RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The present study included three experiments dealing with iron deficiency phenomenon as affected by the applications of Fe, in different forms and rates (Experiment I), combined treatments of different rates of $CaCO_3$ and Fe (Experiment II), and rates of phosphorus applied in presence of what was found to be about optimum level of Fe (Experiment III).

In all treatments, *Sorghum bicolor* grown on sand cultures was utilized as an indicator plant and the following indices were considered; dry weight yields of sorghum plants, concentration and uptake of Fe, P, Ca, Mg, K, N and Mn as well as soluble iron that was leached or that precipitated in different forms in the sand culture.

4.1. Experiment I: Iron chlorosis as affected by Fe applications (source and rate):

In this experiment as mentioned before, sorghum plants grown on sand culture were subjected to Fe application in two sources (Fe-EDTA and $FeSO_4$) at 6 rates of each, namely; 0, 5, 10, 20, 40 and 60 ppm Fe.

4.1.1. Dry matter yield of sorghum as affected by Fe applications:

Data obtained on the dry matter yield of sorghum plants (roots and shoots) as affected by application of Fe-EDTA and $FeSO_4$ at different rates is presented in table (2) and depicted in Fig. (1).

Plant roots:

Results indicate that, the low applications of iron either as chelated or mineral Fe, increased the dry matter yield of sorghum plant roots up to a certain concentration where a maximum yield was produced, after which a diminishing tendency was revealed.

In this regard Fe-EDTA seemed to be more effective as the application of 5 ppm Fe as Fe-EDTA or $FeSO_4$, increased the dry matter yield of plant roots by about 2.1 and 1.9 fold in comparison with the control treatment, respectively.

It is obvious that the maximum increase in yield of plant roots was achieved at a relatively low rate (5 ppm Fe) in case of chelated Fe but at a comparatively higher rate of $FeSO_4$ (10-20 ppm). The effect of Fe-EDTA at most rates tended to be less effective compared to the corresponding rates of $FeSO_4$. This is specially true with the higher levels of the latter which would indicate an adverse effect of the chelated form at such higher rates.

Plant shoots:

As with roots, applications of iron increased the weight of the aboveground plant parts, but exhibited a progressive response along a wider range of Fe application, Table (2): Dry matter yield in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA. (g/pot)

Source	Rate of application (ppm)						
	0	5	10	20	40	60	Mean
				Roots			
Fe-EDTA	2.18	4.57	4.53	3.67	3.47	3.07	3.58
$FeSO_4$	2.13	4.07	5.57	5.37	4.10	4.97	4.37
Mean	2.16	4.17	5.05	4.52	3.78	4.02	
L.S.D. 0.05	S	0.47	R	0.81	S,R.	1.15	
0.01		0.64		1.11		1.56	
				Shoots			
Fe-EDTA	5.87	8.10	7.77	8.47	7.73	7.33	7.55
$FeSO_4$	6.57	7.70	7.93	7.73	8.47	7.50	7.65
Mean	6.22	7.90	7.85	8.10	8.10	7.42	
L.S.D. 0.05	S	n.s.	R	1.58	S.R.	n.s.	
0.01		n.s		2.15		n.s.	
				Whole plants			
Fe-EDTA	8.05	12.67	12.30	12.14	11.20	10.40	11.13
$FeSO_4$	8.70	11.77	13.50	13.10	12.57	12.47	12.02
Mean	8.38	12.22	12.90	12.62	11.89	11.44	
L.S.D. 0.05	S	n.s.	R	1.58	S.R.	n.s.	
0.01		n.s.		2.15		n.s.	

S = Source

R = Rate

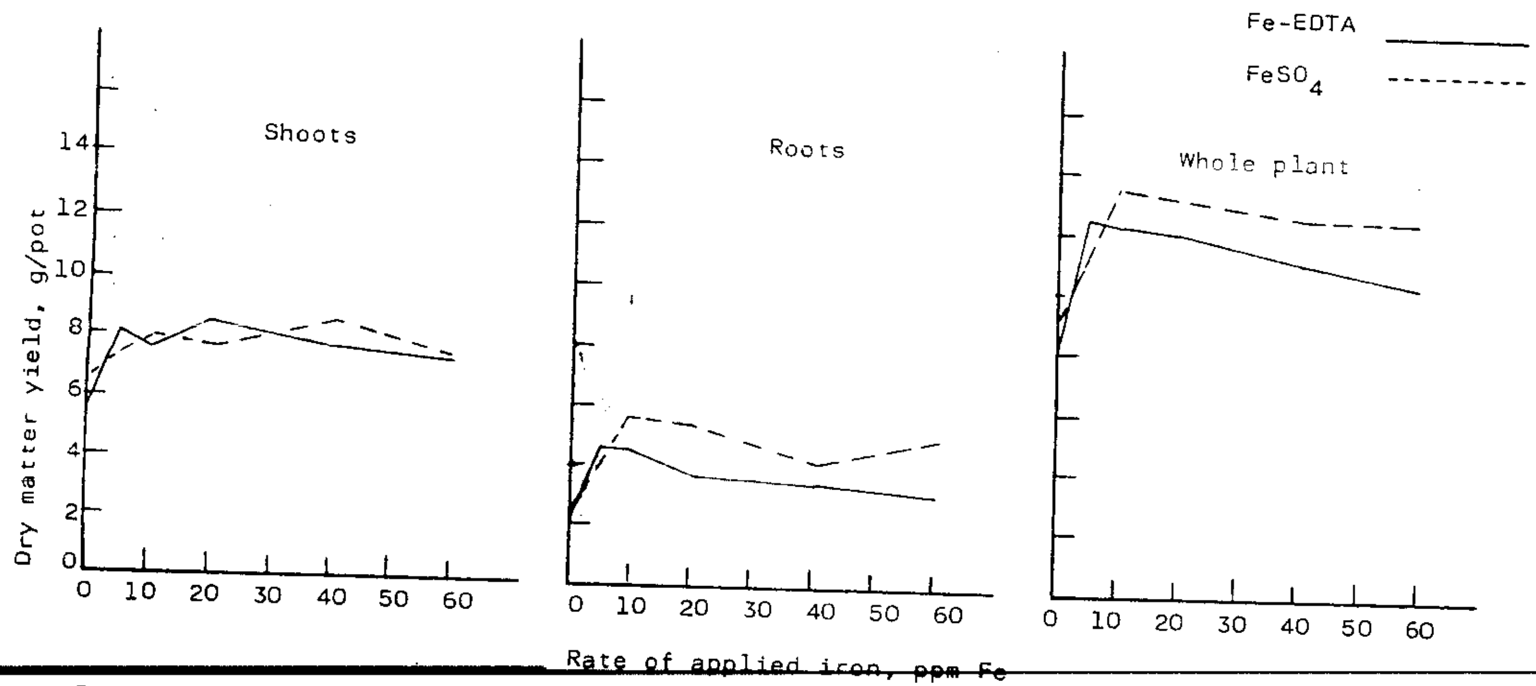


Fig. (1): Effect of applied iron (source and rate) on dry matter yield of sorghum plants.

(up to 20 ppm Fe as Fe-EDTA, and up to 40 ppm as $FeSO_4$), where the maximum dry matter of shoots was produced. At higher rates, however, a slight reduction occurred in the dry matter yield of plant shoots.

As compared with Fe in the chelated form, almost at all rates, the $FeSO_4$ tended to be slightly superior. Such trend is, in general, in agreement with that noticed with the root.

Whole plants:

Regarding both iron source and rate of application the pattern of response of sorghum plants, as whole, to Fe application resembled materially that of the shoots, which comprise more than two-thirds of the plant dry weight.

It is worthy mentioning that severe tipical iron deficiency symptoms, chlorosis and stunted plant growth, was observed with the control treatment plate (1).

These results are in harmony with those reported by Mathers (1970) that the mineral forms of $FeSO_4$ were effective in rectifying Fe chlorosis in sorghum. Dahiya and Singh (1982) reported that the increase in dry matter yield of oats was also recorded with increasing the rate of Fe applied as $FeSO_4$. However, Mortvedt (1982) showed that $FeSO_4$ gave lower forage yields of Sudan grass as compared with Fe-EDTA.

4.1.2. Nutrient elements in sorghum as affected by iron application:

Status of some nutrient elements, that are believed to be involved either directly or indirectly in the phenomenon of iron chlorosis was determined and the results were discussed with respect to the concentration and uptake of each element. The data obtained, are given in tables (3 through 12) and illustrated in Figs. (2 to 11).

The results of the imposed treatments showed significant variations only with respect to Fe, P, Ca, Mg and Mn, but not with N and K. Accordingly, the significant relations of the former group of nutrients only are presented and discussed in the following part of text.

4.1.2.1. Iron concentration and uptake by sorghum:

Iron concentration in sorghum roots and shoots:

The results of iron concentration in sorghum plant parts are shown in table (3) and graphically illustrated in Fig. (2).

Plant roots:

Both forms of applied iron (chelated and mineral) significantly increased the Fe concentration in sorghum roots, Fe-EDTA showed higher effect as compared with Fe sulfate particularly when applied at low rates. The maximum increase in Fe concentration was observed with the 5 ppm Fe rate in case of Fe-EDTA and at the 20 ppm Fe

Table (3): Iron concentration in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mgFe/g dry matter)

Source		Rate of application (ppm)						Mean
		0	5	10	20	40	60	
					Roots			
Fe-EDTA		0.36	1.96	1.34	0.58	1.02	0.99	1.04
$FeSO_4$		0.50	0.94	1.99	2.24	1.30	1.57	1.42
Mean		0.43	1.45	1.67	1.41	1.16	1.28	
L.S.D.	0.05	S	n.s.	R	0.72	S.R.	1.02	
	0.01		n.s.		0.98		1.39	
					Shoots			
Fe-EDTA		0.169	0.187	0.203	0.231	0.356	0.389	0.256
$FeSO_4$		0.192	0.176	0.187	0.196	0.194	0.199	0.199
Mean		0.181	0.182	0.195	0.214	0.275	0.294	
L.S.D.	0.05	S	0.028	R	0.049	S.R.	0.069	
	0.01		0.038		0.066		0.094	

S = Source.
R = Rate

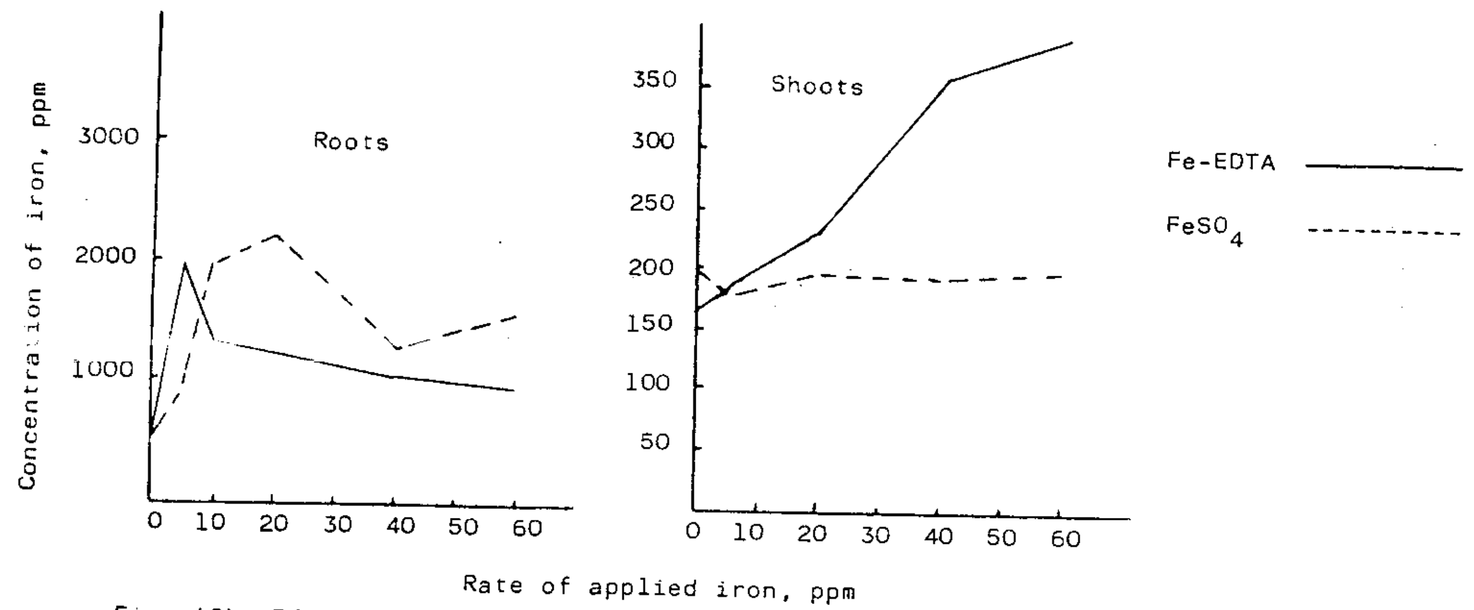


Fig. (2): Effect of applied iron (source and rate) on concentration of iron in sorghum plants.

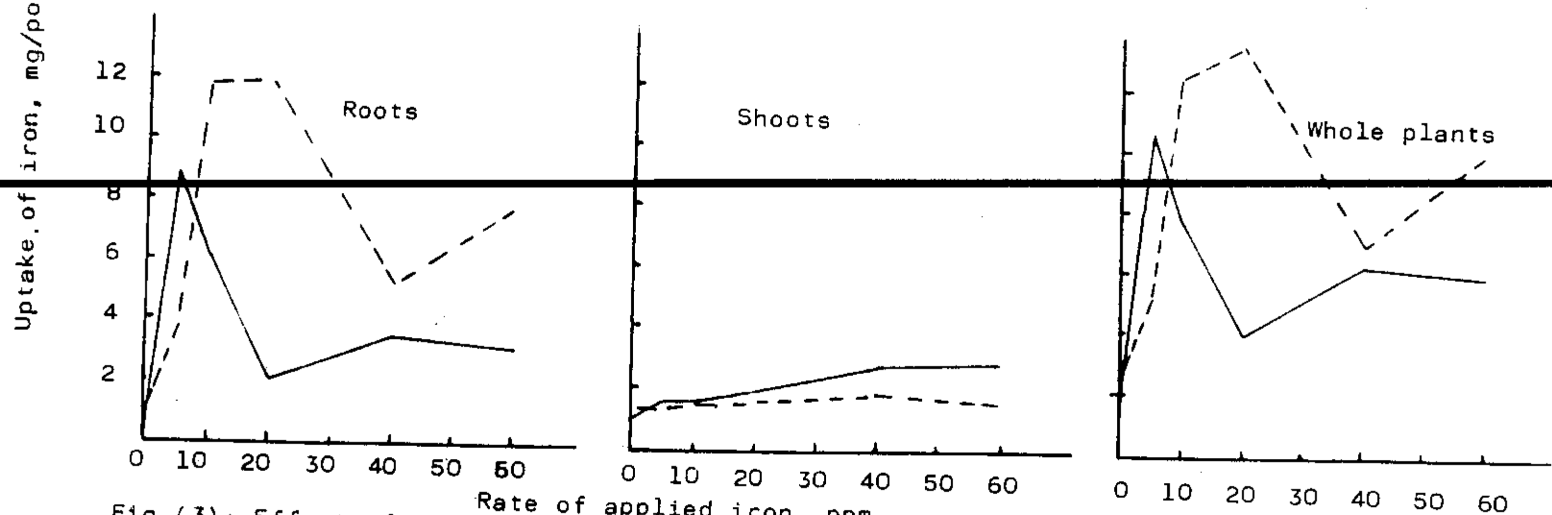


Fig.(3): Effect of applied iron (source and rate) on uptake of iron by sorghum plants.

in case of $FeSO_4$. Such maximum, however, was slightly higher with the use of the latter compound. The iron concentration in roots tended to decrease with further rates of either sources.

