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PLANT RESPONSE TO MICRONUTRIENTS
III. INTERACTION BETWEEN MANGANESE AND ZINC IN MAIZE AND BARLEY PLANTS

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SUMMARY

Maize and barley plants were grown in a deficient soil with different levels of manganese and zinc in order to study the interaction between manganese and zinc and, further, to determine if the presence of zinc would influence the absorption and/or translocation of manganese and vice versa.

Mn^{54} and total manganese content of roots, sheaths and blades of maize were remarkably reduced by zinc application. The effect of zinc on Mn^{54} and manganese content of barley plants, however, was less pronounced. The total Mn^{54} uptake in maize was reduced by more than 40 per cent, although the percentage distribution of Mn^{54} among roots, sheaths and blades was not affected by zinc application. The effect of zinc on Mn^{54} uptake and percentage distribution in barley was marginal.

Zn^{65} and total zinc content of roots, sheaths and blades of maize and barley were observed not to be affected by manganese application except at the highest level of zinc, where marginal effect was noticed. The total Zn^{65} uptake and percentage distribution among roots, sheaths and blades of maize and barley were not affected by manganese application.

It is concluded that the effect of zinc on Mn^{54} uptake and translocation is predominantly at the transport site and not in the internal distribution or translocation. The manganese seems to play very little role either in transport or translocation of zinc in plants.

INTRODUCTION

Antagonisms between manganese and zinc and other nutrient elements have been reported by several investigators. Hawf and Schmid [4] showed in solution culture experiment with bush bean plants that manganese as an added cation, had an effect on Zn^{65} uptake at high concentration only, but did not alter the internal distribution. Ishizuka and Ando [5], working with rice plants, found that the amount of manganese absorbed by plants was remarkably re-

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duced with increasing zinc concentration and thatt he zinc prevented manganese toxicity. It has also been reported that manganese toxicity symptoms of crops were reduced by addition of iron [1 8 11] and aluminium [6]. This type of interaction, however, has been found mainly in solution or sand culture experiments. Little is known about such interactions in soil medium and especially in relation to absorption and translocation of nutrient elements.

The present experiment was undertaken to study the interaction between manganese and zinc in maize and barley plants, principally in relation to its effect on the absorption and/or translocation of the respective nutrients.

METHODS

Planting, harvesting and analytical procedures have been previously described. Unlike methods outlined in previous papers harvesting was done only once after 6 weeks growth. The application levels for manganese and zinc as well as the radioactivity levels were identical to those previously reported [9 10]. The method of determination and separation of Mn^{54} and Zn^{65} activities is described here.

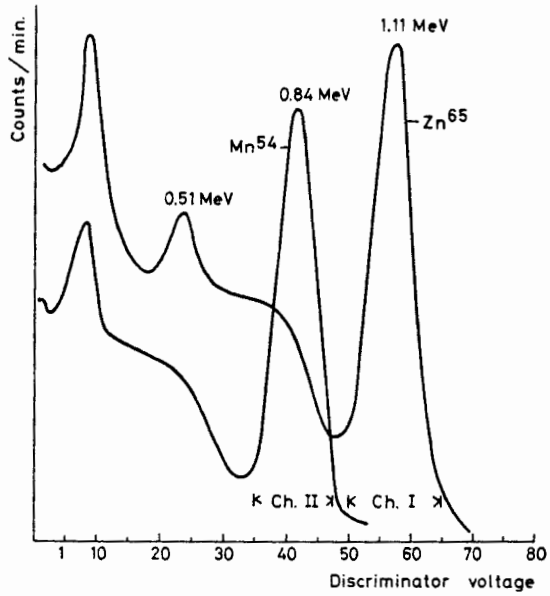

Fig. 1. Gamma-spectra of Mn^{54} and Zn^{65} measured in a well type NaI-scintillation spectrometer.

