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INFLUENCE OF IRON ON THE UPTAKE OF PHOSPHORUS BY MAIZE

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SUMMARY

Experiments were carried out with maize in solution culture at three different iron levels at each of which P solubilities were varied through a relatively wide range (upto 80 per cent). Studies were made of the interactions between iron and phosphorus in their effects upon the dry matter production, iron and phosphorus uptake. The results revealed that iron above 5 mg per litre adversely affected the growth as well as P uptake. At higher P solubility levels, translocation of iron from the roots to the shoots was reduced, indicating an internal inactivation of iron by the phosphorus.

INTRODUCTION

The prime importance of trace elements in the nutrition of plants is indisputable. One of the trace elements, iron, associates itself in one way or another with the important functions of plant metabolism. Investigations of the problem of iron availability [5 13] has led to the general acceptance of the theory that it is the soluble form in the plant which plays an important role in iron metabolism. It is evident [12] that this element by being precipitated within the tissues may become inactivated and therefore unavailable to metabolism processes of the plant. In acid conditions iron gets activated and precipitates the applied phosphorus into its compounds thus rendering the phosphorus less soluble and less available to plants.

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A high P supply was found to be associated with incipient iron (Fe) chlorosis due to iron precipitation [7]. Iron concentrations from 0–50 ppm had no appreciable effect on the uptake of radiophosphorus [11]. Other studies [1] have shown that polyvalent cations often promote the uptake of anions. Further the availability of larger amounts of phosphorus in the soils is believed to help in correcting the toxicity of iron [2 3 4]. There is no agreement, however, as to the manner in which phosphates render iron non-toxic.

The results of many workers [5 7 10] indicate that while application of large amounts of easily available phosphorus to acid soils do, to a considerable extent, directly precipitate the active iron present in the soil solution, its most important function is performed within the plants themselves where a certain portion of the absorbed phosphorus precipitates iron into an immobile form and is, in turn, rendered unavailable for normal nutritional purposes. It was observed that iron was internally inactivated principally by phosphorus and calcium [14]. Also it was observed that iron absorption by cultures is reduced by F_1 probably by H_2PO_4 ions especially at pH values around 6 [6].

Ivanova [8] observed in his water and sand culture trials that the chlorophyll content per gram fresh leaf was 2–3 times less in plants supplied with a triple rate of phosphorus than it was in the control plants receiving normal rates of phosphorus and iron. Tadano [15] observed that Fe uptake by healthy plants from culture solution with high Fe level was decreased by the presence of P (10 ppm) in the solution but was not affected by other elements.

Phosphorus in calcium hydroxy-apatite $[3\ Ca_3\ (PO_4)_2 . Ca(OH)_2]$ obtained from conversion of calcium ortho-phosphate in fairly acid and alkaline soils is very slowly available even under favourable conditions. Existence of monocalcium phosphates in the soil can be easily excluded and the dicalcium phosphate which is sparingly soluble in water seems to be fairly steadily available in the soil.

Only apatitic forms of phosphorus and dicalcium phosphates are available in plenty in German markets. In acid soils of the types prevailing in Germany, a combination of both dicalcium phosphate and apatites would form an ideal combination in supplementing the required amounts of phosphorus to the crops throughout the growth period and in the meanwhile controlling the iron toxicity.

Solution culture trials were, therefore, tried to study the influence of increased amounts of soluble phosphorus on the growth, phosphorus and iron uptake by maize under different levels of iron.

MATERIALS AND METHODS

The trials were conducted in nutrient solution culture under acid conditions with maize as the test crop. Maize seedlings were raised in saw dust medium. When the plants grew to a height of 5–8 cm, seedlings of uniform growth were transferred to a complete nutrient solution (Crone's solution) contained in a four litre glazed pot at the rate of seven healthy plants per vessel. Iron was given as Fe-EDTA, containing 13 per cent. Micronutrients were added at the following rates per litre of the solution mixture. Manganese as $MnCl_2$. $4H_2O$ at 702.4 mg, copper as $CuCl_2$. 2 H_2O at 148 mg, zinc as $ZnCl_2$ at 145 mg, molybdenum as $NaMnO_4$.2 H_2O at 17.6 mg and boron as H_3BO_3 at 194.2 mg. Various solubility products of phosphorus was prepared by adding different proportions of apatite and dicalcium phosphate (DCP) as follows. P was applied at the rate of 160 mg P per litre.