Plant shoots:

Significant and gradual responses due to increasing the rate of applied Fe occurred with the chelated form. With iron sulfate however, a slight reduction in iron concentration with the first two rates, increased very slightly thenafter it remained almost constant. Such trend could be referred to the dilution effect, on one hand, and the limited translocation of Fe when applied as $FeSO_4$ on the other. The low values of Fe concentration in sorghum plants of the control treatment and the cute chlorosis symptoms observed, at the same time, on these plants (plates 1, 2), evidenced that such symptoms are due to Fe deficiency.

Application of iron at the rate of 5 ppm Fe as Fe-EDTA, or 20 ppm as $FeSO_4$ clearly raised to the Fe concentration in sorghum plants and rectified the iron chlorosis symptoms. However, it can be noticed that, as compared with control, iron concentration in plant shoots was increased by 1.1, 1.2, 1.37, 2.11 and 2.3 times with increasing the application rate to 5, 10, 20, 40 and 60 ppm

Plate (1): Growth and color of sorghum plants as affected by added iron, as Fe-EDTA. It is noticable that the degree of yellowish in plant color is severely developed in case of the control treatment.

Plate (2): Growth and color of sorghum plants as affected by iron added as $FeSO_4$. The gradual development in the yellow color of plants could be noticed in the low Fe supply treatments.

Fe as Fe-EDTA, respectively. With iron sulfate, however, only a very slight increase was noticed. Such results are in good agreement with those obtained by Somers and Shive (1942), Weinstein and Robbins (1955) and Twyman (1951).

Iron uptake by sorghum:

The data obtained for Fe uptake and contained in sorghum roots and shoots are tabulated in table (4) and shown in Fig. (3).

Iron uptake by plant roots:

The results show that iron uptake by roots was significantly increased with the application of either Fe-EDTA or $FeSO_4$. It may be profitable to observe that the maximum increase in Fe uptake in sorghum roots was produced with the application of $FeSO_4$ at rate of 20 ppm Fe, or FeEDTA at a rate of 5 ppm Fe. However, the maximum value was significantly higher with $FeSO_4$ as a source of iron supply. Further rates resulted in very sharp reduction in root iron content which was more obvious with Fe-EDTA (the higher soluble form).

Iron uptake in shoots:

The values of Fe uptake by plant shoots were much lower than those of the roots and increased by 1.53, 1.59, 1.94, 2.77 and 2.86 times with Fe-EDTA applied at the

Table (4): Iron uptake by sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg Fe/pot).

Source	Rate of application (ppm) 0	5	10	20	40	60	Mean
				Roots			
Fe-EDTA	0.79	8.95	6.10	2.14	3.54	3.03	4.09
$FeSO_4$	1.07	3.82	11.09	12.00	5.32	7.81	6.85
Mean	0.93	6.39	8.60	7.07	4.43	5.42	
L.S.D. 0.05	S	2.38	R	4.11	S.R	5.83	
L.S.D. 0.01		3.23		5.58		7.92	
				Shoots			
Fe-EDTA	1.00	1.53	1.59	1.94	2.77	2.86	1.95
$FeSO_4$	1.26	1.36	1.48	1.51	1.65	1.46	1.45
Mean	1.13	1.45	1.53	1.73	2.21	2.16	
L.S.D. 0.05	S	0.26	R	0.46	S.R	0.65	
L.S.D. 0.01		0.36		0.62		0.88	
				Whole plants			
Fe-EDTA	1.79	10.48	7.69	4.08	6.31	5.89	6.04
$FeSO_4$	2.33	5.18	12.57	13.51	6.97	9.97	8.42
Mean	2.06	7.83	10.13	8.80	6.64	7.93	
L.S.D. 0.05	S	n.s.	R	4.13	S.R	n.s.	
L.S.D. 0.01		n.s.		5.61		n.s.	

S = Source R = Rate

rates of 5, 10, 20, 40, and 60 ppm, respectively. Increasing applications of Fe up to 40 ppm Fe in the mineral form also enhanced the Fe concentration, but the magnitude of increase was always less than the corresponding rates of Fe-EDTA and slightly higher than the untreated control plants.

The results elucidate the importance of maintaining adequate supply of iron to plants in order to produce healthy plant growth of both roots and shoots. As previously mentioned, a rate of Fe application as low as 5 ppm Fe as chelated form (Plate 1) or as higher as 20 as $FeSO_4$ (Plate 2) could be enough for maintaining adequate growth of sorghum plants under the conditions prevalent in sandy cultures. Chlorotic appearance was still observed on plants supplied with iron up to the rate of 5 ppm as $FeSO_4$ (plate 3).

Immediately following Fe absorption by roots, it should be easily translocated to plant stems and leaves where it stays, Tiffin (1972). It may even be further mobile from old leaves to young ones, Kannan and Pondy (1982). In spite of that phosphates may render iron inactive and precipitate it inside plant tissues, besides, adsorption of iron cations would certainly occur on the root surface of plants grown in $FeSO_4$ treatments, Chaney and Coulombe (1982). The superiority of the chelated sources over the mineral ones

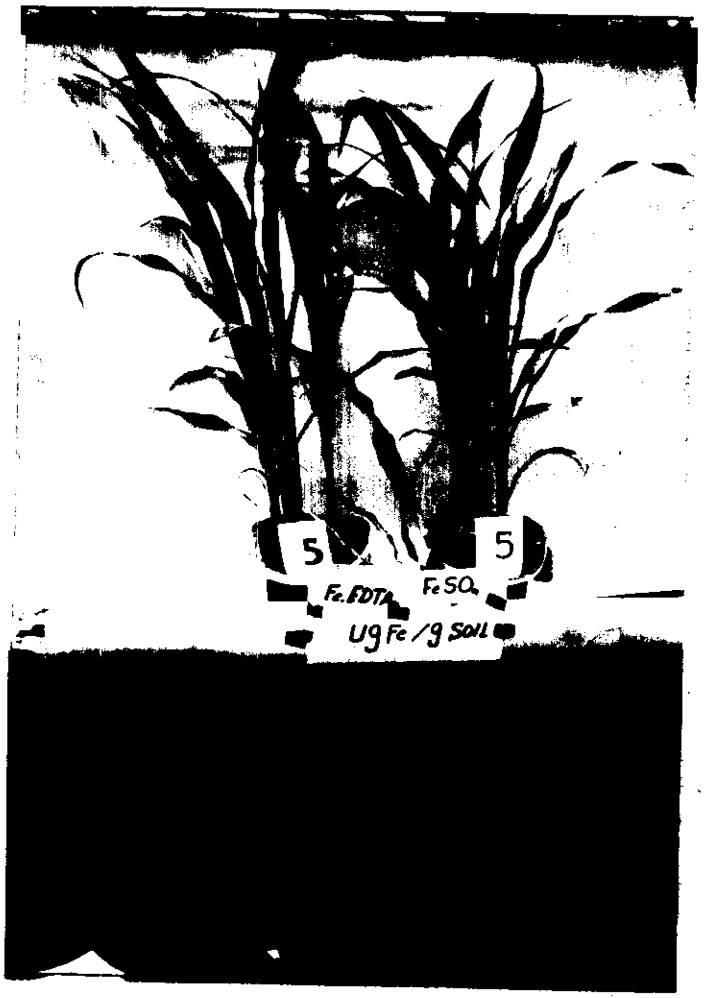


Plate (3): The superiority of Fe-EDTA in correcting the chlorosis was reported over the last three decades by many investigators such as Leonard and Stwart (1953), Mortvedt (1982) and Lindsay and Schwab (1982).

Accordingly and in view of these concepts, the relatively high values of both concentration and total Fe contained in sorghum roots together with their relatively low values in the shoots when $FeSO_4$ was the source of iron supply. This behaviour could be referred to a low mobility of Fe when absorbed in the mineral form as compared with the chelated one, or to adsorption and precipitation of Fe in the free space or on the sites of adsorption on the root surfaces, Chaney and Coulombe (1982). Accordingly the values of Fe content in plant roots may be considered as apparent figures rather than realy indicator for the status of iron in plant.

On this basis, it may be concluded that $FeSO_4$ as a source of iron could be effective in supplying Fe to plants, but at higher rates than those of chelated iron, to compensate the various mechanisms altering its availability and mobility to the shoots of the plant.

4.1.2.2. Phosphorus concentration and uptake by sorghum:

The values of P concentration and total P uptake by sorghum plants are shown in tables (5 & 6) and graphically illustrated in Fig's (4 & 5).

Table (5): Phosphorus concentration in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg P/g dry matter).

Source		Rate of application (ppm)						
		0	5	10	20	40	60	Mean
					Roots			
Fe-EDTA		1.12	0.83	0.75	0.84	0.82	0.84	0.87
$Fe\text{-}SO_4$		1.33	1.04	0.81	0.74	0.93	0.95	0.97
Mean		1.23	0.94	0.78	0.79	0.86	0.90	
L.S.D.	0.05	S	n.s.	R	0.19	S.R	n.s.	
	0.01		n.s.		0.26		n.s.	
					Shoots			
Fe-EDTA		2.34	1.72	1.80	1.38	1.85	1.46	1.76
$FeSO_4$		2.47	1.81	1.95	1.92	1.74	1.79	1.95
Mean		2.41	1.77	1.88	1.65	1.63		
L.S.D.	0.05	S	n.s.	R	n.s.	S.R	n.s.	
	0.01		n.s.		n.s.		n.s.	

S = Source

R = Rate

Table (6): Phosphorus uptake by sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg P/pot)

Source		Rate of application (ppm)						Mean
		0	5	10	20	40	60	
Roots								
Fe-EDTA		3.47	3.47	3.38	3.07	2.85	2.57	3.18
$FeSO_4$		2.79	4.08	4.47	3.94	3.59	4.68	3.93
Mean								
L.S.D	0.05	S	0.49	R	n.s.	S.R.	n.s.	
	0.01		0.67		n.s.		n.s.	
Shoots								
Fe-EDTA		14.71	13.71	13.94	11.67	14.16	10.74	13.15
$Fe-SO_4$		16.12	13.81	13.11	14.89	14.74	13.43	14.35
Mean		15.42	13.76	13.53	13.28	14.45	12.09	
L.S.D.	0.05	S	n.s.	R	n.s.	S.R	n.s.	
	0.01		n.s.		n.s.		n.s.	
Whole plants								
Fe-EDTA		18.18	17.45	17.31	14.74	17.01	13.31	16.33
$FeSO_4$		18.91	17.89	17.58	18.83	18.33	18.11	18.28
Mean		18.55	17.67	17.45	16.79	17.67	15.71	
L.S.D.	0.05	S	1.91	R	n.s.	S.R.	n.s.	
	0.01		2.59		n.s.		n.s.	

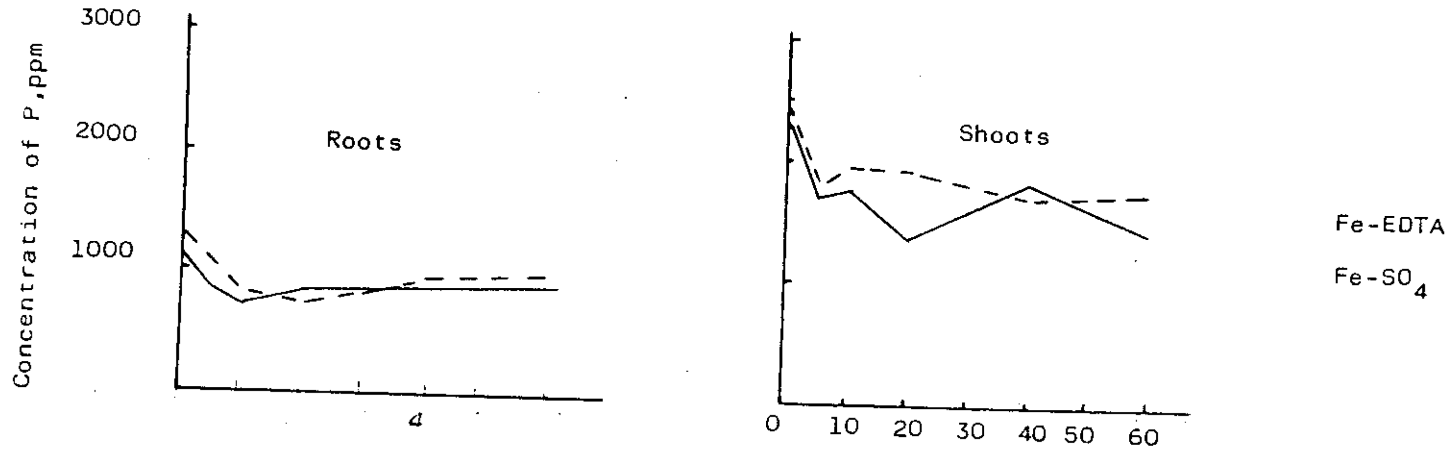


Fig. (4): Effect of applied iron (source and rate) on concentration of P in sorghum plants.

