decrease of Zn uptake averaging 28 % for grains and 30 % for straw. The decrease in Zn uptake due to presence of $CaCO_3$ was progressive with the decrease in the diameter of $CaCO_3$, i.e. with increased fineness. The mean values of Zn uptake in grains due to $CaCO_3$ application in diameters of D_1, D_2, D_3 and D_4 were 122, 113, 100 and 77 μg Zn pot^{-1}, respectively. Corresponding values regarding Zn uptake in straw were 178, 161, 141 and 115 μg pot^{-1}, respectively.

The significant interaction caused by Zn rates on the response to $CaCO_3$ fineness (concerning straw) show that the progressive negative effect caused by increased fineness occurred only under conditions of 10 or 20 μg Zn g^{-1}. Under conditions of 0 or 5 μg Zn g^{-1}, the negative effect of $CaCO_3$ fineness was not always significant.

4.2.5. Effect of applying zinc and clay soil material on wheat growth and Zn in plant:

4.2.5.1. Dry matter yield:

Data presented in Table 27 and Fig. 30 show grains and straw dry matter yields as affected by application of Zn in various rates and addition of clay (soil material of a clay soil).

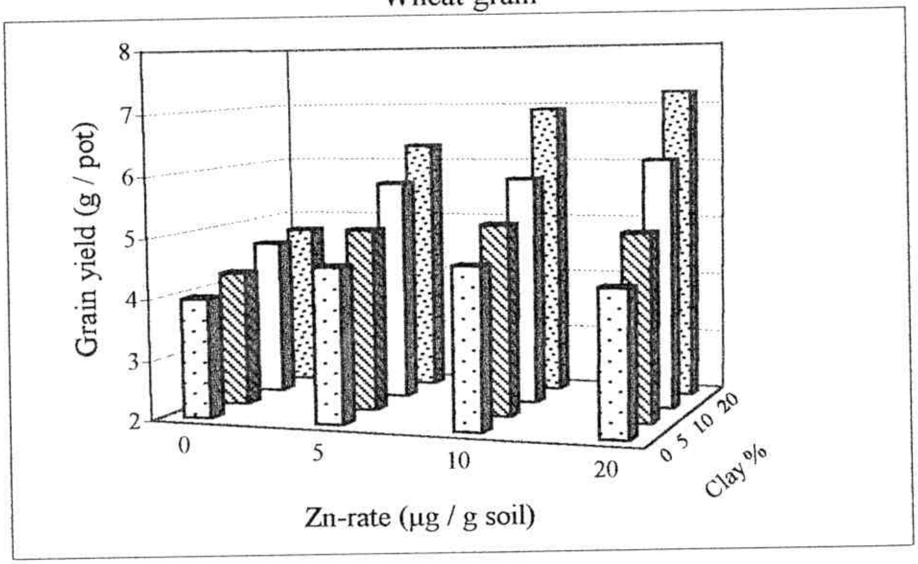
Application of Zn caused increases in yields of grains and straw. However, rates of 5 to 20 μg g^{-1} gave similar response in grain yield; but concerning straw, increasing the rate of applied

Table (27): Effect of zinc application and clay addition to the sand soil on the dry matter yield of wheat plants.

Applied Clay % [C]	Dry matter yield (g/pot)				
	Zn-rate (μg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	3.97	4.55	4.62	4.33	4.37
5	4.24	5.02	5.14	5.05	4.86
10	4.62	5.69	5.78	6.11	5.55
20	4.74	6.28	6.91	7.20	6.28
Mean	4.39	5.38	5.62	5.67	
LSD (0.05):	[Zn] = 0.47		[C] = 0.47	[Zn C] = NS	
	Straw				
0	6.90	7.90	9.00	7.84	7.91
5	8.33	9.14	10.72	10.95	9.79
10	9.18	10.05	11.25	12.05	10.63
20	10.06	11.62	12.49	13.49	11.92
Mean	8.62	9.68	10.86	11.09	
LSD (0.05):	[Zn] = 0.65		[C] = 0.65	[Zn C] = NS	

NS = not significant.