1. 100 per cent P as apatite
2. 90 per cent P as apatite + 10 per cent P as DCP
3. 80 per cent P as apatite + 20 per cent P as DCP
4. 70 per cent P as apatite + 30 per cent P as DCP
5. 60 per cent P as apatite + 40 per cent P as DCP

The above five treatments were tried in two levels of iron content namely 5 and 10 mg per litre. All the ten treatment combinations were replicated four times.

After harvest of the first trial, it was repeated again with modifications to accommodate more soluble phosphorus and iron. The following five P solubilities were tried.

1. 100 per cent P as apatite
2. 80 per cent P as apatite + 20 per cent P as DCP
3. 60 per cent P as apatite + 40 per cent P as DCP
4. 40 per cent P as apatite + 60 per cent P as DCP
5. 20 per cent P as apatite + 80 per cent P as DCP

The above treatments were tried under three levels of Fe, namely, 10 mg Fe/litre, 20 mg Fe/litre and 30 mg Fe/litre. All the 15 treatment combinations were replicated four times.

The culture solution was daily aerated and the nutrient solution was renewed at fortnightly intervals. The nutrient solution was maintained at a constant pH of 5.6 and a constant volume by addition of distilled water. After eight weeks, the plants were cleaned with deionised water and blotted. The plant is separated into roots and shoots, dried at 75°C for 24 hours, ground and wet digested with H_2SO_4, HNO_3 and $HClO_4$ mixture and analysed for iron by atomic absorption spectrophotometer. Phosphorus was estimated in the triple acid extract colorimetrically by the vanadomolybdate method [2].

RESULTS AND DISCUSSION

Dry matter

The dry matter yield data of maize plants are presented in Table 1. Dry matter yield was maximum at 10 per cent availability of phosphorus. When the availability was further increased a general trend of dry matter decrease was observed. Further, when the iron concentration in the nutrient solution was increased from 5 mg per

TABLE 1

Dry matter yield (gm) of maize (Mean value of 4 replications)*

Treatments	Plant part	I Trial		II Trial		
		Fe 5 mg/l	Fe 10 mg/l	Fe 10 mg/l	Fe 20 mg/l	Fe 30 mg/l
1. Apatite	Root	6.06	4.58	7.38	6.04	5.48
	Shoot	13.54	8.37	23.61	18.51	14.89
	Whole plant	19.60	12.95	30.99	24.55	20.74
2. 90% apatite plus 10% DCP	Root	6.13	5.55	7.35	6.13	5.15
	Shoot	14.86	9.65	23.04	15.30	11.34
	Whole plant	20.99	15.20	30.39	21.43	16.49
3. 80% apatite plus 20% DCP	Root	6.03	4.99	6.80	6.63	6.42
	Shoot	12.81	8.31	19.54	15.00	13.54
	Whole plant	18.84	13.30	26.34	21.63	19.96
4. 70% apatite plus 20% DCP	Root	5.62	4.90	7.13	5.79	5.64
	Shoot	12.44	7.26	22.91	12.87	12.05
	Whole plant	18.06	12.16	30.04	18.66	17.69
5. 60% apatite plus 40% DCP	Root	4.24	5.21	6.43	5.57	5.62
	Shoot	9.21	9.14	21.67	11.87	11.06
	Whole plant	13.45	14.35	28.10	17.44	16.68

* Dry weight on oven dry basis
DCP = Dicalcium phosphate

TABLE 2

Percentage yield and uptake of nutrients in Fe 10 mg/l level when Fe 5 mg/l level is considered 100

T.No.	Treatments	Dry matter yield		Phosphorus uptake		Iron uptake	
		Root	Shoot	Root	Shoot	Root	Shoot
1.	Apatite	76	62	48	52	65	54
2.	90% apatite plus 10% Dicalcium phosphate (DCP)	91	65	36	68	64	52
3.	80% apatite plus 20% DCP	83	65	64	66	124	45
4.	70% apatite plus 30% DCP	87	58	49	53	65	47
5.	60% apatite plus 40% DCP	123	100	74	73	106	76