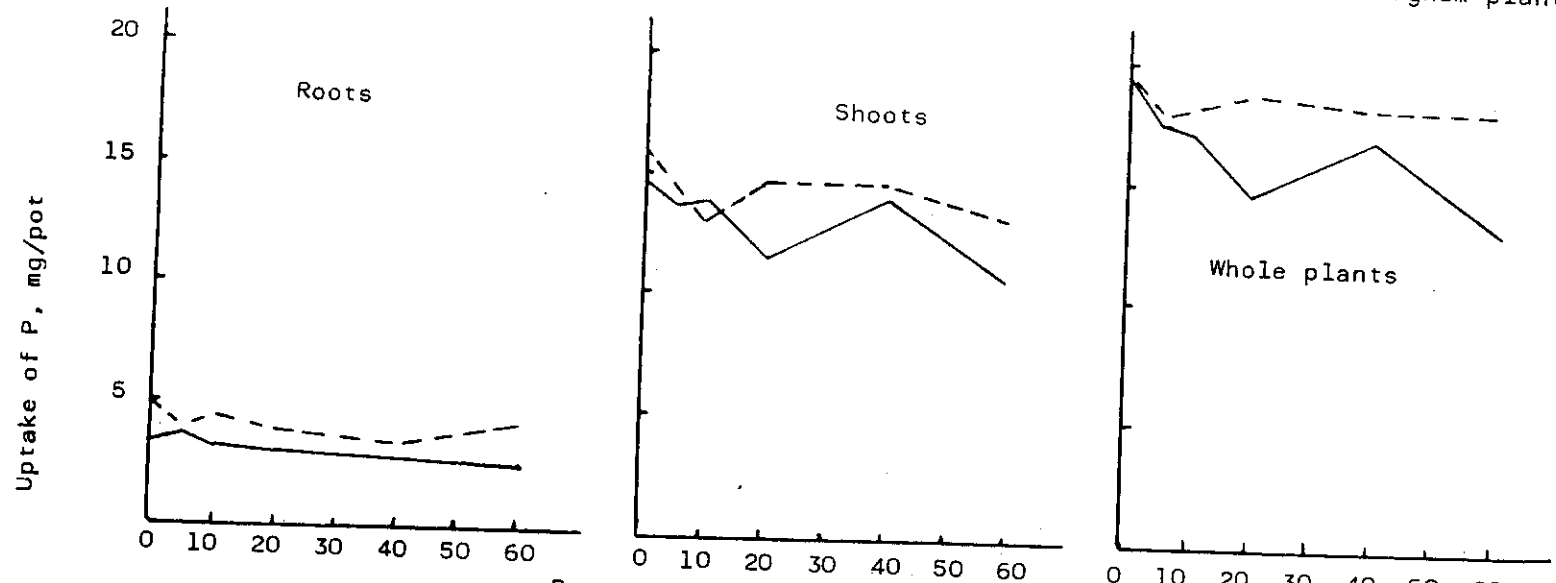


Fig. (5): Effect of applied iron(source and rate) on uptake of P by sorghum plants.

The results showed no significant differences between the iron sources. Compared to the control, the P concentration in plant roots tended to be decreased with Fe application, with its minimum being at 10 and 20 ppm Fe for Fe-chelate and $FeSO_4$, respectively, after which slight increases with both sources were observed. Such trend could be due to the dilution effect as these two rates are quite close to those which gave the highest root growth.

Generally, $FeSO_4$ treatments tended to yield plants containing higher P levels in roots and shoots than did Fe-EDTA treatments.

In plant shoots, P concentration was clearly decreased with increasing the rate of added iron of both sources, which could be again due to the dilution effect brought about by the better growth specially at lower rates of Fe.

Concerning the P uptake by sorghum roots, no significant differences due to the different rates of applied iron were found, but significant differences occurred between sources. The $FeSO_4$-treated plants, at any rate, tended to show higher P uptake than with Fe-EDTA-treatments, where P uptake remained constant with the 5 ppm Fe rate, above which a decreasing tendency was obvious. However, all of these differences were not significant.

Regarding Phosphorus uptake by sorghum shoots, plant shoots contained much more P than the roots with no significant differences existing regarding P uptake contained by shoots as a result to the different sources or rates of applied iron. However, $FeSO_4$-treated plants tended to show slightly high content of P in their shoots at almost all rates compared to those supplied with Fe-EDTA.

Concerning the total P uptake by sorghum plants (whole plants) no significant variations due to the different rates on P uptake could be observed.

With respect to the Fe sources, the mineral source ($FeSO_4$) yielded plants of significantly higher values of P uptake, particularly when applied at high rates.

The results of P concentration presented in table (5) and Fig. (4) show significant increase in the P concentration in the chlorotic plants. However, such trend was not significant with respect to the total P uptake.

Such results are in good agreement with Dekock (1955), who suggested that the high P content of chlorotic plant tissue may result from a decrease in the content of oxidizing enzymes. It was also observed by Jodice et al. (1982) that the chlorotic leaves of control plants contained higher P than the green iron treated leaves.

In contrast, these results are opposed by Shata (1982) who obtained a highly significant increase in phosphorus concentration in Spinach plants with increments of Fe-EDTA.

The P/Fe ratio of the control treatment in sorghum roots (2.66), gradually decreased to 0.61 and 0.85 with increasing Fe application up to 60 ppm, as $FeSO_4$ and Fe-EDTA, respectively.

Regarding the sorghum shoots the corresponding P/Fe ratio diminished from 13 to 8.99 and 3.75 with Fe applications increasing up to 60 ppm, as $FeSO_4$ and Fe-EDTA, respectively. This result is confirmed by many investigators such as Khruslova (1965) who reported that iron chlorosis in mustard was associated with higher P/Fe ratio in chlorotic leaves. It was also referred by Mengle and Kirby (1979) that P/Fe ratio is frequently higher in plants suffering Fe chlorosis than in green plants.

4.1.2.3. Calcium concentration and uptake by sorghum:

Data in tables (7, 8) and Figs. (6, 7) show significant effect on Ca concentration only in roots of sorghum plants due to iron application in the different sources and rates. Calcium concentration in plant roots was significantly decreased with increasing the rate of added FeEDTA up to

Table (7): Calcium concentration in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg Ca/g dry matter).

Source	Rate of application (ppm)						Mean
	0	5	10	20	40	60	
				Roots			
Fe-EDTA	7.520	5.280	4.800	5.040	4.800	5.120	5.43
$FeSO_4$	8.240	5.450	4.840	5.680	6.100	7.040	6.23
Mean	7.880	5.370	5.360	5.450	6.080		
L.S.D. 0.05	S	0.64	R	1.12	S.R	n.s.	
L.S.D. 0.01		0.87		1.52		n.s.	
				Shoots			
Fe-EDTA	3.89	5.76	5.79	5.36	4.80	5.168	5.1
$FeSO_4$	5.20	6.00	5.20	5.92	6.24	5.28	5.6
Mean	4.60	5.90	5.50	5.60	5.50	5.20	
L.S.D. 0.05	S	n.s.	R	n.s.	S.R	n.s.	
L.S.D. 0.01		n.s.		n.s.		n.s.	

S = Source

R = Rate

Table (8): Calcium uptake by sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg/pot)

Source		Rate of application (ppm)						Mean
		0	5	10	20	40	60	
					Roots			
Fe-EDTA		17.3	24.1	21.7	22.6	16.7	15.6	19.7
$FeSO_4$		17.9	22.1	26.6	29.3	23.7	34.6	25.7
Mean		17.6	23.1	24.15	25.25	20.2	25.1	
L.S.D.	0.05	S	2.883	R	4.98	S.R.	7.05	
	0.01		3.920		6.766		9.59	
					Shoots			
Fe-EDTA		22.301	47.144	44.908	45.366	37.28	38.475	39.25
$FeSO_4$		35.32	46.680	40.168	45.288	52.928	39.728	43.35
Mean		28.80	46.90	42.540	45.330	45.100	39.100	
L.S.D.	0.05	Source	n.s.	Rate	n.s.	S.R.	n.s.	
	0.01		n.s.		n.s.		n.s.	
					Whole plant			
Fe-EDTA		42.928	71.208	66.613	67.976	53.936	54.0896	59.46
$FeSO_4$		63.216	68.781	61.308	74.52	76.581	74.344	69.79
Mean		53.07	69.99	63.96	71.25	65.26	64.22	
L.S.D.	0.05	S	n.s.	R	n.s.	S.R.	n.s.	
	0.01		n.s.		n.s.		n.s.	

S = Source R = Rate

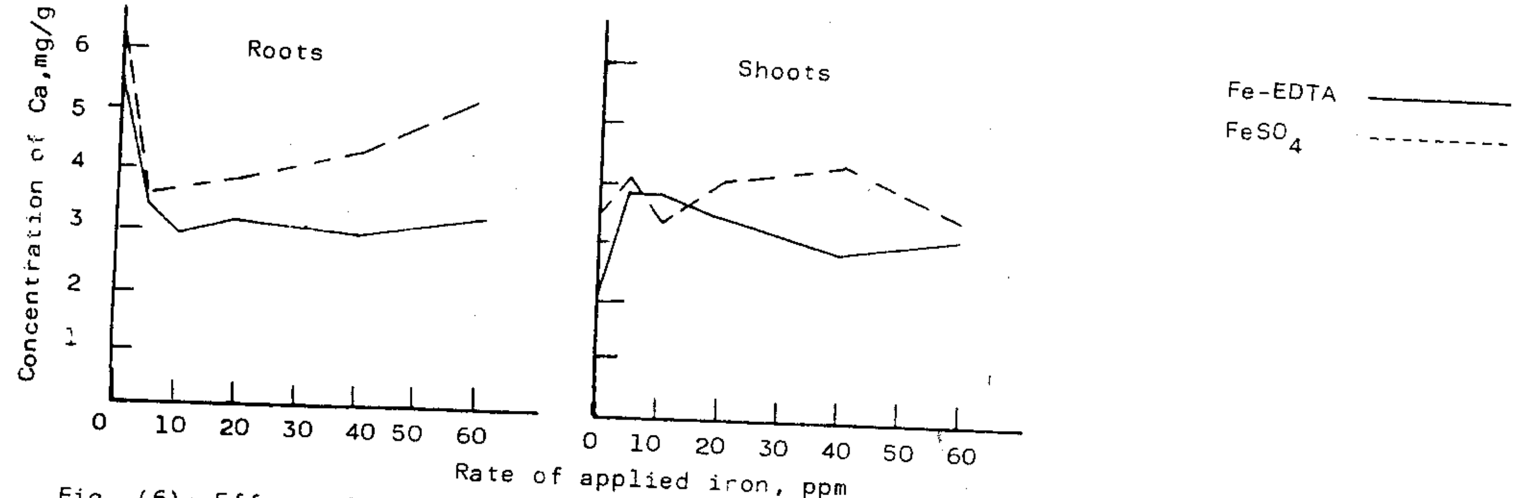


Fig. (6): Effect of applied iron (source and rate) on concentration of Ca in sorghum plants.

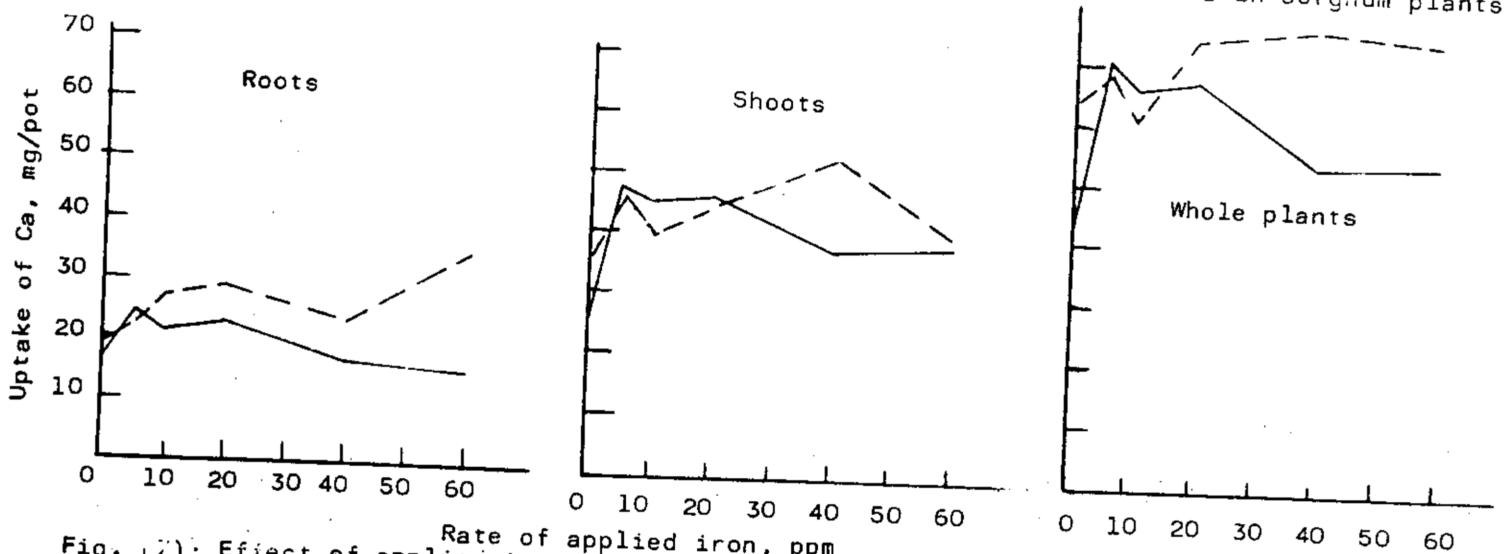


Fig. (7): Effect of applied iron (source and rate) on uptake of Ca by sorghum plants.

10 ppm Fe, thenafter it tended to remain almost constant. In the case of $FeSO_4$, however, Ca content reached its minimum also at the 10 ppm rate but was followed with a gradual increase with increasing the rate of iron supply.

In general, concentration of Ca in roots and shoots of $FeSO_4$-treated plants was higher than those Fe-EDTA-treated.

In plant shoots, calcium concentration was slightly increased, but no significant variations were obtained with regard to either the source or rate of Fe application.

Regarding the uptake of Ca contained by plant roots, highly significant differences were obtained due to both sources and rates of applied Fe. Calcium uptake contained by sorghum roots generally increased with Fe application. In presence of Fe-EDTA, the Ca uptake reached a maximum value with the rate of 5 ppm Fe, after which a decreasing tendency was detected. On the other hand, in case of $FeSO_4$, a fluctuated trend was obvious where a gradual increase was initially yielded up to the rate of 20 ppm Fe, after which the Ca uptake tended to decrease but again increased to a maximum value at the rate of 60 ppm Fe.

Accordingly it may be concluded that, the roots of the chlorotic plants are characterized with relatively higher Ca concentration as compared with the healthy plants while the inverse is quite true with respect to the shoots. Regarding the Ca uptake in plant shoots, no obvious affect was noticed due to, either source or rate of applied iron

4.1.2.4. Magnesium concentration and uptake by sorghum:

Data of magnesium concentration and uptake in tables (9 &10) and Figs. (8 & 9), show no clear trend in the concentration of magnesium in plant roots due to the different treatments involved.

However, slight depressive effect was observed for magnesium concentration in plant shoots due to increasing Fe application, either as chelated or mineral sources, with $FeSO_4$ being more effective in this regard.

Concerning the uptake of magnesium by sorghum plants, no significant differences either due to sources or rates of Fe application were obtained.