Wheat grain



Wheat straw

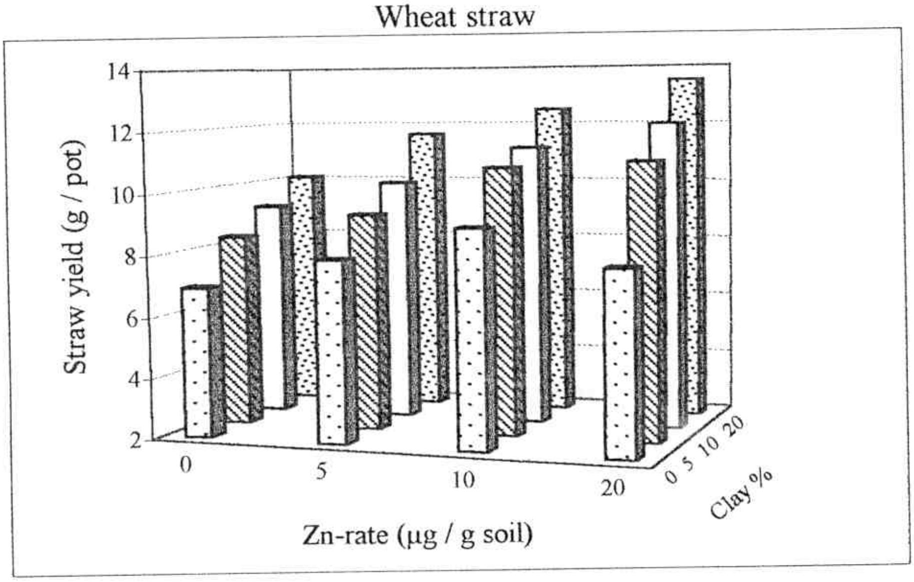


Fig. (30): Effect of zinc and clay treatments on the dry matter yield of wheat plants.

Zn was associated with a progressive increase up to 10 μg Zn g^{-1} in straw yields. Therefore, increases in the yield caused by Zn application beyond 5 μg g^{-1} for grains and 10 μg g^{-1} for straw were not significant. The mean values of the percentage increase of the dry weight of grains (over the no-Zn treatments) were 22.6, 28.0 and 29.2 % for treatments receiving 5, 10 and 20 μg Zn g^{-1} soil, respectively. The corresponding mean values for straw were 12.3, 26.0 and 28.7 %, respectively.

Regarding the effect of adding clay application (clay soil material) to such a sand soil, results show that the yields of grains and straw were significantly increased due to application of clay. The increase was progressive with increasing the rate of applied clay up to the highest rate of 20 % clay. Application of clay at the rates of 5, 10 and 20 % resulted in percentage increases in yield of grains of 11.2, 27.0 and 43.7 %, respectively. In the case of straw, the corresponding percentages were 23.8, 34.4 and 50.7 %, respectively. The positive response of added clay soil material on wheat production might be due to the higher content of essential nutrients for plant growth brought about by the added clay soil material (see Table 2). There was no significant interaction affecting response to Zn or clay addition, i.e. no interaction between Zn and clay addition. Increased dry matter yield caused by increased Zn application or increased clay application occurred under all conditions. The highest yield (7.20 g grains and 13.49 g straw pot^{-1}) occurred with 20 μg Zn g^{-1} + 20 % clay. The lowest (3.97 g grains and 6.90 g straw pot^{-1}) occurred with no-Zn nor applied clay.

The aforementioned results show that yields of both wheat components (grains and straw) were more affected by clay application than Zn application since the magnitude of response to clay application was between about 11.2 to 51 % compared with 12.3 to 29 % due to Zn application.

Eskandar (2001) applied Zn at up to 10 µg Zn g^{-1} soil and found that application of Zn increased dry matter yield of sorghum plants grown on clay and sand soils; the increase in dry matter yield was more obvious in the clay soil than the sand one.

4.2.5.2. Zinc in plant:

Data presented in Tables 28 and 29 and Figs. 31 and 32 show Zn concentration and uptake by wheat plants as affected by application of zinc and application of the clay soil material.