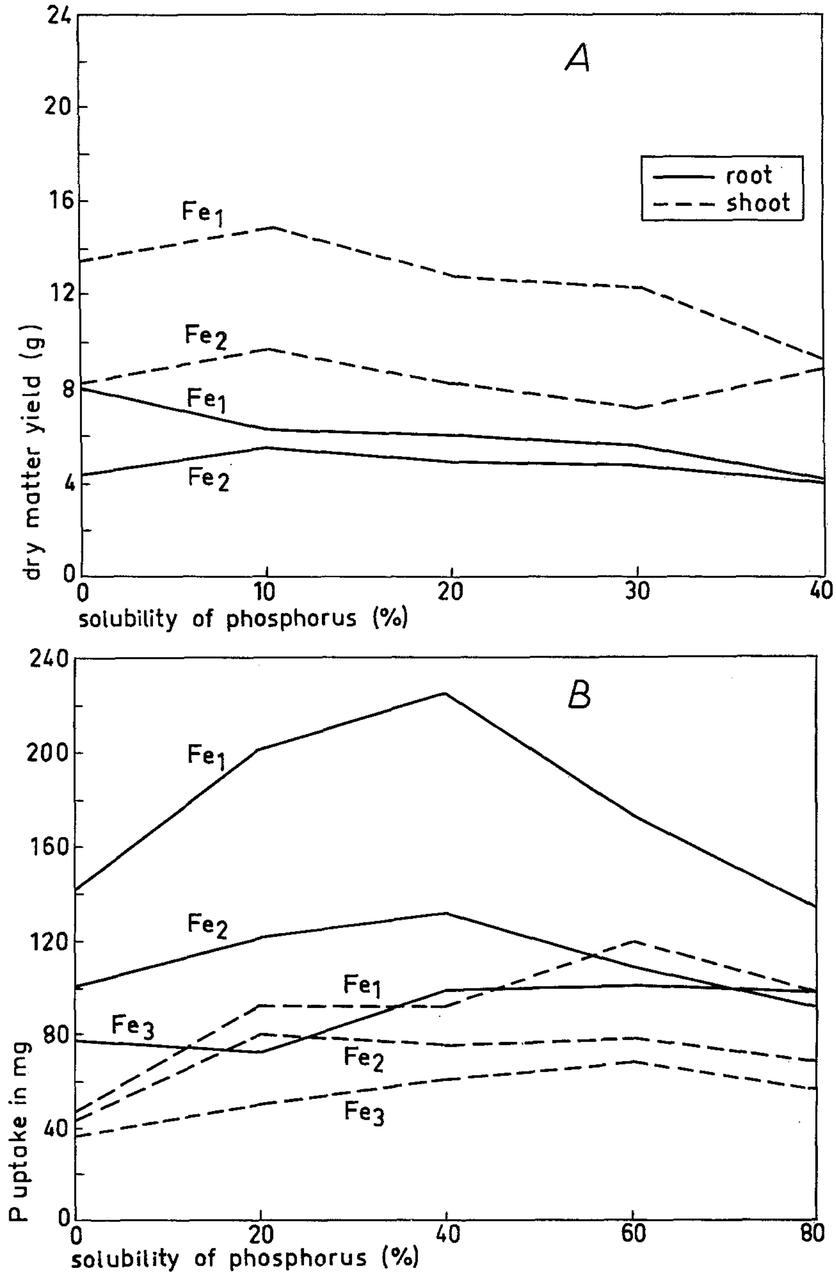

Fig. 1. **A**. Dry-matter production as influenced by solubility of phosphorus at 2 levels of iron.
B. P-uptake as influenced by solublility of phosphorus at 3 levels of iron.

litre to 10 mg per litre, the yield reduced considerably, ranging from 27 to 34 per cent (Fig. 1). The reduction is more in the shoots (35–42 per cent) than in the roots (13–24 per cent) Table 2. The availability of phosphorus within the range of 0 and 30 per cent did not have any marked influence on the dry matter yield but at 40 per cent P availability level, the yield increase was about 6.7 per cent. In the second trial, an increase in Fe supply from 10 mg per litre to 30 mg per litre had a depressive effect on the dry matter yield. At all the three levels of Fe, the dry matter yield was depressed as the availability of P eas increased from 0 to 80 per cent.