4.1.2.5. Manganese concentration and uptake by sorghum:

The results in tables (11 & 12) and Figs. (10 & 11) show that the concentration of Mn in sorghum roots was not significantly affected neither with the different sources nor with the rates of Fe.

Table (9): Magnesium concentration in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg/g dry matter).

Source	Rate of application (ppm)						
	0	5	10	20	40	60	Mean
			Roots				
Fe-EDTA	4.22	3.23	2.77	3.36	3.53	3.78	3.48
$FeSO_4$	3.44	3.07	1.76	2.78	2.69	3.70	2.71
Mean	3.83	3.15	2.27	3.07	3.11	3.47	2.91
LSD 0.05	S	n.s.	R	n.s.	S.R.	n.s.	
LSD 0.01						n.s.	
			Shoots				
Fe-EDTA	6.47	3.35	4.83	2.35	5.46	4.03	4.42
$FeSO_4$	5.92	6.34	2.73	4.16	2.69	4.07	4.32
Mean	6.20	4.85	3.78	3.26	4.07	4.05	
LSD 0.05	S	n.s.	R	1.81	S.R	2.89	
LSD 0.01		n.s.		2.46		3.93	

S = Source
R = Rate

Table 10 : Magnesium uptake by sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg/pot).

Source		Rate of application (ppm)						Mean
		0	5	10	20	40	60	
Roots								
Fe-EDTA		6.597	14.704	12.478	12.88	12.337	11.457	11.74
$FeSO_4$		7.174	10.912	9.614	14.786	12.28	18.068	12.14
Mean		6.890	12.810	11.050	13.830	12.310	14.760	
L.S.D.	0.05	S	n.s.		R	n.s.	S.R	n.s.
	0.01		n.s.			n.s.		n.s.
Shoots								
Fe-EDTA		36.564	32.903	37.174	19.521	42.454	29.199	32.97
$FeSO_4$		39.409	49.157	22.533	32.025	22.247	30.421	32.63
Mean		37.97	41.03	29.85	25.773	32.35	29.81	
L.S.D.	0.05	S	n.s.		R	n.s.	S.R	n.s.
	0.01		n.s.			n.s.		n.s.
Whole plants								
Fe-EDTA		40.769	47.609	49.652	32.403	54.793	40.656	44.31
$FeSO_4$		46.582	60.201	32.147	46.810	34.528	48.489	44.79
Mean		43.680	53.910	40.900	39.610	44.750	44.570	
L.S.D.	0.05	S	n.s.		R	n.s.	S.R.	n.s.
	0.01		n.s.			n.s.		n.s.

S = Source R = Rate

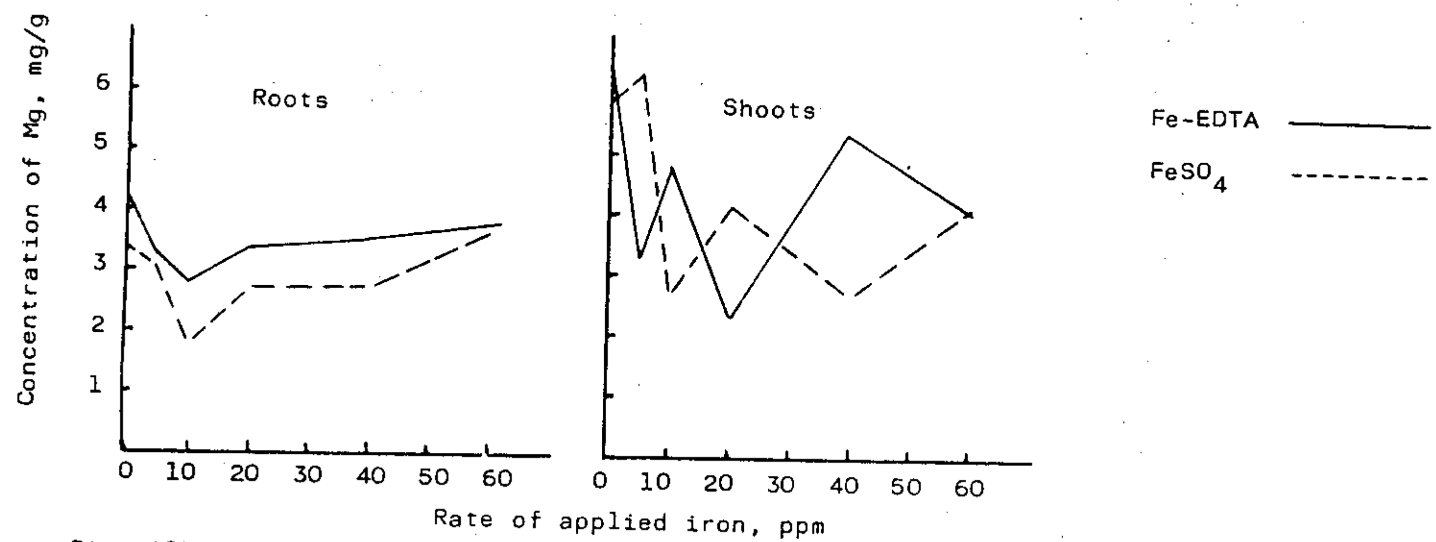


Fig. (8): Effect of applied iron (source and rate) on concentration of Mg in sorghum plants.

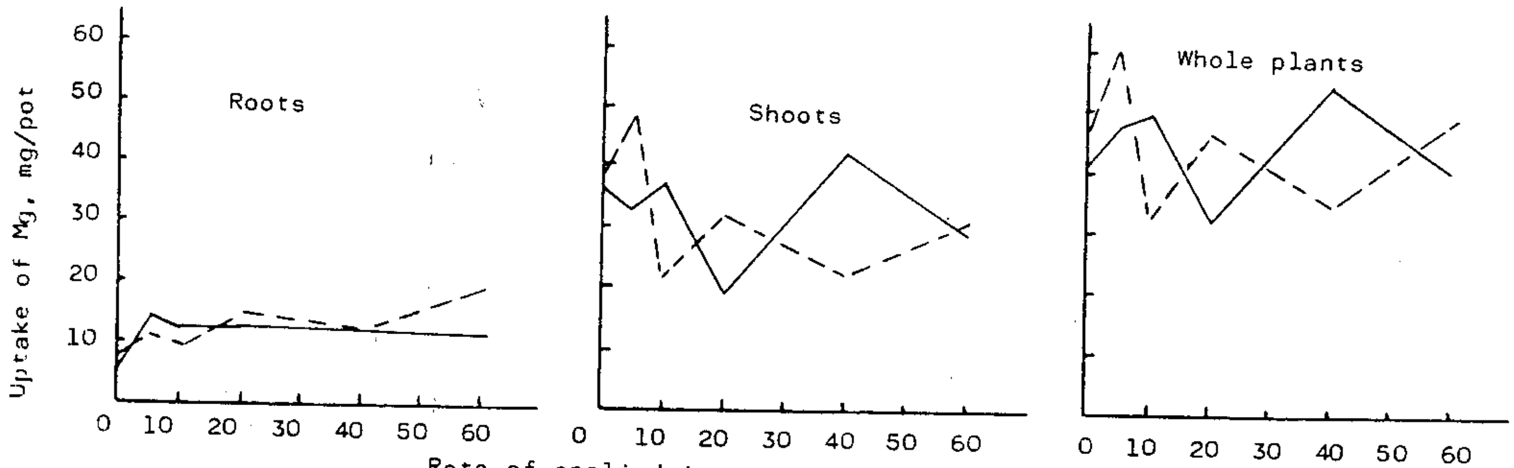


Fig. (9): Effect of applied iron (source and rate) on uptake of Mg by sorghum plants.

Table (11): Manganese concentration in sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA ppm

Source		Rate of application (ppm)						Mean
		0	5	10	20	40	60	
					Roots			
Fe-EDTA		52.340	16.777	28.183	36.237	50.997	36.907	30.76
$FeSO_4$		41.603	31.537	50.997	55.023	27.513	33.550	40.04
Mean		47.02	24.16	39.59	45.63	39.260	35.230	
L.S.D.	0.05	S	n.s.	R	n.s.	S.R	n.s.	
	0.01		n.s.		n.s.		n.s.	
					Shoots			
Fe-EDTA		111.387	86.560	68.440	77.167	55.693	72.467	78.62
$FeSO_4$		102.663	91.265	62.403	86.560	85.220	104.677	88.80
Mean		107.03	88.910	65.420	81.860	70.460	88.570	
L.S.D.	0.05	S	n.s.	R	25.41	S.R	n.s.	
	0.01		n.s.		34.53		n.s.	

S = Source R = Rate

Table (12 : Manganese uptake by sorghum plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA (mg/pot)

Source	Rate of application (ppm)						Mean
	0	5	10	20	40	60	
				Roots			
Fe-EDTA	0.151	0.077	0.133	0.133	0.179	0.110	0.131
$FeSO_4$	0.095	0.140	0.283	0.293	0.114	0.160	0.181
Mean	0.123	0.109	0.208	0.213	0.147	0.135	
L.S.D. 0.05	S	0.046	R	0.079	S.R.	0.112	
0.01		0.062		0.108		0.152	
				Shoots			
Fe-EDTA	0.662	0.699	0.526	0.561	0.426	0.538	0.569
$FeSO_4$	0.676	0.706	0.498	0.669	0.722	0.783	0.676
Mean	0.67	0.703	0.512	0.615	0.574	0.661	
L.S.D. 0.05	S	n.s.	R	n.s.	S.R.	n.s.	
0.01		n.s.		n.s.		n.s.	
				Whole plants			
Fe-EDTA	0.814	0.776	0.660	0.784	0.606	0.649	0.715
$FeSO_4$	0.771	0.845	0.781	0.961	0.835	0.943	0.856
Mean	0.793	0.811	0.721	0.873	0.721	0.796	
L.S.D. 0.05	S	0.102	R	n.s.	S.R.	n.s.	
0.01		0.138		n.s.		n.s.	

S = Source R = Rate

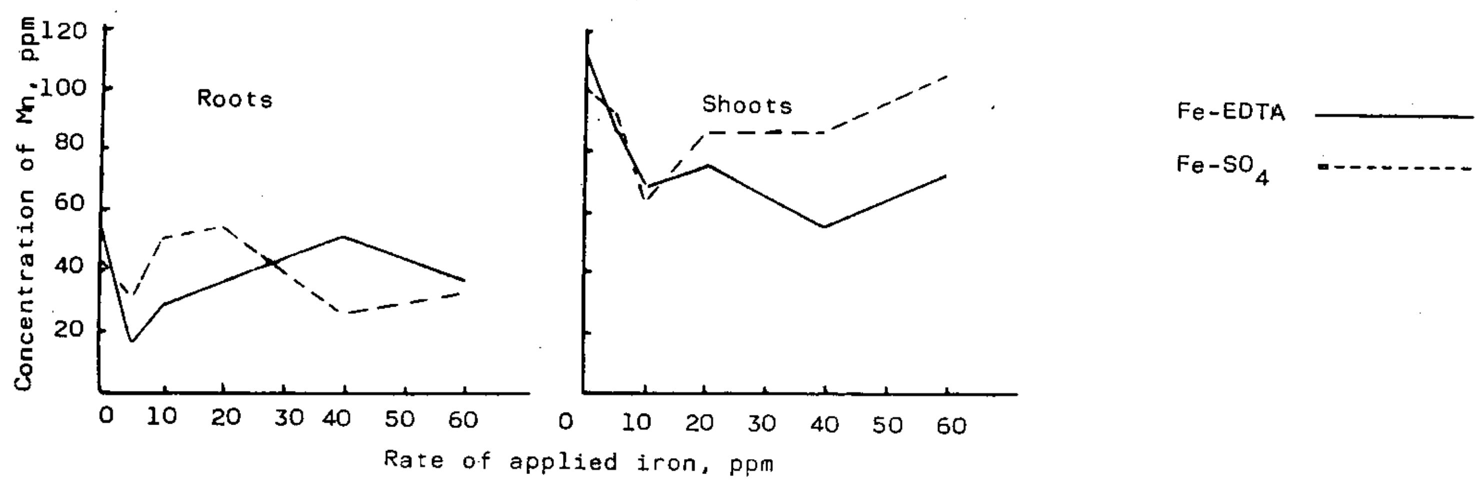


Fig. (10): Effect of applied iron (source and rate) on concentration of Mn - in sorghum plants.

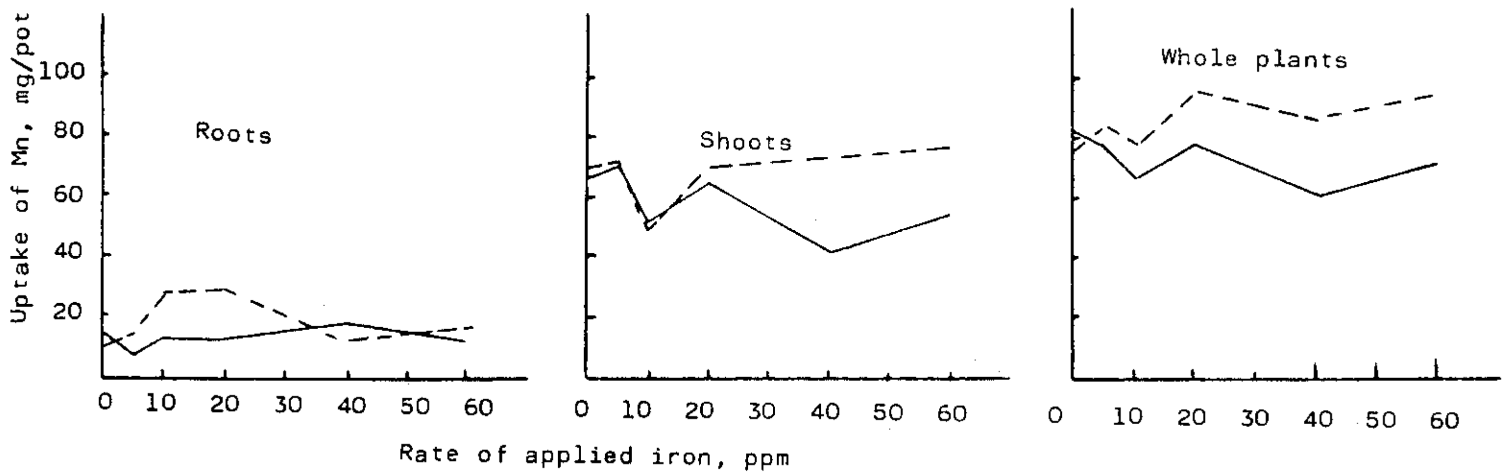


Fig. (11): Effect of applied iron (source and rate) on uptake of Mn by sorghum plants.