I. Zinc concentration: (Table 28 and Fig. 31)

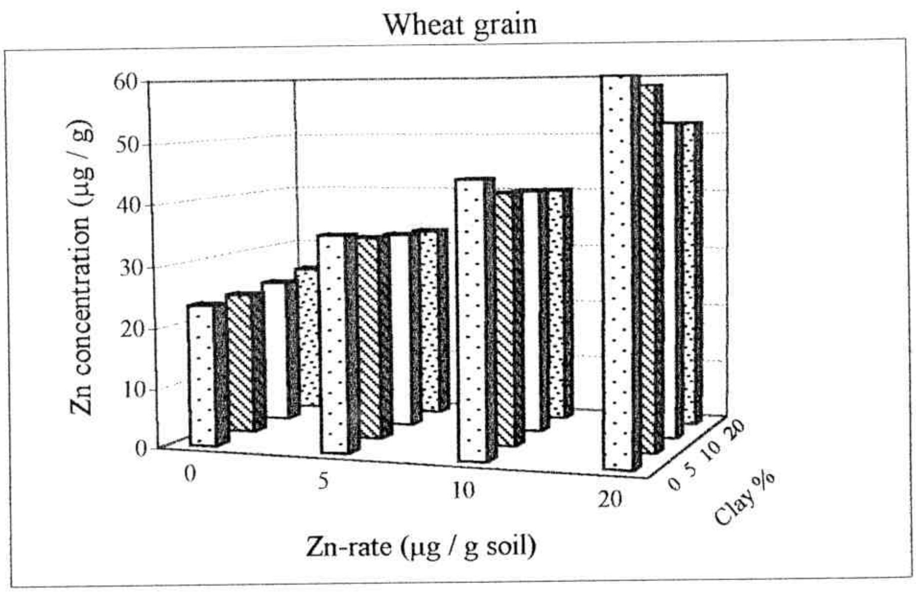
Data presented show that zinc concentration in grains and straw of wheat plants was significantly increased with application of Zn. The increase progressed with increasing the rate of applied Zn. The mean values of Zn concentration ranged from 24.3 to 55.6 µg Zn g^{-1} for grains and from 17.5 to 41.8 µg Zn g^{-1} for straw.

Regarding the effect of the applied clay soil material, the results show that applying clay (as clay soil material) to the sand soil had no significant effect concerning Zn concentration in grains and straw, since the slight decrease in Zn concentration caused by clay application was not statistically significant. The mean value of Zn concentration in grains decreased from 40.7 µg Zn g^{-1} in the no-clay treatment to 39.3, 37.7 and 37.6 µg g^{-1} for the rates of 5, 10 and 20 % clay, respectively. In the case of

Table (28): Effect of zinc and clay treatments on Zn concentration in wheat plants.

Applied Clay % [C]	Zn concentration (µg g⁻¹) Zn-rate (µg g⁻¹ soil) [Zn] 0	5	10	20	Mean
	Grains				
0	23.4	35.2	44.3	59.9	40.7
5	23.7	33.7	41.4	58.4	39.3
10	24.4	33.2	40.9	52.2	37.7
20	25.5	32.7	40.2	51.9	37.6
Mean	24.3	33.7	41.7	55.6	
LSD (0.05):	[Zn] = 3.5		[C] = NS		[Zn C] = NS
	Straw				
0	17.2	23.5	33.3	44.0	29.5
5	16.3	23.5	31.0	42.2	28.3
10	17.6	22.9	30.3	41.2	28.0
20	18.9	22.4	28.2	39.7	27.3
Mean	17.5	23.1	30.7	41.8	
LSD (0.05):	[Zn] = 2.3		[C] = NS		[Zn C] = NS

NS = not significant.