The Mn^{54} and Zn^{65} activities were determined by a gamma scintillation spectrometer, as in the previous papers. The simultaneous use of the two radiotracers, however, makes the counting procedure a little more complicated. First, the gamma spectra for the two isotopes were run separately. The results are shown in fig. 1. By an appropriate choice of the counting channels, the activities of Mn^{54} and Zn^{65} in the samples can be separated. In channel I, only the Zn^{65} is measured (Fig. 1). In channel II both Mn^{54} and Zn^{65} are counted, the latter, however, at a reduced counting rate as compared to channel I. The ratio of the measured activities in the two channels is determined with a pure Zn^{65} sample. For a mixed sample the activity is first counted in channel I, giving the Zn^{65} activity only. By multiplying this with the ratio of the activities in the two channels, the Zn^{65} activity measured in channel II is obtained. By subtracting this value from the activity of Mn^{54} + Zn^{65} counted in channel II, the activity of Mn^{54} is obtained. The Mn^{54} and Zn^{65} activities are, as usual, compared with standards of known specific activities. The comparison is used to convert measured activities to amounts of Mn and Zn that have been drawn by the plants from the isotope labelled sources added to the soil.

RESULTS

Irrespective of manganese level, typical zinc deficiency symptoms were observed in all maize plants at the 0 ppm level of zinc. No symptoms were observed in barley. However, in the beginning both crops exhibited stunted growth in this treatment. Manganese deficiency symptoms were not seen in either of the crops.

Application of zinc significantly increased the dry matter yield in maize plants and the effect was larger in the blades than in sheaths or roots. Although the dry matter yield of barley did not differ significantly among treatments, numerically superior yields were obtained in zinc treated pots (Table 1).

In maize, Mn^{54} content of roots, sheaths and blades was substantially decreased with an increasing level of zinc application. For barley plants, however, the effect of zinc on Mn^{54} content was less pronounced (Table 2). In both crops, the blades had highest Mn^{54} content followed by the roots and sheaths. In maize plants, the total Mn content of roots, sheaths and blades followed the pattern established for Mn^{54} content. However, in barley the distribution pattern of total manganese differed slightly, in that the roots had highest manganese content followed by blades and sheaths (Table 3).

The effect of zinc on total manganese content of barley plants was again less pronounced than in maize plants. In maize plants,

TABLE 1

The effect of Mn and Zn application on the total dry matter yield of maize and barley plants

Part	Mn rate ppm	Zn rate ppm					
		Maize			Barley		
		0	5	25	0	5	25
Roots	0	3.32	3.26	3.54	0.74	0.80	0.70
	50	2.83	3.12	3.43	0.73	0.88	0.82
	100	2.67	3.15	3.80	0.70	0.78	0.69
Sheaths	0	5.33	6.86	7.07	2.94	3.74	3.93
	50	6.57	7.79	7.00	3.48	4.04	3.98
	100	6.22	6.52	7.41	2.88	4.03	4.11
Blades	0	6.38	9.87	10.57	2.67	3.29	3.06
	50	7.09	8.52	10.78	3.01	3.07	3.53
	100	7.74	10.08	10.53	2.62	3.34	3.22
Total	0	15.04	19.99	21.12	6.33	7.86	7.72
	50	16.50	19.44	21.21	7.23	8.06	8.32
	100	16.65	19.76	21.75	6.20	8.16	8.01

LSD at 0.05: Maize (total) 3.05; Barley (total) NS

TABLE 2

The effect of zinc application on Mn^{54} content of maize and barley plants

Part	Mn rate ppm	Zn rate ppm					
		Maize			Barley		
		0	5	25	0	5	25
Roots	0	0.2	0.1	0.1	0.3	0.4	0.4
	50	39.8	36.1	31.2	63.3	61.1	57.7
	100	113.5	84.5	69.7	71.4	75.9	86.4
Sheaths	0	0.4	0.2	0.1	0.4	0.3	0.3
	50	73.7	26.6	24.1	66.3	48.9	36.0
	100	76.4	49.9	50.7	71.1	82.6	67.6
Blades	0	0.7	0.3	0.3	0.8	0.7	0.6
	50	156.1	50.1	47.6	119.4	70.5	82.7
	100	162.0	77.8	67.9	125.8	102.7	125.0

LSD at 0.05	Part	Maize	Barley
	Roots	55.4	53.1
	Sheaths	28.6	22.3
	Blades	59.3	56.8

TABLE 3

The effect of zinc application on the total Mn content of maize and barley plants