With respect to Mn concentration in sorghum shoots however, a significant decrease occured with increasing the rate of Fe supply in both sources. This trend was also noticed by Somers and Shive (1942), Tiffin (1967), Ohno et al. (1978), Shata (1982) and Jodice et al. (1982) who observed an inverse relation between Fe and Mn concentration in plants supporting the Fe and Mn antagonistic relationship.

Concerning Mn uptake by sorghum roots, significant effects due to Fe sources and rates also occurred.

In sorghum plants treated with Fe-EDTA, the uptake of Mn was decreased with all rates of applied Fe, except the 40 ppm rate. In plants treated with $FeSO_4$, uptake of Mn increased by Fe application, where the highest effect was achieved with the rate of 20 ppm Fe.

Evidently the total Mn content in sorghum roots of plants treated with $FeSO_4$ was generally, higher than in those of plants treated with Fe-EDTA.

4.1.2.6. Relative occurrence of P, Fe, Mn and Ca in sorghum plants as affected by Fe application:

Several nutrient ratios such as Fe/Mn, P/Fe and Ca/Fe have been reported as indices for the nutritional status of iron chlorotic plants.

To investigate the occurrence of some nutrients, Mn, P and Ca, in relation to Fe in sorghum plants treated with iron at various rates, the ratios of nutrient pairs and the average value of each ratio were calculated. The data obtained on concentrations of these nutrients and the computed ratios are presented in tables (13 & 14).

The results obtained indicate the following trends:

1. The relative occurrence of nutrients in sorghum roots in most cases did not reveal significant relation with either the source or rate of Fe application, that could be due to Fe accumulation in sorghum roots, its binding and/or precipitation on root surfaces.
2. A positive trend was revealed in sorghum shoots, with respect to Fe/Mn ratio either with Fe-EDTA or $FeSO_4$ application. However, this trend was almost significant in case of Fe-EDTA rather than with Fe-SO_4. The values of Fe/Mn ratio in plant shoots ranged from 1.5 to 6.4 with an average of 3.99 in case of Fe-EDTA, and from 1.9 to 3.0 with an average of 2.29 in case of $FeSO_4$. In the roots, however, the average of all treatments was 27.58 in the case of Fe-EDTA and increased to 40.72 where $FeSO_4$ was the iron source.
3. A negative relation of P/Fe ratio that was significant in the case of Fe-EDTA and very close to significancy with $FeSO_4$

Table (13): Ratios of (Fe/Mn = P/Fe and Ca/Fe) in sorghum as affected by application of Fe as $FeSO_4$ and Fe-EDTA.

Rate of iron, ppm	Roots		Shoots	
	EDTA - Fe	$FeSO_4$	Fe - EDTA	$FeSO_4$
			Fe/Mn	
0	6.88	12.20	1.50	1.90
5	116.80	29.80	2.20	1.93
10	47.50	39.00	2.97	3.00
20	16.00	40.70	3.00	2.30
40	20.00	47.30	6.40	2.30
60	26.80	46.80	5.40	1.90
	27.58	40.72	3.99	2.29
			P/Fe	
0	3.10	2.66	13.85	12.86
5	0.42	1.11	9.20	10.30
10	0.56	0.40	8.90	10.43
20	1.45	0.33	5.97	9.80
40	0.80	0.72	5.20	8.97
60	0.85	0.61	3.75	9.00
	0.82	0.63	6.60	9.70
			Ca/Fe	
0	20.89	16.48	23.00	27.00
5	2.69	5.80	31.00	34.00
10	3.58	2.40	28.50	27.80
20	8.69	2.54	23.20	30.00
40	4.70	4.69	13.50	32.00
60	5.17	4.48	14.80	26.50
	4.97	3.98	22.20	30.06

Table (14): Relative occurrence of P, Fe, Mn and Ca (concentration) in sorghum plants as affected by Fe application.

Nutrient ratio	Source of applied iron	(r)	Correlation coefficient
Fe/Mn	Fe-EDTA	S	0.76
		R	0.40
	$FeSO_4$	S	0.78
		R	0.52
P/Fe	Fe-EDTA	S	-0.87*
		R	-0.36
	$FeSO_4$	S	-0.80
		R	-0.50
Ca/Fe	Fe-EDTA	S	-0.83*
		R	-0.31
	$FeSO_4$	S	-0.20
		R	-0.42

S = Shoots.
R = Roots.

treatments, was revealed in sorghum shoots. This trend is in accordance with the known fact of mutual adverse effects of P and Fe. Values of the P/Fe ratio in sorghum shoots ranged from 3.75 to 13.85 in case of Fe-EDTA, and from 9 to 12.86 with $FeSO_4$, with an average of 6.60 and 9.70 being decreased to 0.82 and 0.63 in the roots for the two sources, respectively.

4. A negative significant relation for Ca/Fe ratio in sorghum shoots was obtained with the rate of applied Fe-EDTA. The nonsignificancy of the ratio in case of $FeSO_4$ could be mainly because considerable fraction of the Fe absorbed from this source was accumulated or inactivated somewhere in root tissues and only small Fe amounts translocated to shoots. The values of this ratio ranged from 13.5 to 31 with an average of 22.20 in case of Fe-EDTA, and from 26.50 to 34 with an average of 30.06 in case of $FeSO_4$. In plant roots, this ratio was quite narrow and averaged 4.97 with the chelate treatment but decreased to 3.98 in the case of $FeSO_4$.

It is quite obvious that increasing the rate of applied iron was associated with increasing values of Fe/Mn and decreasing those of both P/Fe and Ca/Fe as compared with the control plants. The magnitude of these variations was much higher in case of $FeSO_4$ treated plants. Such trend could be referred to the accumulation of iron in plant roots as inorganic precipitates specially when applied in a mineral form.

With respect to plant shoots, it is clear from the aforementioned presentation that the values of Fe/Mn were lower, while those of P/Fe and Ca/Fe were much higher in the shoots compared to the corresponding values in the roots. Again, the magnitude of variation was much higher with the $FeSO_4$ supplied plants. This trend provided further confirmation to possibility of iron accumulation in roots with low quantity moving upward to organs of the plant shoot, particularly when using inorganic iron sources. This conclusion is confirmed by Olsen (1958) who reported that Fe/Mn ratio represents a reasonable index of the iron status of plant, being low in the chlorotic tissue.

Also Chaney and Coulmbe (1982) reported that phosphates may render iron inactive and precipitate it inside plant tissues.

4.1.3. Iron that remained or lost during and at the end of experiment:

The status of iron in the sand culture was followed up through determining the quantity in the leachate collected during conducting the experiment as well as that trapped in the culture after removal of plants. The obtained results are presented in table (15) and Fig (12).

Table (15): Leached iron and extracted iron fractions during and after removal of plants as influenced by application of Fe as $FeSO_4$ and Fe-EDTA.

Source of iron	Rate of iron (ppm) 0	5	10	20	40	60	Mean
			Leached iron, mg/pot				
Fe-EDTA	0.10	1.31	3.32	6.69	19.63	23.85	9.15
$FeSO_4$	0.56	0.06	-	0.04	0.01	0.56	0.21
Mean	0.33	0.69	1.60	3.37	9.82	12.21	
L.S.D. (0.05)	Source	0.68	Rates 1.2		S.R 1.7		
(0.01)		0.93	1.64		2.3		
			Iron soluble in 0.1 N HCl, Mg/pot				
Fe-EDTA	2.5	4.5	3.4	6.4	8.6	16.0	6.9
$FeSO_4$	3.8	4.5	6.3	11.5	21.4	22.7	11.7
Mean	3.15	4.5	4.85	8.95	15.0	19.35	
L.S.D. (0.05)	Source	1.04	Rates 1.80		S.R. 2.55		
(0.01)		1.41	2.45		3.47		
			Available iron mg/pot				
Fe-EDTA	0.15	0.44	1.02	2.04	2.2	5.6	1.91
$FeSO_4$	0.15	0.60	1.20	1.80	3.5	4.4	1.94
Mean	0.15	0.52	1.11	1.92	2.85	5.0	
L.S.D. (0.05)	Source	N.S	Rates 0.57		S.R 0.73		
(0.01)		N.S	0.71		0.99		

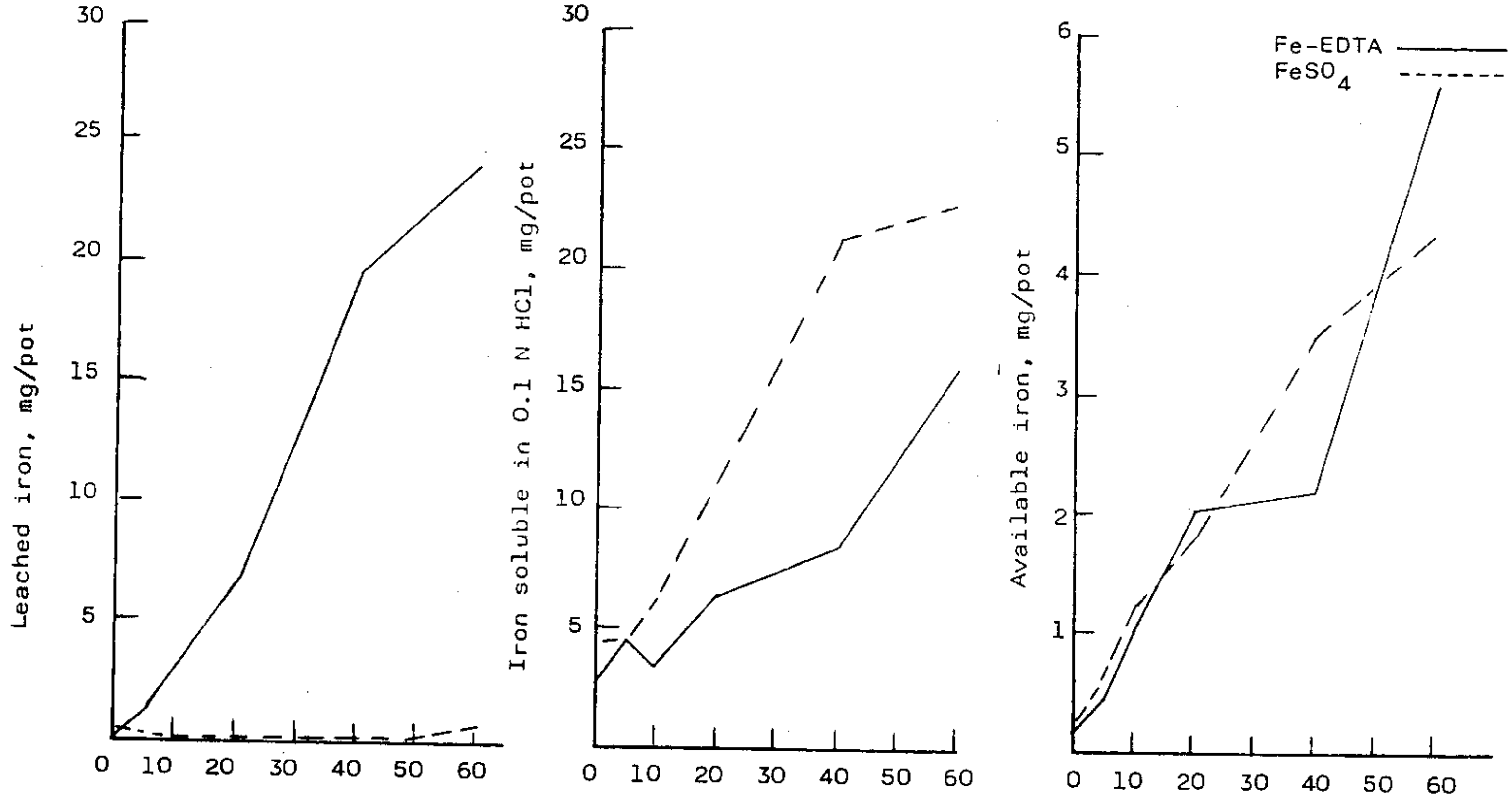


Fig. (12): Effect of applied iron (source and rate) on Leached iron, iron soluble in 0.1 N HCl and available iron during and after harvested plants.

4.1.3.1. Leached iron:

The results show clearly that leachates of the Fe-EDTA treatments contained considerable amounts of Fe, that gradually and significantly increased with the increasing rates of applied Fe. These values ranged from 0.1 to 23.85 mg Fe/pot, which reflect the high solubility of Fe-EDTA. On the other hand, with the $FeSO_4$ treatments, minute values of leached Fe were recorded through the course of experiment, indicating that the soluble $FeSO_4$ applied was rapidly converted into insoluble forms.

4.1.3.2. Available iron form:

Concerning the available iron, extracted by NH_4OAC (pH 4.8); significant differences were found between Fe rates of both Fe sources (Fe-EDTA and $FeSO_4$). However, the values of available iron increased significantly and steadly by increasing the rate of applied Fe.

The amount of available iron extracted by NH_4OAC (pH 4.8) reflect, in general, the potential supply of Fe to plants grown on soils, as stated by Olson (1965) who pointed out that most of soil available iron occur in a ferrous form.

With respect to iron fraction extractable by 0.1 N HCl solution, from sand cultures after plant removal, significant differences were found between sources and also between rates. This Fe fraction significantly increased with increasing the rate of applied Fe.

The ferrous sulfate-treated cultures yielded more 0.1 N HCl-extractable Fe than did those treated with Fe-EDTA. This trend is in accordance with the extremely low Fe quantities leached from the cultures when $FeSO_4$ was used as a source of iron supply and the relatively high amounts leached from the culture in case of Fe-EDTA treatments. This result is confirmed by Leeper (1952) who reported that most iron compounds occurring naturally in soils are quite insoluble and that ferrous ions are unstable in aerated soils with a pH value of 6.0 or higher alkalinity and aeration favour oxidation of iron..

4.2. Experiment II: Iron chlorosis as affected by $CaCO_3$ and Fe applications:

In this experiment, as mentioned before, sorghum plants grown on sand culture were subjected to $CaCO_3$ and Fe applications. Calcium carbonate was added at four levels namely, 0, 2, 4 and 8% while iron treatments included three rates namely; 0, 10 and 20 ppm Fe as $FeSO_4$. The values of dry matter yield of sorghum plants were recorded and the nutritional status was also evaluated through determination of Fe, P, Ca, Mg and Mn uptake.

4.2.1. Dry matter yield of sorghum as affected by $CaCO_3$ and Fe applications:

Data obtained for the dry matter yield of sorghum plant parts (roots and shoots) as influenced by $CaCO_3$ and Fe applications are presented in table (16). The data are discussed with respect to both plant parts and whole plants as well.

For plant roots, the results indicate that, the combined application of $CaCO_3$ and Fe did not significantly affect the dry matter yield of plant roots.

Concerning plant shoots, the values of dry matter yield were significantly decreased with the application of $CaCO_3$ at rates of 2, 4 and 8%, either in presence or in absence of applied iron.