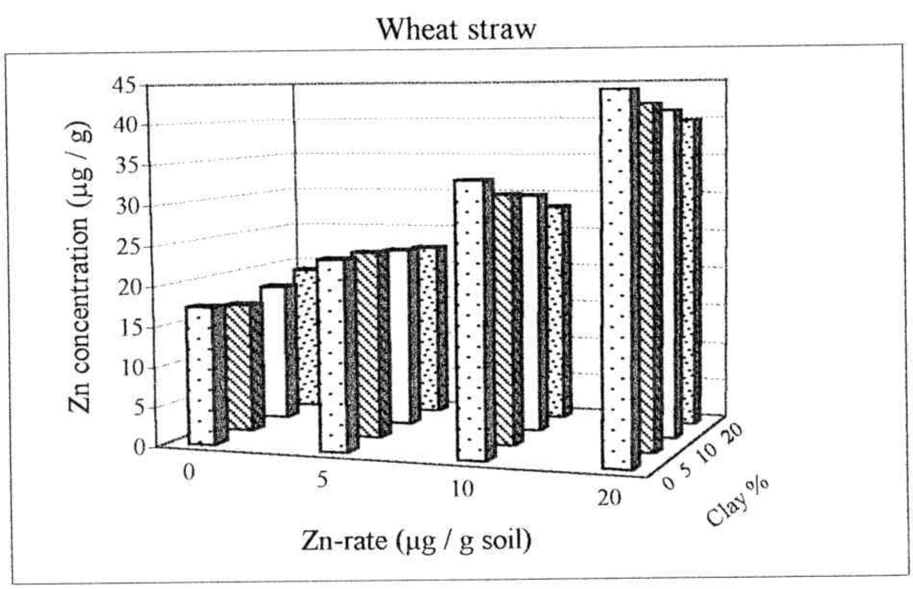


Fig. (31): Effect of zinc and clay treatments on Zn concentration in wheat plants.

straw, the corresponding values were 29.5 µg Zn g^{-1} for the no-clay treatment and 28.3, 28.0 and 27.3 µg g^{-1} for the three applied clay rates, respectively. The decrease in Zn concentration caused by applying clay reflects a "dilution effect" due to increased plant growth causing by increasing clay application.

II. Zinc uptake: (Table 29 and Fig. 32)

Data reveal that uptake of Zn by both grains and straw of wheat plants followed a trend similar to that of plant yields and Zn concentration with regard to the effect of Zn rate, i.e. yield and Zn concentration increased by Zn application, and the increase progressed with increasing the rate of Zn. The mean values of Zn uptake in grains increased significantly from being 106 µg pot^{-1} (no-Zn treatment) to 181, 232 and 310 µg pot^{-1} with rates of 5, 10 and 20 µg Zn g^{-1}, respectively. In the case of straw, the corresponding values were 152 µg pot^{-1} for no-Zn treatment and 223, 332 and 460 µg pot^{-1} for the 5, 10 and 20 µg Zn g^{-1} treatments, respectively.

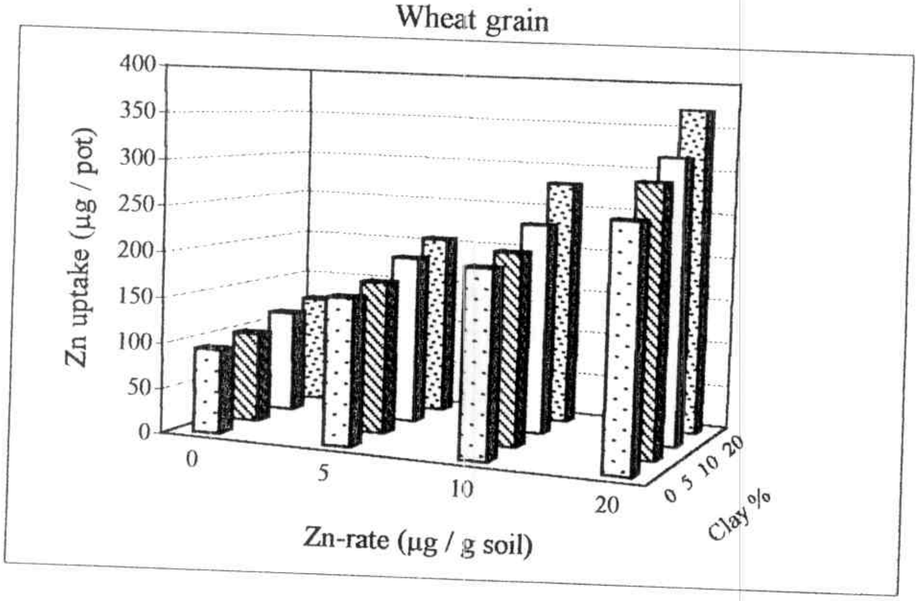
Concerning the applied clay material, the data indicate that its application to such a sand soil gave a response rather similar to that of plant yields; i.e. caused a significant increase in Zn uptake. Increasing the rate of applied clay was associated with a progressive increase in Zn uptake. However, some successive rates were similar in effect; there was no difference between no-clay and 5 % clay concerning Zn uptake by grains. In the case of straw, there was no difference between the 5 and 10 % clay; neither between the 10 and 20 % clay. The mean values of Zn uptake in grains of wheat plants of treatments of no-clay, 5, 10 and 20 % of applied clay were 178, 194, 214 and 243