Part	Mn rate ppm	Zn rate ppm					
		Maize			Barley		
		0	5	25	0	5	25
Roots	0	31.7	18.1	22.0	70.4	78.2	77.7
	50	51.2	52.6	52.1	199.8	208.3	194.6
	100	131.5	103.1	83.3	243.5	246.6	271.5
Sheaths	0	20.0	8.4	7.4	18.0	16.6	14.0
	50	74.9	27.4	25.6	68.4	49.8	38.5
	100	78.5	57.3	52.7	72.4	84.5	68.4
Blades	0	31.2	16.4	13.4	34.5	29.9	27.3
	50	175.3	53.1	47.8	121.2	72.5	89.5
	100	167.9	82.9	72.4	127.2	104.5	135.2

LSD at 0.05

Part	Maize	Barley
Roots	53.6	–
Sheaths	26.9	31.3
Blades	62.3	56.5

the radioactive and total uptake of manganese was substantially decreased with increasing level of zinc application (Fig. 1). This is similar to the pattern found in total Mn^{54} and manganese content. In barley plants uptake of radioactive and total manganese by sheaths and blades decreased with increasing level of zinc up to 50 ppm level of manganese but not to the 100 ppm level (Fig. 2). There was no particular trend of decrease in roots.

In order to study the effect of zinc application on absorption and/or translocation of manganese in plants, total uptake and percentage distribution of manganese among roots, sheaths and blades were calculated. As total manganese and zinc in plants more or less followed the pattern of total Mn^{54} and Zn^{65}, the percentage distribution and total uptake were calculated only for Mn^{54} and Zn^{65}. Results are presented in Table 4. It is evident that the percentage distribution of Mn^{54} among roots, sheaths and blades of maize was not affected by zinc application. Overall, the total uptake from substrate to roots was substantially decreased by zinc application. At the 5 and 25 ppm levels of zinc the Mn^{54} uptake was only 56 and 58 per cent of the uptake at the 0 ppm level in maize and 97 and

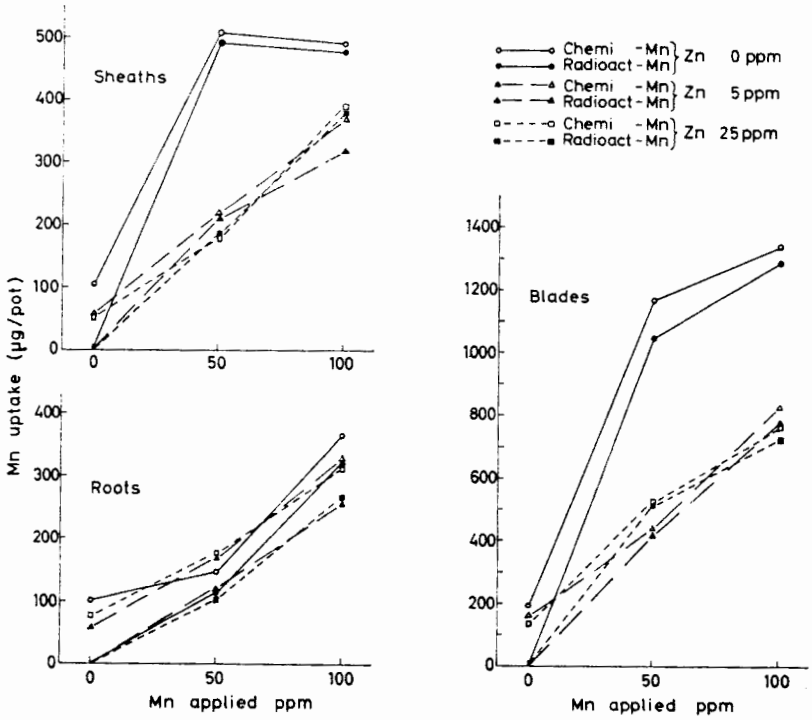

Fig. 2. Effect of zinc on manganese uptake by maize plants.