Table (16): Effect of soil application of $CaCO_3$ and Fe on dry matter yield (g/pot).

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ %														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	2.19	3.05	2.41	2.38	2.51	8.9	7.86	8.02	6.62	7.85	11.10	10.93	10.43	9.00	10.37
10.0	2.72	2.39	2.69	2.10	2.48	9.02	8.43	8.06	6.21	7.93	10.00	11.75	10.83	10.75	8.26
20.0	2.90	2.65	1.99	2.35	2.47	9.00	7.92	8.24	7.31	8.12	11.90	10.24	10.67	9.65	10.62
Mean	2.60	2.70	2.36	2.28		8.97	8.07	8.11	6.71		11.58	10.67	10.62	8.97	
	$CaCO_3$		Fe	$CaCO_3$.Fe		$CaCO_3$		Fe	$CaCO_3$.Fe		$CaCO_3$		Fe	$CaCO_3$.Fe	
L.S.D 0.05	n.s.		n.s.	n.s.		0.64		n.s.	n.s.		0.81		n.s.	n.s.	
L.S.D 0.01	n.s.		n.s.	n.s.		0.86		n.s.	n.s.		1.10		n.s.	n.s.	

In presence of applied Fe, $CaCO_3$ level of 2, 4 and 8% reduced the dry matter yield of shorghum shoots, on average basis, by 10, 9.5 and 25% as compared to the control, respectively. In absence of Fe application, the corresponding reductions were 11.7, 9.8 and 25%, respectively.

With respect to the effects due to Fe applications, though an increasing tendency on dry matter yield of sorghum shoots due to Fe application was observed, no significant variations were recorded. For example, in absence of Fe application the $CaCO_3$ at a level of 8%, reduced the average values of dry matter yield of shoots by 25%. However, this reduction was slightly corrected (to 18%), when Fe was applied at a rate of 20 ppm Fe as $FeSO_4$.

Concerning the whole sorghum plants, the pattern of response to both $CaCO_3$ and Fe applications resembles, to some extent, that of the shoots, which comprise the bigger portion of the plant. The decrease resulted in the dry matter yield with increasing the levels of $CaCO_3$, may be due to a reducing effect of $CaCO_3$ on the availability of iron and phosphorus. The inactivation effect due to $CaCO_3$ on both P and Fe was reported by many investigators, such as Brown and Hendricks (1952) who showed that the reduction in iron availability in the presence of excess $CaCO_3$, is due to the conversion of soluble iron into insoluble ferric hydroxides or ferric oxides. Dahiya and Singh (1982) also reported that increasing the $CaCO_3$ level decreased the concentration and uptake of iron drastically.

The obtained results are confirmed by Patil and Patil (1981) who found that the dry matter yield of sorghum plants was adversely affected with increasing the level of $CaCO_3$. However, the contradicted result revealed by Dahiya and Singh (1982) who obtained an increase in dry matter yield of oat plants with increasing levels of $CaCO_3$ and Fe, was attributed to a probable increase in Ca availability and Fe arising from amorphous $CaCO_3$ and applied iron through the rhizosphere because of the solubilizing effect of root exudates on $CaCO_3$, as the soil they used was marginal in exchangeable Ca and deficient in iron.

4.2.2. Nutrient elements in sorghum as affected by $CaCO_3$ and Fe applications:

The status of some nutrients which are usually thought to be involved either directly or indirectly in the phenomenon of iron chlorosis namely, Fe, P, Ca, Mg and Mn are presented and discussed in this part of text with respect to their concentration and uptake by sorghum plant.

4.2.2.1. Iron concentration and uptake by sorghum:

The results obtained for Fe concentration and uptake as influenced by $CaCO_3$ and Fe applications are presented in tables (17 and 18).

Table (17): Effect of soil application of $CaCO_3$ and Fe on iron concentration in sorghum plants ppm

Part of plant	Roots					Shoots				
Level of iron (ppm)	Levels of $CaCO_3$%									
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	327.66	614.71	252.72	419.08	403.54	108.5	84.0	84.0	35.0	77.88
10.0	639.67	315.12	602.16	463.32	505.07	105.0	77.0	108.5	91.0	95.38
20.0	720.72	503.22	386.88	334.33	486.31	108.5	129.5	94.5	122.5	113.75
Mean	562.7	477.72	413.92	405.58		107.3	96.83	95.67	82.83	
	$CaCO_3$	Fe		$CaCO_3$ x Fe		$CaCO_3$	Fe		$CaCO_3$ x Fe	
L.S.D. 0.05	n.s.	n.s.		n.s.		n.s.	n.s.		n.s.	
L.S.D. 0.01	n.s.	n.s.		n.s.		n.s.	n.s.		n.s.	

Table (18): Effect of soil application of $CaCO_3$ and Fe on iron uptake by sorghum plants **mg/pot**

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ (%)														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	0.62	0.94	0.61	1.00	1.04	0.498	0.671	0.674	0.230	0.520	1.120	2.615	1.279	1.228	1.560
10.0	2.00	0.75	1.66	0.98	1.35	1.166	0.650	0.873	0.768	0.864	2.138	1.402	2.530	1.747	1.954
20.0	2.06	1.37	0.94	0.83	1.30	0.965	1.030	0.357	1.116	0.867	3.029	2.395	1.295	1.943	2.163
Mean	1.56	1.35	1.07	0.94		0.88	0.78	0.64	0.71		2.96	2.14	1.70	1.60	

L.S.D	Roots $CaCO_3$	Roots Fe	Roots $CaCO_3$.Fe	Shoots $CaCO_3$	Shoots Fe	Shoots $CaCO_3$Fe	Whole plants $CaCO_3$	Whole plants Fe	Whole plants $CaCO_3$.Fe
0.05	n.s.	n.s.	n.s.	n.s.	0.189	0.377	n.s.	n.s.	1.064
0.01	n.s.	n.s.	n.s.	n.s.	0.257	0.513	n.s.	n.s.	1.446

respect to Fe uptake by plant shoots. Also, significant reduction in Fe uptake with increasing the amounts of $CaCO_3$ was observed by Singh and Dahiya (1976) and Dahiya and Singh (1982).

Whole plants, behaved almost similarly to plant shoots, with respect to Fe uptake.

Interaction of $CaCO_3$ with Fe applications of iron uptake by sorghum plants was significant in shoots and whole plants while in roots it was not significant.

4.2.2.2. Phosphorus concentration and phosphorus uptake by sorghum:

The values of P concentration in sorghum roots and shoots and P uptake as affected by $CaCO_3$ and Fe applications, presented in tables (19 and 20), show significant differences in P concentration in plant roots. The average values of P concentration in roots was reduced from 1.4 to 0.48, 0.51 and 0.54 mg P/g for 0, 2, 4 and 8% rates of applied $CaCO_3$.

The results reveal no serious effect on P concentration in sorghum roots due to Fe applications. It is obvious that the lowest level of $CaCO_3$ (2%) was quite enough to drastically reduce the phosphorus concentration in plant roots to a degree that increasing $CaCO_3$ beyond this level did not result in any further reduction in P concentration.

Table (19): Effect of soil application of $CaCO_3$ and Fe on phosphorus concentration in sorghum plants (mg/g).

Part of plant	Roots					Shoots				
Level of iron (ppm)	Levels of $CaCO_3$ (%)									
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	1.15	0.58	0.46	0.46	0.75	2.78	0.64	0.62	0.84	1.22
10.0	1.55	0.40	0.56	0.66	0.79	2.36	0.52	0.79	0.73	1.10
20.0	1.15	0.46	0.50	0.49	0.86	2.69	0.63	0.78	0.72	1.21
Mean	1.40	0.48	0.51	0.54		2.61	0.60	0.73	0.76	

L.S.D.	$CaCO_3$ (Roots)	Fe (Roots)	$CaCO_3$ x Fe (Roots)	$CaCO_3$ (Shoots)	Fe (Shoots)	$CaCO_3$ x Fe (Shoots)
0.05	0.34	n.s.	n.s.	0.15	n.s.	n.s.
0.01	0.46	n.s.	n.s.	0.20	n.s.	n.s.

Table (20) : Effect of soil application of $CaCO_3$ and Fe on phosphorus uptake by sorghum plants (mg/pot).

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ (%)														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	24.70	4.97	4.98	5.49	10.04	3.39	1.70	1.10	1.10	1.82	28.11	6.67	6.07	6.60	11.86
10.0	21.26	4.36	6.33	4.51	9.12	4.09	0.95	1.41	0.92	1.84	25.34	5.36	7.82	5.44	10.98
20.0	24.15	4.92	6.38	5.23	10.17	4.18	1.22	1.22	1.14	1.94	28.33	6.15	7.59	6.47	10.11
Mean	23.38	4.75	5.90	5.11		3.89	1.29	1.24	1.05		27.26	6.04	7.16	6.17	
L.S.D.		$CaCO_3$	Fe	$CaCO_3$.Fe		$CaCO_3$	Fe		$CaCO_3$.Fe		$CaCO_3$	Fe		$CaCO_3$.Fe	
0.05		1.22	n.s.	n.s.		0.71	n.s.		n.s.		1.74	n.s.		n.s.	
0.01		1.72	n.s.	n.s.		0.96	n.s.		n.s.		2.39	n.s.		n.s.	

With respect to plant shoots, similar trends were also revealed, where the values of P concentration were reduced from an average of 2.61 to 0.60, 0.73 and 0.76 mg P/g, with 0, 2, 4 and 8% $CaCO_3$ levels, respectively.

Phosphorus concentration, however, was not significantly affected with increasing the rate of Fe application.

No significant interaction existed between $CaCO_3$ and Fe in concern with their combined effect on P concentration, neither in plant roots nor in plant shoots. Such results are confirmed by Singh and Dahiya (1976) who observed a drastic decrease in phosphorus concentration with increasing levels of $CaCO_3$ in pea plant and also with Dahiya and Singh (1982), who reported the same result with oat plants. In this regard, Buehrer (1932) reported that in soils of high pH, phosphate precipitation occurred mostly by $CaCO_3$.

The values of P uptake by plant roots and shoots and hence the whole plant were significantly reduced with $CaCO_3$ application even at the low level (2%).

Thus it may be concluded that $CaCO_3$ seems to be a main factor influencing the concentration and uptake of both P and Fe. Such conclusion presents further evidence to the involvement of $CaCO_3$ in the Fe chlorosis phenomenon.

4.2.2.3. Calcium concentration and uptake by sorghum:

The values of Ca concentration and uptake by sorghum plants are presented in tables (21, 22).

Concerning the concentration of Ca in plant roots, it was significantly increased at all levels of $CaCO_3$ over the control. This increase may be attributed to the increased content of Ca ions in the culture and the solubilizing action of root exudates on $CaCO_3$.

Increasing iron concentration from 0 to 20 ppm in absence of $CaCO_3$, Ca concentration was decreased, but increased when $CaCO_3$ was present with all levels of applied Fe. However, the interaction effect of $CaCO_3$ and Fe on Ca concentration in roots was not significant.

Such results are confirmed by Dahiya (1973) and Singh and Dahiya (1976) who recorded an increase in Ca concentration with increasing applications of $CaCO_3$ in pea crop.

With respect to Ca concentration in plant shoots, it was significantly decreased at all levels of $CaCO_3$ as compared with control. This result is in accordance with those of Bennett (1945) and Linder and Harley (1944) who showed that plants growing on some calcareous soils may contain less Ca because of the retarded process of absorption due to high pH of such soils that prevented adsorption of several nutrients, including Fe.

Table (21): Effect of soil application of $CaCO_3$ and Fe on calcium concentration in sorghum plants (mg /g)

Part of plant	Roots					Shoots				
Level of iron (ppm)	Levels of $CaCO_3$ (%)									
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	7.46	15.39	16.66	21.74	15.30	6.66	4.44	3.97	3.81	4.72
10.0	7.30	13.01	17.14	24.75	15.55	6.35	5.71	3.97	5.71	5.44
20.0	6.66	15.55	15.55	18.33	14.02	6.98	4.44	4.60	2.28	4.58
Mean	7.14	14.65	16.45	21.16		6.66	4.86	4.18	3.93	

L.S.D	Roots $CaCO_3$	Roots Fe	Roots $CaCO_3$ x Fe	Shoots $CaCO_3$	Shoots Fe	Shoots $CaCO_3$ x Fe
0.05	2.84	n.s.	n.s.	1.47	n.s.	n.s.
0.01	3.86	n.s.	n.s.	2.00	n.s.	n.s.

Table (22): Effect of soil application of $CaCO_3$ and Fe on calcium uptake by sorghum plants (mg/pot).

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ (%)														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	16.30	46.23	40.94	51.10	38.6	59.18	34.42	31.59	25.73	37.73	75.47	80.65	72.53	76.81	76.37
10.0	19.25	31.43	45.57	49.84	36.5	57.36	47.92	31.90	36.20	43.35	76.61	79.26	77.46	78.34	77.92
20.0	19.25	40.10	37.49	43.13	35.0	61.23	35.33	36.66	31.65	41.22	80.49	75.40	74.15	74.77	76.20
Mean	18.30	39.25	41.30	48.00		59.26	39.22	33.38	31.19		77.52	78.44	74.71	76.46	
	$CaCO_3$	Fe		$CaCO_3$.Fe		$CaCO_3$	Fe		$CaCO_3$.Fe		$CaCO_3$	Fe		$CaCO_3$.Fe	
L.S.D 0.05	9.42	n.s.		n.s.		11.95	n.s.		n.s.		n.s.	n.s.		n.s.	
L.S.D 0.01	12.8	n.s.		n.s.		16.20	n.s.		n.s.		n.s.	n.s.		n.s.	

As iron applications increased from 0 to 20 ppm, in absence of applied $CaCO_3$, Ca concentration was not affected. Also, the interaction of $CaCO_3$ and Fe applications on Ca concentration in plant shoots was not significant.

Uptake of Ca by plant roots showed a sharp increase with increasing levels of $CaCO_3$. Calcium uptake by plant roots was decreased with increased levels of applied Fe. Values of Ca uptake was, 38.6, 36.5 and 35 mg Ca/pot at 0, 10 and 20 ppm $FeSO_4$, respectively.

Interaction of applied $CaCO_3$ and Fe on Ca uptake was not significant.

Regarding the effect of $CaCO_3$ on Ca uptake contained by plant shoots, it significantly decreased with increasing the rate of $CaCO_3$ application.

In absence of $CaCO_3$ application, calcium uptake did not follow a distinct trend with increasing the level of applied iron.

Application of $CaCO_3$ yielded an increase in Ca uptake by plant roots but it caused a decrease in that of plant shoots. However, the effect of $CaCO_3$ on Ca uptake by whole plants was not significant. The effect of iron application was also not significant with respect to the total uptake of Ca.