Iron

Iron content as well as the uptake of iron due to the various treatment combinations in both the trials are furnished in Table 2. When the P availability in the nutrient solution is increased to 40 per cent (First trial) the iron content as well as the iron uptake was

TABLE 3

Iron content and uptake in maize (Mean value of 4 replications)

T. No.	Plant part	Iron									
		First trial				Second trial					
		Content, mg/100 g 10^{-4}				Content in mg/100 g 10^{-4}			Uptake (mg × 10^{-4})		
		Fe 5 mg/l	Fe 10 mg/l	Fe 5 mg/l	Fe 10 mg/l	Fe 10 mg/l	Fe 20 mg/l	Fe 30 mg/l	Fe 10 mg/l	Fe 20 mg/l	Fe 30 mg/l
1.	Root	190	165	11.52	7.53	33	31	29	2.5	1.8	1.7
	Shoot	84	73	11.40	7.85	152	136	184	35.8	25.5	27.4
	Whole plant	274	238	22.92	15.28	185	167	213	38.2	27.0	29.1
2.	Root	242	170	14.43	9.43	30	33	34	2.2	2.1	1.8
	Shoot	89	71	13.15	8.38	194	164	163	44.6	25.0	18.5
	Whole plant	331	241	87.98	17.81	224	197	197	46.8	27.1	20.3
3.	Root	198	297	11.95	14.83	52	48	44	3.2	3.2	3.0
	Shoot	106	74	13.61	7.91	204	170	160	39.8	25.5	21.7
	Whole plant	304	371	25.56	22.74	256	218	204	43.3	28.7	24.7
4.	Root	305	226	16.99	11.09	41	38	76	2.9	2.2	5.4
	Shoot	86	69	10.69	6.97	197	146	181	45.1	18.8	27.2
	Whole plant	391	295	27.68	18.06	238	184	257	48.0	21.0	32.6
5.	Root	405	349	17.14	18.20	64	44	94	4.1	2.4	6.4
	Shoot	92	66	8.48	7.03	174	152	177	39.5	18.1	21.7
	Whole plant	497	415	25.62	25.23	238	196	271	43.6	20.5	28.1

increased. When the iron content was increased in the nutrient solution from 5 mg/litre to 10 mg/litre the uptake of Fe was depressed. A similar trend was obtained in the second trial also. When the availability of phosphorus is increased the amount of Fe taken up by the plants also increased. At the lower levels of P availability (upto 40 per cent available P content in the nutrient solution), uptake of Fe was hindered by additional Fe in the solution. As the concentration was increased from 10 mg to 30 mg per litre, the reduction in the uptake was upto 39 per cent. When the availability of P was increased beyond 40 per cent the influence of Fe on the uptake of Fe was not regular. An increase in the Fe/P ratio (Table 5) at higher P availability was observed in the roots. This suggested an accumulation of Fe in the roots under higher P concentration. This is in line with the findings of Holmes [7]. The dry matter yield in the second trial was higher than the first trial. But the Fe content was higher in the first trial than the second under its same conditions of treatment. This is due to the dilution effect since it could be seen in the table that when the total Fe uptake was more in the second trial corresponding to its higher dry matter content.

Phosphorus

The phosphorus content in plants which received dicalcium phosphate in parts along with apatite, is definitely more than the plants which received the entire P from apatite. In the first trial, when the soluble P content in the nutrient solution was increased P content also increased (Table 4) in the first level of Fe addition namely, 5 mg Fe per litre. Similarly at the higher level of Fe application also (10 mg Fe per litre), the P uptake was increased, as the P availability is increased. Keeping P availability constant, when iron application was increased from 5 mg per litre to 10 mg per litre, the P content was reasonably reduced. The same trend was reflected in the uptake of P also. In the second trial, the data showed that when more available P is added more phosphorus was taken up by the plants. The maximum was taken up when the availability of P was 20 per cent in the solution and the rate of increased uptake decreases with each additional does of available P (Fig. 2).

At any level of available P, when the Fe content is increased, the P content and the uptake decreased. The reduction in the uptake ranged from 19 to 54 per cent. The percentage decrease is more dras-

TABLE 4

Phosphorus content and uptake in maize (Mean value of 4 replications)