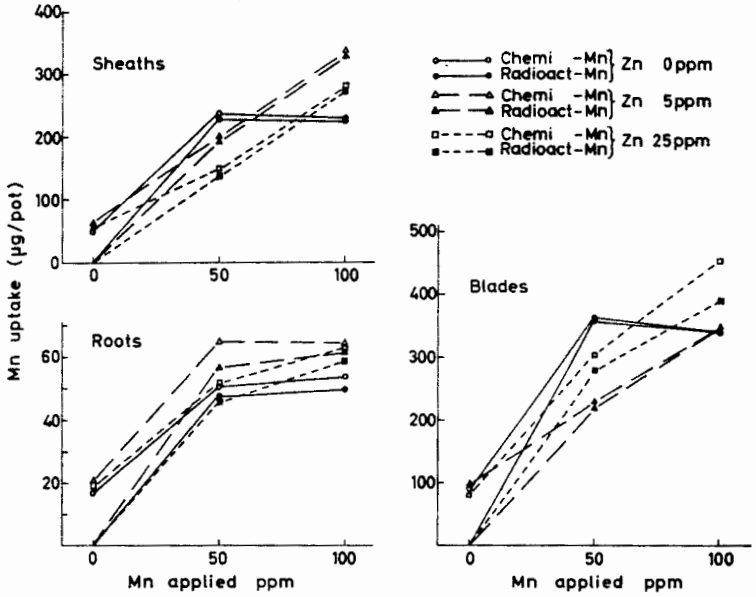

Fig. 3. Effect of zinc on manganese uptake by barley plants.

TABLE 4

The effect of zinc application on Mn^{54} uptake, distribution and/or translocation in maize and barley plants

Plant	Part	Mn rate ppm	Zn rate ppm 0		5		25	
			Uptake µg/pot	% of total	Uptake µg/pot	% of total	Uptake µg/pot	% of total
Maize	Roots	0	0.7	10	0.2	4	0.2	5
		50	114.7	7	118.7	16	103.9	13
		100	320.8	15	258.9	19	265.3	19
	Sheaths	0	1.9	26	1.1	24	1.0	24
		50	493.1	30	213.3	28	188.7	23
		100	476.9	23	322.9	24	377.7	28
	Blades	0	4.6	64	3.2	71	2.9	71
		50	1048.2	63	418.5	56	519.9	64
		100	1288.6	62	777.4	57	728.3	53
	Total	0	7.2		4.5		4.1	
		50	1656.0		750.5		812.5	
		100	2086.3		1359.2		1371.3	
Barley	Roots	0	0.2	6	0.3	8	0.3	9
		50	47.9	8	57.0	12	46.2	10
		100	49.8	8	62.0	9	59.8	8
	Sheaths	0	1.1	33	1.3	34	1.1	33
		50	230.9	36	197.6	42	140.9	30
		100	228.7	37	331.1	45	278.3	38
	Blades	0	2.0	61	2.2	58	1.9	58
		50	355.7	56	221.0	46	280.3	60
		100	334.8	55	338.8	46	390.1	54
	Total	0	3.3		3.8		3.3	
		50	634.5		475.6		467.4	
		100	613.3		731.9		728.2	

95 per cent in barley. These percentages are the means of three Mn rates.

Application of manganese had less effect on the Zn^{65} content of roots, sheaths and blades of maize and barley, than had the contrasting application of zinc on Mn^{54} content. However, in barley plants, an effect on Zn^{65} content of roots, sheaths and blades was noticeable at the highest concentration (25 ppm) of zinc (Table 5). The trends found in total zinc content in roots, sheaths and blades were similar in maize and barley (Table 6).

TABLE 5

The effect of Mn application on Zn^{65} content of maize and barley plants

Part	Zn rate ppm	Mn rate ppm: Maize 0	Maize 50	Maize 100	Barley 0	Barley 50	Barley 100
Roots	0	0.03	0.03	0.02	0.05	0.05	0.03
	5	8.7	7.9	8.8	22.5	19.9	17.5
	25	50.6	67.6	57.9	84.9	76.4	74.6
Sheaths	0	0.05	0.04	0.04	0.05	0.06	0.05
	5	19.5	19.6	21.2	34.1	29.1	28.1
	25	79.1	67.7	70.4	101.7	90.4	100.2
Blades	0	0.03	0.02	0.02	0.04	0.05	0.04
	5	13.9	11.7	12.2	20.5	18.3	17.7
	25	26.0	29.2	29.8	52.3	50.4	47.2

LSD at 0.05

Part	Maize	Barley
Roots	11.0	13.9
Sheaths	10.4	5.2
Blades	3.2	5.0

TABLE 6

The effect of Mn application on the total zinc content of maize and barley plants