4.2.2.4. Magnesium concentration and uptake by sorghum:

It is clear from tables (23 and 24) that the concentration of Mg in plant roots significantly increased by application of $CaCO_3$ at all levels. Magnesium concentration in plant shoots, was significantly decreased at all levels of applied $CaCO_3$, while it did not follow any consistent trend with iron increasing.

Uptake of Mg by plant roots was significantly increased by application of $CaCO_3$. It is obvious that the maximum increase in Mg uptake by plant roots was achieved with 4% $CaCO_3$, while 8% $CaCO_3$ caused less increase. On the other hand, Mg uptake by roots increased with increasing the rate of iron application, when no $CaCO_3$ was added.

Uptake of Mg by plant shoots, was significantly decreased with increasing rates of $CaCO_3$ when compared with control.

The pattern of response to $CaCO_3$ and Fe, showed a significant decrease in Mg uptake by whole plants with increasing $CaCO_3$ applications while no clear trend could be noticed as a result to Fe additions.

4.2.2.5. Manganese concentration and uptake by sorghum:

The values of Mn concentration in plant roots and shoots and Mn uptake as affected by $CaCO_3$ and Fe applications are presented in tables (25 and 26). These values

Table (23): Effect of soil application of $CaCO_3$ and Fe on magnesium concentration in sorghum plants (mg /g)

Part of plant	Roots					Shoots				
Level of iron (ppm)	Levels of $CaCO_3$ (%)									
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	7.23	11.31	13.01	8.42	9.99	7.82	5.44	5.10	4.93	5.82
10.0	5.44	9.86	12.24	14.41	10.49	6.72	3.49	5.10	3.19	4.63
20.0	6.46	12.84	13.09	9.69	10.52	7.23	5.23	6.12	3.95	5.63
Mean	6.38	11.34	12.78	10.84		7.27	4.72	5.44	4.02	

L.S.D.	Roots: $CaCO_3$	Roots: Fe	Roots: $CaCO_3$ x Fe	Shoots: $CaCO_3$	Shoots: Fe	Shoots: $CaCO_3$ x Fe
0.05	2.70	n.s.	n.s.	1.37	n.s.	n.s.
0.01	3.66	n.s.	n.s.	1.86	n.s.	n.s.

Table (24): Effect of soil application of $CaCO_3$ and Fe on Magnesium uptake by sorghum plants (mg/pot).

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ (%)														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	15.62	33.20	31.50	20.66	25.25	70.03	40.68	40.98	32.82	46.13	85.65	73.88	72.14	53.49	71.29
10.0	14.74	23.58	32.66	29.99	25.24	47.99	29.45	37.76	19.44	33.66	75.10	53.03	70.42	49.43	62.00
20.0	18.73	33.69	31.65	22.77	26.71	65.17	41.53	49.91	29.44	46.51	83.91	75.22	81.56	52.22	73.23
Mean	16.36	30.16	31.94	24.47		61.06	37.22	42.88	27.23		81.55	67.38	74.71	51.71	
	$CaCO_3$		Fe	$CaCO_3$Fe		$CaCO_3$	Fe		$CaCO_3$Fe		$CaCO_3$		Fe	$CaCO_3$.Fe	
L.S.D. 0.05	6.64		n.s.	n.s.		11.88	10.29		n.s.		12.8		n.s.	n.s.	
L.S.D. 0.01	9.02		n.s.	n.s.		16.15	13.98		n.s.		17.4		n.s.	n.s.	

Table (25): Effect of soil application of $CaCO_3$ and Fe on manganese concentration in sorghum plants (ppm).

Part of plant		Roots					Shoots				
Level of iron (ppm)		Levels of $CaCO_3$ (%)									
		0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0		50.00	30.00	29.33	36.76	36.50	90.00	42.33	14.33	44.76	54.58
10.0		43.33	32.67	33.33	35.33	36.17	101.33	56.67	49.33	46.67	63.50
20.0		54.67	38.00	32.00	31.33	39.00	100.00	63.33	60.00	52.00	68.83
Mean		49.33	33.56	31.55	34.44		97.11	54.11	50.22	47.78	
		$CaCO_3$	Fe		$CaCO_3$ x Fe		$CaCO_3$	Fe		$CaCO_3$ x Fe	
L.S.D.	0.05	6.57	n.s.		n.s.		12.4	n.s.		n.s.	
	0.01	8.49	n.s.		n.s.		18.2	n.s.		n.s.	

Table (26): Effect of soil application of $CaCO_3$ and Fe on Manganese uptake by sorghum plants (mg/pot).

Part of plant	Roots					Shoots					Whole plants				
Level of iron (ppm)	Levels of $CaCO_3$ (%)														
	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean	0.0	2.0	4.0	8.0	Mean
0.0	0.112	0.091	0.070	0.098	0.093	0.79	0.34	0.33	0.29	0.438	0.900	0.427	0.401	0.388	0.529
10.0	0.107	0.079	0.091	0.065	0.086	0.77	0.40	0.401	0.25	0.455	0.879	0.482	0.492	0.312	0.541
20.0	0.158	0.103	0.085	0.058	0.101	0.90	0.51	0.50	0.30	0.550	1.02	0.609	0.585	0.353	0.640
Mean	0.126	0.091	0.082	0.074		0.82	0.42	0.41	0.28		0.933	0.380	0.493	0.351	
	$CaCO_3$		Fe	$CaCO_3$.Fe		$CaCO_3$		Fe	$CaCO_3$.Fe		$CaCO_3$		Fe	$CaCO_3$.Fe	
L.S.D. 0.05	0.022		n.s.	0.038		0.13		n.s.	n.s.		0.14		n.s.	n.s.	
L.S.D. 0.01	0.030		n.s.	0.052		0.18		n.s.	n.s.		0.18		n.s.	n.s.	

show significant differences in Mn concentration in the roots, the average values of Mn concentration in plant roots was reduced from 49.3 to 33.6, 31.0 and 34.4 ppm with application of $CaCO_3$ at the rates of 0, 2, 4 and 8%, respectively.

The results reveal an increase of Mn concentration in plant roots with increasing Fe applied, this increase however, was not significant.

It is interesting to observe that the lowest level of $CaCO_3$ (2%) was quite enough to drastically reduce the manganese concentration in plant roots. While further levels of $CaCO_3$ did not induce the resulted reduction in Mn concentration.

With respect to plant shoots, similar findings were also revealed, as the values of Mn concentration were reduced from an average value of 97.1 to 54.1, 50.2 and 47.8 ppm for $CaCO_3$ levels at 0, 2, 4 and 8%, respectively.

Results also show that the values of manganese concentration were not significantly affected with Fe application though a slight increasing tendency could be observed.

No significant interaction existed between $CaCO_3$ and Fe in concern with their combined effect on Mn concentration neither in plant roots nor in plant shoots. Such results are in good agreement with those of Dahiya and Singh (1982).

Considering the effect of $CaCO_3$ on Mn concentration in plant shoots, the concentration of Mn was decreased with increasing $CaCO_3$. The decrease in Mn concentration in presence $CaCO_3$ could be caused by decreased availability of Mn owing to possible precipitation and oxidation at higher pH and due to its adsorption on $CaCO_3$ surfaces. Similar observations were also reported by Singh and Dahiya (1976).

It is obvious from the aforementioned presentation that addition of $CaCO_3$ tended to decrease the concentration and total content of P, Fe and Mn in both sorghum roots and shoots. Regarding Ca, its concentration and total content increased in roots but materially decreased in the shoots with increasing rates of $CaCO_3$. Such behaviour may confirm the adverse influence of $CaCO_3$ on the solubility and thus the availability of many nutrients specially those of the micro-group. Under such conditions, excess Ca and deficiency of several other nutrients, an unbalanced state could have resulted with the mechanism of absorption being affected where Ca and, to some extent, Mg seemed to move into the roots inactively as they may accumulate somewhere in a state not ready to move to the shoots.

Finally it may be concluded that $CaCO_3$ seems to be a main factor affecting the concentration and uptake of Fe, Mn and several other nutrients in plant which, may give further attention to the probable role of $CaCO_3$ in the Fe chlorosis phenomenon.

4.3. Experiment III: Iron chlorosis as affected by phosphate applications:

This experiment was conducted to investigate the effects of P applications on the concentration and uptake of some nutrients that are usually reported as being involved in the iron chlorosis phenomenon. Sorghum plants grown on sand culture and watered with modified Hogland solution lacking P and Fe, were subjected to P applications as (KH_2PO_4) at four rates: namely 0, 20, 40 and 60 ppm P, while Fe was applied as $FeSO_4$ at one rate (20 ppm Fe).

It was observed that plant growth was better with P applications, while it was very much restricted in the complete absence of P application and the plants were very stunted.

The results obtained for nutrient concentrations and uptake are presented in tables (27 and 28) and graphically illustrated in Figs. (13 to 18).

4.3.1. Phosphorus concentration and uptake by sorghum:

4.3.1.1. Phosphorus concentration in sorghum roots and shoots:

The results show clearly that P concentration in plant roots as well as in shoots was significantly increased with

Table (27): Nutrient concentrations (ppm) in sorghum roots and shoots as affected by phosphorus levels in growth medium.

P level ppm		P	Fe	CO	Mg
			Roots		
0.0		347	393	6820	5610
20.0		437	509	9040	7310
40.0		545	980	7140	6380
60.0		660	2286	10160	7230
L.S.D.	0.05	113	NS	NS	NS
	0.01	170	NS	NS	NS
			Shoots		
0.0		341	91	5080	2210
20.0		664	163	6510	3230
40.0		858	130	6820	3740
60.0		932	154	6030	4000
L.S.D.	0.05	22	45	NS	NS
	0.01	33	68	NS	NS

Table (28): Nutrient uptake by sorghum (mg/pot) as affected by phosphorus levels in growth medium.

P level ppm		P	Fe	Ca	Mg
			Roots		
0.0		0.406	0.454	8.03	6.636
20.0		1.219	1.380	24.51	19.850
40.0		1.919	3.495	25.51	22.890
60.0		1.940	2.405	30.37	22.010
L.S.D.	0.05	0.210	1.320	9.76	7.88
	0.01	0.310	0.200	14.79	11.94
			Shoots		
0.0		0.735	0.194	10.84	4.817
20.0		4.427	1.083	43.40	21.513
40.0		6.400	0.959	49.41	28.060
60.0		7.200	1.140	44.64	29.350
L.S.D.	0.05	2.18	0.367	21.29	13.75
	0.01	3.30	0.556	32.25	20.83
			Whole plant		
0.0		1.141	0.648	18.89	11.45
20.0		4.546	2.460	68.00	41.36
40.0		8.320	4.450	75.00	50.95
60.0		9.138	3.540	75.03	51.36
L.S.D.	0.05	4.450	1,250	23.74	20.33
	0.01	6.750	1.980	35.96	30.81

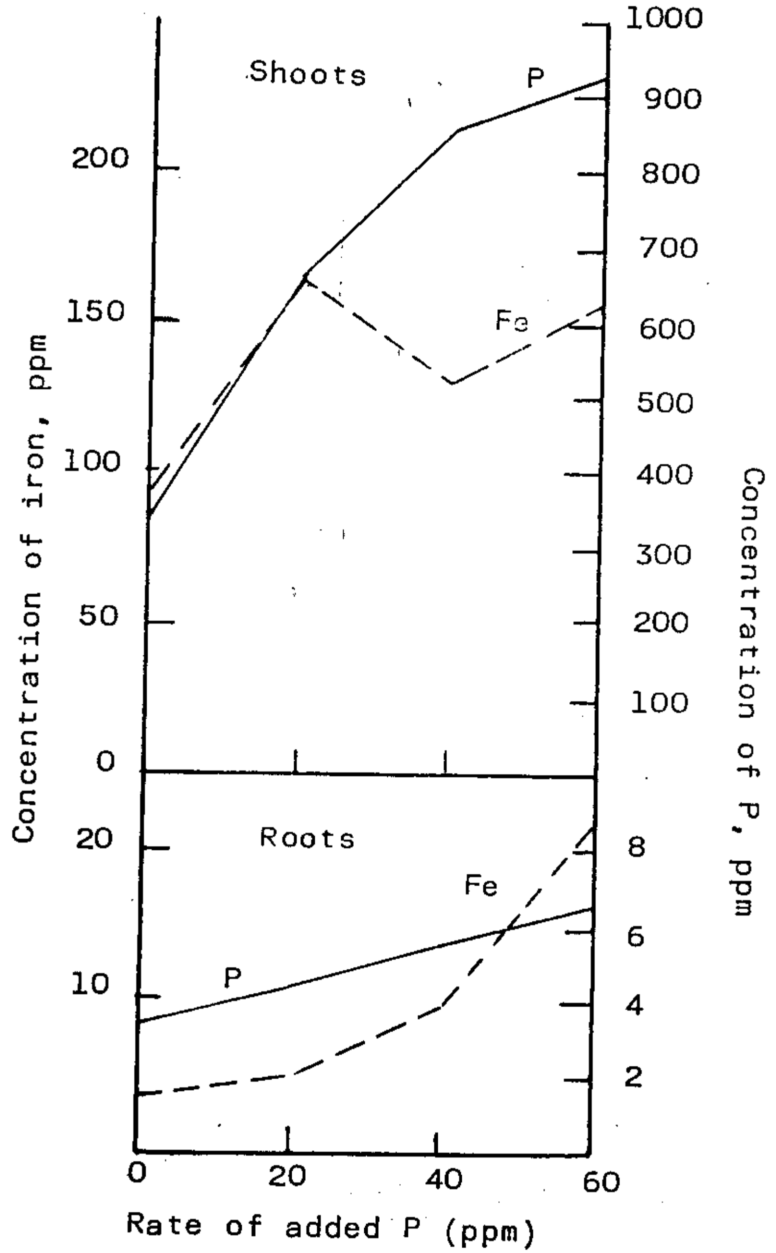


Fig. (14): Effect of P rates on Fe and P concentration in sorghum plants.