S. No.	Plant part	Phosphorus Content mg/100 g Fe 5 mg/l	Content mg/100 g Fe 10 mg/l	Uptake mg 10^{-4} Fe 5 mg/l	Uptake mg 10^{-4} Fe 10 mg/l	Content mg/100 g 10^{-4} Fe 10 mg/l	Content mg/100 g 10^{-4} Fe 20 mg/l	Content mg/100 g 10^{-4} Fe 30 mg/l	Uptake g 10^{-4} mg $\times$ 10^{-4} Fe 10 mg/l	Uptake g 10^{-4} mg $\times$ 10^{-4} Fe 20 mg/l	Uptake g 10^{-4} mg $\times$ 10^{-4} Fe 30 mg/l
1.	Root	634.6	404.3	38.44	18.40	1929	1618	1337	142.3	99.7	78.03
	Shoot	215.4	182.8	29.16	15.31	204	242	247	48.1	44.7	36.74
	Whole plant	850.0	487.1	67.60	33.81	2233	1860	1584	190.4	144.4	114.77
2.	Root	857.4	338.4	52.55	18.76	2731	2004	1561	200.7	122.5	80.37
	Shoot	274.9	289.5	40.85	27.92	400	468	439	92.0	71.6	49.73
	Whole plant	1132.3	627.9	93.40	46.68	3131	2472	2000	292.7	184.1	130.10
3.	Root	663.1	511.0	40.01	25.50	2613	1972	1472	223.8	130.8	98.93
	Shoot	486.4	492.2	62.10	40.88	470	505	447	91.8	75.8	60.49
	Whole plant	1149.5	1003.2	102.11	66.38	3083	2477	1919	315.6	206.6	159.42
4.	Root	885.6	497.1	49.78	24.36	2441	1890	1432	174.0	109.3	100.80
	Shoot	580.8	531.3	72.21	38.58	518	608	446	118.7	78.2	67.07
	Whole plant	1466.4	1028.4	121.99	62.94	2959	2498	1878	292.7	187.6	167.87
5.	Root	955.2	577.9	40.48	30.12	2089	1642	1444	134.4	91.4	97.07
	Shoot	736.9	543.4	67.89	49.67	444	567	448	96.3	67.3	55.05
	Whole plant	1692.1	1121.3	108.37	79.79	2533	2209	1892	230.7	168.7	152.12

tic in the case of roots than in shoots, suggesting a fairly uninterrupted movement of P from the roots to the shoots irrespective of Fe content. This was further supported by Fe/P ratio increase with the increasing P availability.

The aforementioned observations that an increase in P availability did not result in increase in dry matter production, though the P uptake increased reveals that P alone is not the criteria for dry matter yield. Further observations are that P content in the roots are more depressed than those of the shoots by every additional iron supply and a general reduction in the P content in the shoots as well as roots as the Fe content is increased. The total percentage of reduction is more in the roots than in the shoots. These observations reveal that iron interfere with P uptake. This may probably be due to the fact that phosphorus gets precipitated as iron phosphate. Iron content in the roots increased as the P availability is increased but the content in the shoots either decreased as the availability is increased or the increase is negligible. This shows that iron gets accumulated in the roots as iron phosphate. The reduction in the Fe content was reflected in reduced yield of dry matter.

TABLE 5

Fe/P ratios as influenced by treatments (10^{-6})

T.No.	Plant part	Fe at 10 mg/l	Fe at 20 mg/l	Fe at 30 mg/l
1.	Root	1.76	1.81	2.18
	Shoot	74.44	56.37	74.50
2.	Root	1.10	1.71	2.24
	Shoot	48.48	34.91	37.19
3.	Root	1.56	2.44	3.03
	Shoot	43.36	33.63	35.88
4.	Root	1.67	2.10	5.47
	Shoot	37.99	24.04	40.55
5.	Root	3.05	2.63	6.59
	Shoot	39.17	26.89	39.42

From the foregoing observations and discussions, the following conclusion may be drawn. As the availability of P increased P uptake is increased. Increased uptake of P is not reflected in the dry matter production of either roots on shoots beyond the availability level of about 40 per cent. Increased iron supply to the plants increased the Fe contents and decreased the P content. At higher P availability levels, iron translocation from the roots to the shoots was affected. Iron, is thus, internally inactivated by phosphorus. This iron phosphorus interaction is further evidenced from the observation that by every additional Fe supply the decrease in P uptake in the shoots is comparatively smaller than the reduction in P uptake in the shoots. That means phosphorus translocation is not interrupted. When availability of P is increased iron gets accumulated in the roots and its translocation to the shoots is restricted. This may be a means of arresting iron toxicity in the plants. This corroborates the findings of Brown *et al.*[2 3 4] and Dekock [5].

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