Part	Zn rate ppm	Mn rate ppm: Maize 0	Maize 50	Maize 100	Barley 0	Barley 50	Barley 100
Roots	0	62.7	62.9	52.8	43.5	34.7	60.7
	5	52.2	49.9	61.6	59.7	70.1	65.2
	25	98.7	96.5	127.1	174.9	108.8	100.8
Sheaths	0	10.4	12.5	12.5	9.9	15.1	17.1
	5	27.2	23.7	27.4	37.9	39.3	37.1
	25	84.1	68.3	73.3	110.1	93.3	104.5
Blades	0	13.9	24.1	17.6	20.5	15.6	16.0
	5	21.9	31.2	21.3	33.0	29.9	33.6
	25	42.5	49.9	36.8	60.8	55.5	57.2

LSD at 0.05

Part	Maize	Barley
Root	33.6	61.8
Sheaths	8.0	10.5
Blade	12.8	12.0

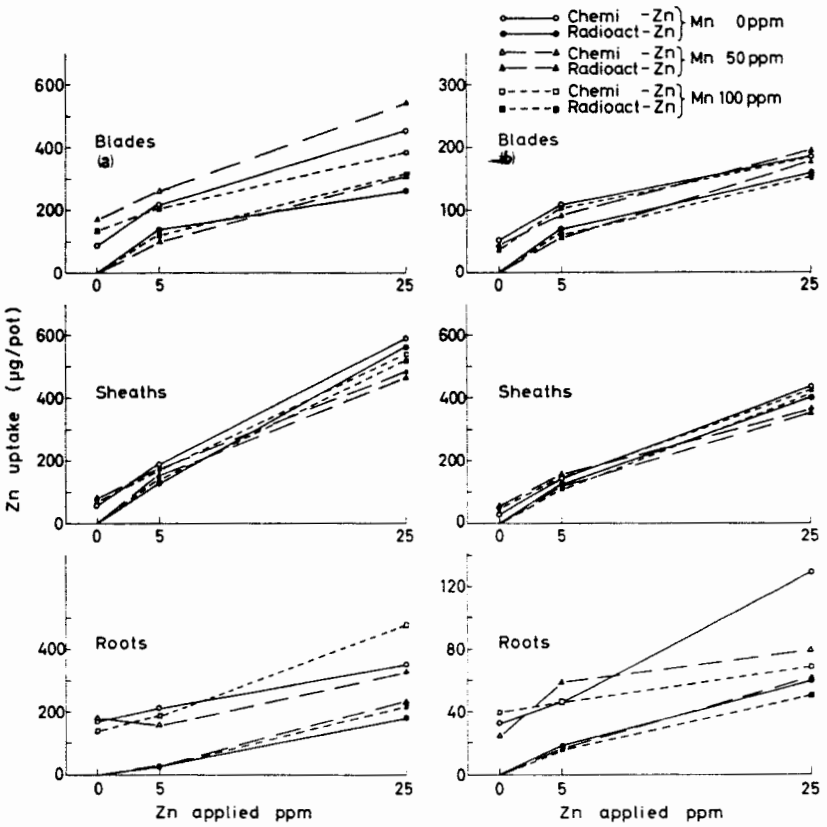

Fig. 4. Effect of manganese on zinc uptake by maize (a) and barley (b) plants.

In both maize and barley plants, Zn^{65} content was highest in sheaths followed by roots and blades. The pattern for total zinc was different, in that content was highest in roots followed by sheaths and blades.

The uptake of Zn^{65} and total zinc (Fig. 4) and percentage distribution of zinc among roots, sheaths and blades (Table 7) of maize were not affected by manganese application. Marginal effects of manganese application on total Zn^{65} uptake from substrate to roots, however, were observed in barley.

TABLE 7

The effect of Mn application on Zn^{65} uptake, distribution and/or translocation in maize and barley plants