Root Fe and P concentration were multiplied by 10^{-2}

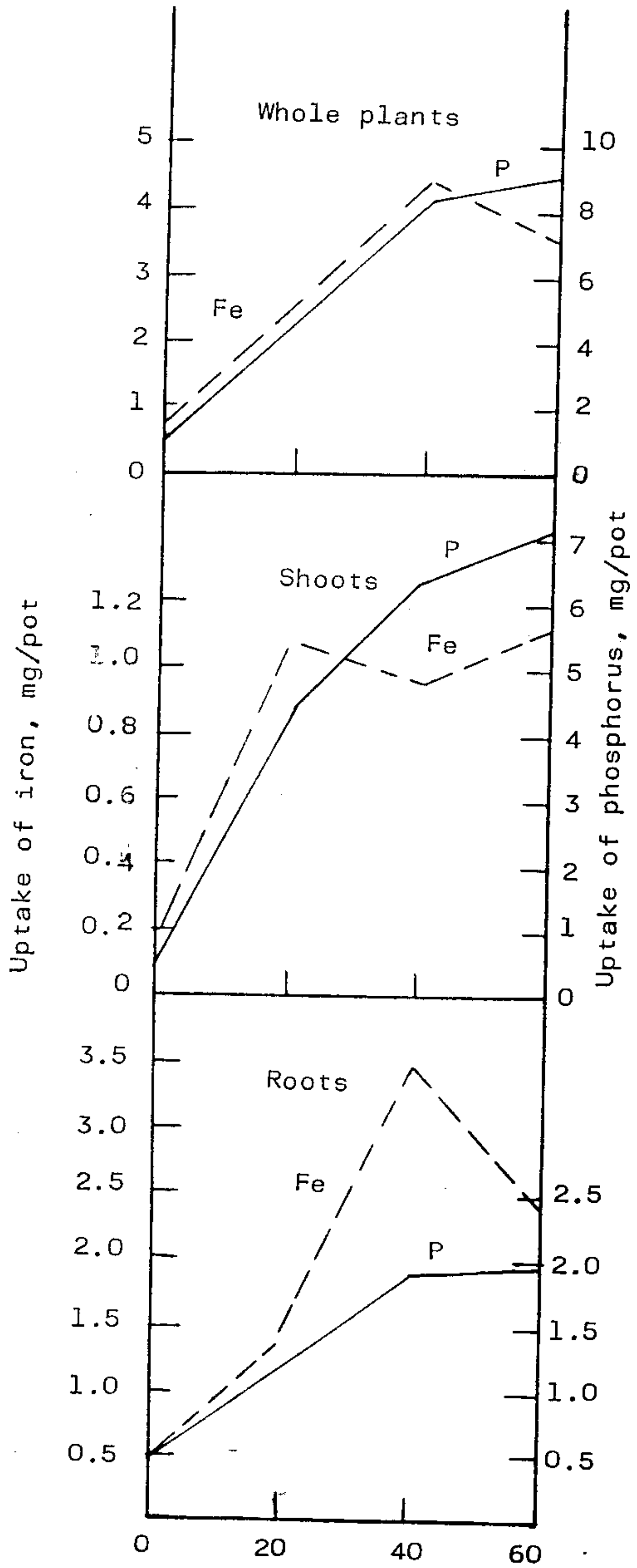


Fig. (14): Effect of P rates on Fe and P uptake by sorghum plants.

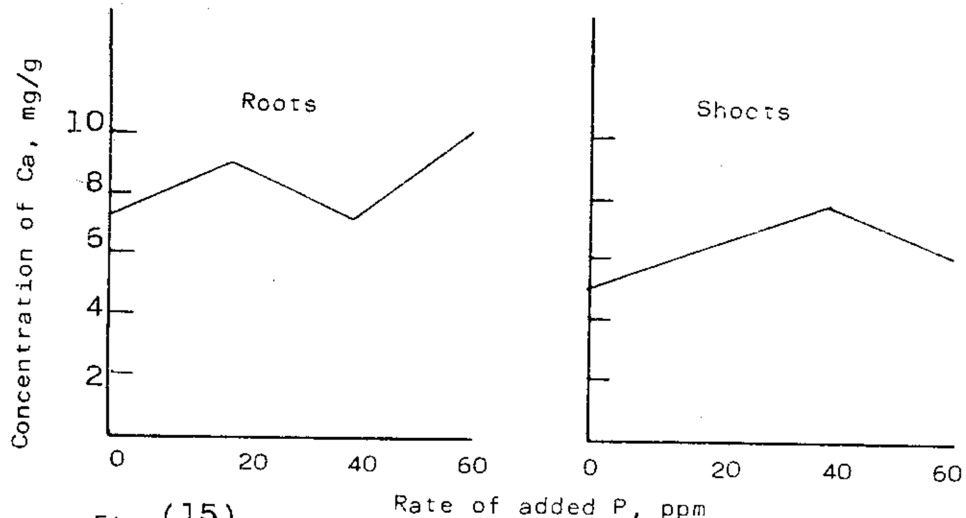


Fig. (15): Effect of P rates on concentration of Ca in sorghum plants.

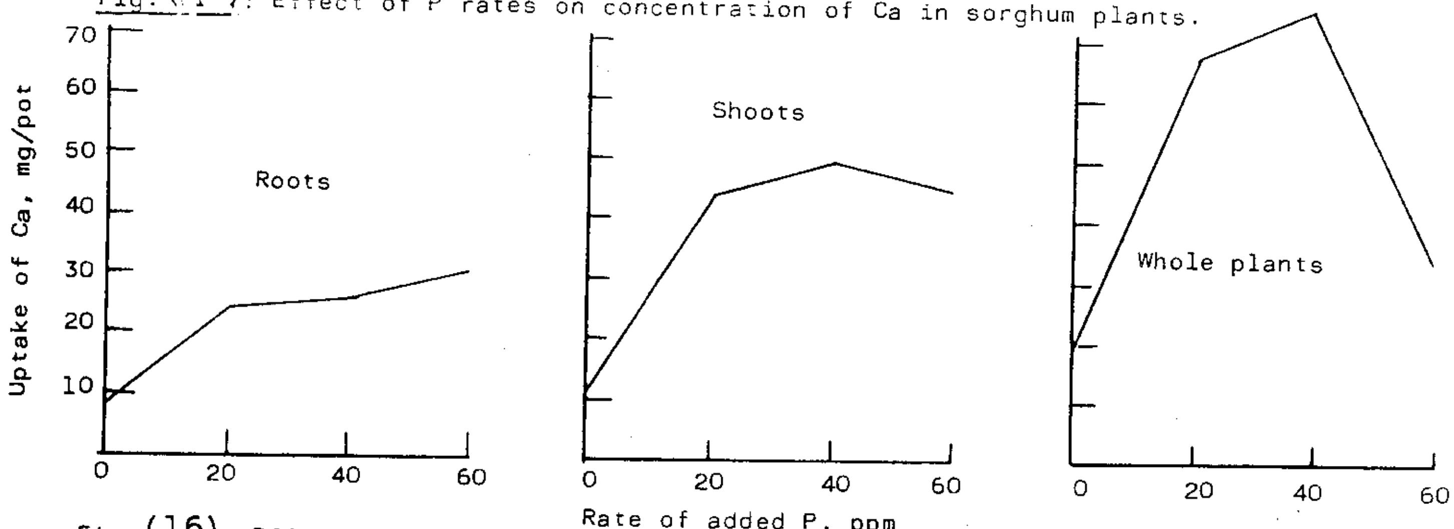
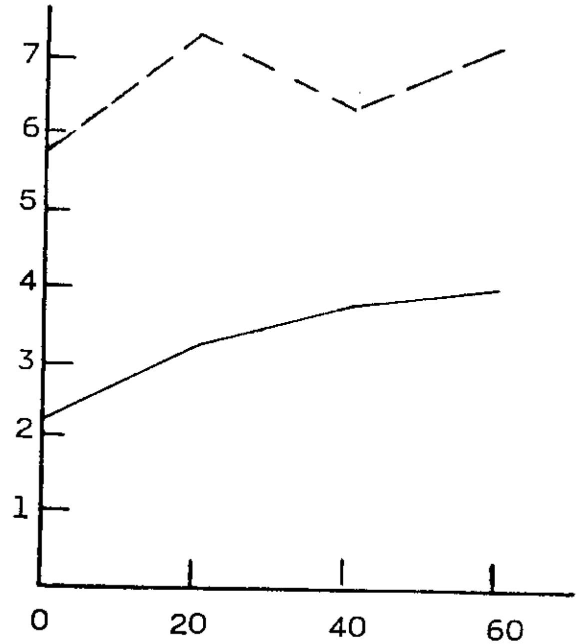
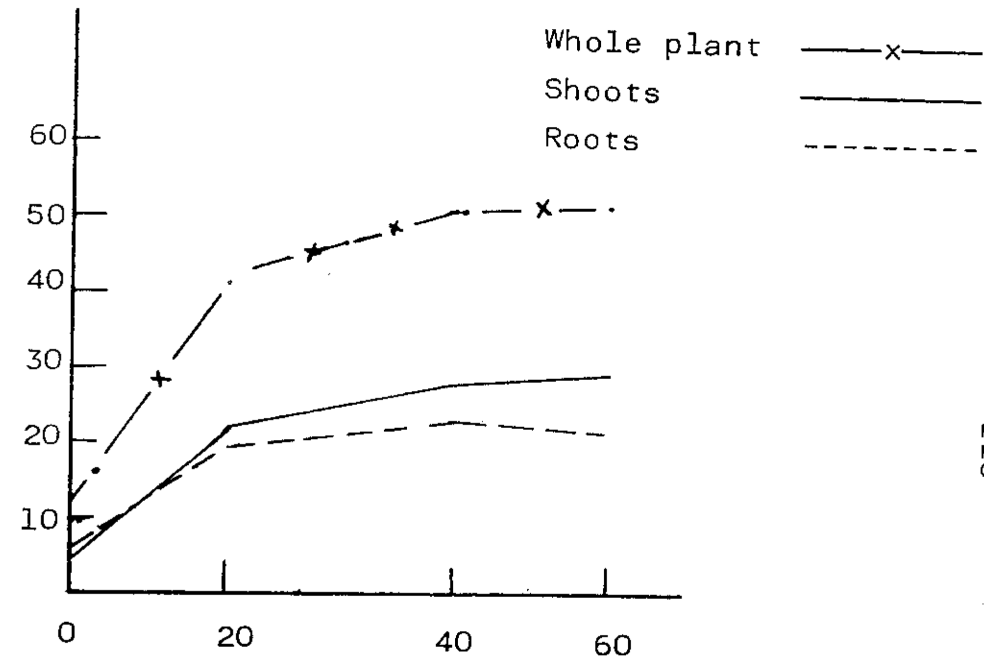


Fig. (16): Effect of P rates on uptake of Ca by sorghum plants.



Rate of added P (ppm)

Fig. (17): Effect of P rates on concentration of Mg in sorghum plants.



Rate of added P (ppm)

Fig. (18): Effect of P rates on uptake of Mg by sorghum plant.

increasing phosphorus level in growth medium. The concentration of P in plant roots averaged, 347, 437, 545, and 660 ppm at 0, 20, 40 and 60 ppm P, respectively.

The corresponding values in plant shoots, though followed the same trend, were very much higher than those in roots, being about 341, 664, 858 and 932 ppm, for the same rates of added P, respectively.

This result is confirmed by Ajakaiye (1979) who reported that phosphorus concentration in shoots and roots of both species (Millet and Sorghum) significantly increased with increasing P levels in growth medium.

4.3.1.2. Phosphorus uptake by sorghum:

Phosphorus uptake by plant roots and shoots as well as total uptake, was significantly increased with increasing the rate of applied P.

Such results are in good agreement with Bidulph and Woodbridge (1952) who showed that plants grown in media supplying excess phosphorus, progressively accumulated this element in the leaves, stems, and roots.

4.3.2. Iron concentration and uptake by sorghum:

4.3.2.1. Iron concentration in sorghum roots and shoots:

The values obtained for Fe concentration in plant roots, were significantly increased with increasing the level of applied P. The Fe concentration increased from 393 to 2286 ppm as the level of applied P was increased from 0 to 60 ppm. However, these increments were not significant.

The concentration of iron in plant shoots, was increased with P application, reached its maximum at the low rate of applied P (20 ppm). Further rates of P, however, tended to reduce Fe concentration as compared with those obtained at the 20 ppm P. The concentration of Fe was much greater in the roots than in the shoots at all P levels, indicating tendency of this element to be accumulated in plant roots. This result is confirmed by Ajakaiye (1979) who found that ^{55}Fe concentration was higher in the roots than in the shoots of the two species, Millet and Sorghum.

4.3.2.2. Iron uptake by sorghum:

The results show clearly that Fe uptake by plant roots was increased by P application. The maximum Fe content occurred at 40 ppm P, which could be attributed to a stimulative effect on root growth and hence the dry matter yield.

With plant shoots, the Fe uptake also increased significantly with increasing the rate of P application. However, the different levels of applied P were not significantly different.

With whole sorghum plants, a trend similar to that shown by plant roots was obvious.

4.3.3. Calcium concentration and uptake by sorghum:

Results of Ca concentration and uptake by sorghum plants, reveal an increasing tendency in both roots and shoots with the increasing rates of applied P. However, the obtained effect was not significant neither in roots nor in shoots.

Concerning the Ca uptake, significant increase was evident with increasing the level of P in the medium. The values of Ca uptake increased from 8.03 to 30.37 mg Ca/pot in roots and from 10.84 to 44.64 mg Ca/pot in shoots as a result to the increasing levels of applied P from 0 to 60 ppm.

As in case of Ca concentration, while Ca uptake contained by roots gradually increased with the progressive increments of applied P, the maximum value attained in the shoots being at the 40 ppm applied P, slightly reduced at the 60 ppm. This could be due to the precipitation of Ca in roots in a form not translocated to the shoots under high rates of applied P.

The total Ca uptake by sorghum plants showed a trend almost similar to that revealed by sorghum roots where, it is increased with the progressive increments of applied phosphorus. up to the of 40 ppm P. after which a decreasing tendency was noticed.

4.3.4. Magnesium concentration and uptake by sorghum:

Data obtained for magnesium concentration and uptake by sorghum plants reveal that the concentration of Mg in sorghum roots increased by increasing the level of applied P but this increase was not significant.

With respect to Mg concentration in plant shoots, no significant differences regarding Mg concentration could be also obtained.

Concerning Mg uptake contained by plant roots and shoots, both were increased with increasing P level over control. However, no significant differences existed between the different P treatments.

Total uptake of Mg by whole plants, behaved similarly to roots and shoots, howevever the progressive increase due to increasing rates of applied P was significant with regard to the whole plant.

4.3.5. Ratio of phosphorus to iron (P/Fe) in tissues of sorghum as affected by phosphorus applications:

It is easy to observe that the P/Fe ratio (table 29) was very much greater in sorghum shoots than in sorghum roots at all levels of applied P.

This result is supported by Ajokaiye (1979) who concluded that, (i) high P in growth medium prevented the plants from taking up and translocating sufficient Fe from

Table (29): Ratio of phosphorus to iron (P/Fe) in tissues of sorghum as affected by phosphorus level.

P level ppm	Shoots	Roots
0.0	3.8:1	0.88:1
20.0	4.1:1	0.86:1
40.0	6.6:1	0.56:1
60.0	6.1:1	0.29:1

the nutrient solution. (ii) the relatively high P supplementals may result in a difficulty in interveinal translocation of Fe, perhaps because Fe was inactivated or precipitated in veins and was not translocated to the mesophyll.