Table (29): Effect of zinc and clay treatments on Zn uptake by wheat plants.

Applied Clay % [C]	Zn uptake (µg pot^{-1})				
	Zn-rate (µg g^{-1} soil) [Zn]				Mean
	0	5	10	20	
	Grains				
0	92	160	203	260	178
5	99	169	212	295	194
10	113	189	236	318	214
20	121	205	278	369	243
Mean	106	181	232	310	
LSD (0.05):	[Zn] = 18		[C] = 18	[Zn C] = NS	
	Straw				
0	119	186	300	347	238
5	136	215	334	463	287
10	161	231	342	496	307
20	190	260	353	534	334
Mean	152	223	332	460	
LSD (0.05):	[Zn] = 33		[C] = 33	[Zn C] = NS	

NS = not significant.

Wheat grain



Wheat straw

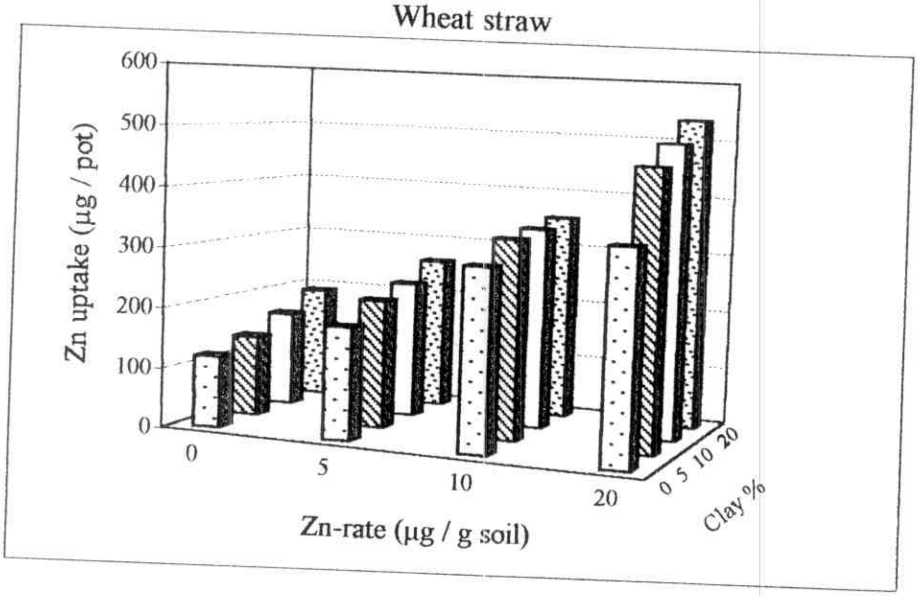


Fig. (32): Effect of zinc and clay treatments on Zn uptake by wheat plants.

μg pot^{-1}, respectively. The corresponding values in straw were 238, 287, 307 and 334 μg pot^{-1}, respectively. There was no significant interaction between addition of zinc and addition of clay, i.e. the pattern of response to Zn application was not affected by clay addition; and that the pattern of response to clay application was not affected by Zn addition.

Hegazy et al. (1991) found that Zn uptake by sorghum plants was highest in plants grown on alluvial soil, least on sand soil and came between on calcareous one.