Plant	Part	Zn rate ppm	Mn rate ppm 0 Uptake µg/pot	0 % of total	50 Uptake µg/pot	50 % of total	100 Uptake µg/pot	100 % of total
Maize	Roots	0	0.1	20	0.1	17	0.1	20
		5	27.9	10	24.9	9	27.7	10
		25	178.2	18	232.9	23	219.6	21
	Sheaths	0	0.2	40	0.3	50	0.3	60
		5	130.0	44	153.4	55	137.9	48
		25	561.8	56	471.0	46	521.7	49
	Blades	0	0.2	40	0.2	33	0.1	20
		5	136.7	46	99.6	36	123.3	42
		25	263.9	26	316.1	31	314.3	30
	Total	0	0.5		0.6		0.5	
		5	294.6		277.9		288.9	
		25	1003.9		1020.0		1055.6	
Barley	Roots	0	0.04	16	0.03	10	0.03	14
		5	18.1	8	17.7	9	14.0	8
		25	60.8	10	61.5	10	51.5	8
	Sheaths	0	0.1	42	0.2	60	0.1	43
		5	127.9	60	117.3	61	111.6	60
		25	400.0	64	357.7	60	412.4	67
	Blades	0	0.1	42	0.1	30	0.1	43
		5	68.1	32	57.2	30	59.3	32
		25	160.7	26	177.0	30	151.2	25
	Total	0	0.24		0.33		0.23	
		5	214.1		192.2		184.9	
		25	621.5		596,2		615.1	

DISCUSSION

This work was undertaken to determine the effect of added zinc on manganese uptake, of added manganese on zinc uptake, and distribution and/or translocation in maize and barley plants. Fried and Shapiro [3] suggested two active steps in the movement of ions from substrate to the shoot. They proposed that an active accumulation of ions occurs at the root surface where the ion combines with the carrier, and that another active process occurs

within the root where the ion is deposited into the vascular system. The purpose of this study was to find out if the presence of one cation would influence the absorption and/or translocation of another.

By employing the double tracer technique for ion competitors, it can be determined if absorption or translocation of manganese is influenced by zinc and vice versa. Sakaguchi[7] has used this technique to examine the influence of various anions on the uptake and translocation of strontium and Hawf and Schmid[4] to study the effect of other cationic species on zinc uptake and translocation in bush bean plants.

If for example, zinc interfered only with absorption this would appear as a reduction in total Mn^{54} uptake. If it interfered with internal translocation this would be indicated by changes in the relative percentage of Mn^{54} in roots, sheaths and blades.

In this study, Mn^{54} and total manganese content and their uptake in roots, sheaths and blades of maize and barley plants, were substantially decreased with increasing levels of applied zinc. Ishizuka and Ando[5] found that the amount of manganese absorbed by rice plants markedly decreased with increasing concentration of zinc in nutrient solution. Vlamis and Williams[12] reported that iron and hydrogen ions were even more effective than Ca, Mg and NH_4 ions in reducing manganese uptake in barley plants. They hypothesized that the depression in manganese uptake by these cations was the result of ionic competition. Similarly, the reduction in manganese uptake by maize and barley plants in the present study might be caused by ionic competition between manganese and zinc in the process of absorption.

Observations in Table 4 show that total uptake of Mn^{54} in maize plants at 5 ppm and 25 ppm of zinc were reduced by 44 and 42 per cent, respectively, compared with the 0 ppm Zn level. Furthermore, the percentage distribution of Mn^{54} among roots, sheaths and blades was not altered by zinc application. This indicates that zinc interferes with the absorption of manganese from the substrate to root rather than in the internal distribution and/or translocation. These results are comparable to those obtained by Hawfk and Schmid[4]. They reported that inhibition of Zn^{65} uptake in bush bean plants occurred when copper was added to the nutrient solution in low concentration. At the same levels copper did not interfere with

translocation of Zn^{65} within plant. Further, Dunne[2] showed that zinc levels within plants and yields of cereal grains were reduced as the level of copper in the soil was increased. In this study, manganese and zinc may have behaved as zinc and copper in the above report. The total uptake of Mn^{54} in barley compared with maize was relatively less affected by an increased level of applied zinc, but a small effect was seen on the percentage distribution of Mn^{54} among roots, sheaths and blades.

Zn^{65} and total zinc content and their respective distributions in roots, sheaths and blades followed the same patterns reported earlier by the authors [10]. Furthermore, Zn^{65} and total zinc content of roots, sheaths and blades were not influenced by manganese. Little effect of manganese on zinc content of barley plants was seen at the highest zinc concentration. (Table 7). These results are comparable to those cited earlier from Hawf and Schmid [4].

It is evident from this study that zinc which competes with manganese ions in maize and barley, exerts its influence mainly at the site of transport of manganese from the substrate into the root. It appears to have little influence on the distribution and/or translocation. Manganese does not play a significant role either in uptake or translocation of zinc in either crop.

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