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**LABORATORY OF NUCLEAR MEDICINE
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**UNIVERSITY OF CALIFORNIA
900 VETERAN AVENUE
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**MINERAL NUTRITIONAL DIFFERENCES IN AN IRON
EFFICIENT AND AN INEFFICIENT CORN HYBRID
AND THEIR RESPONSES TO IRON CHELATES**

**A. Wallace, E. M. Romney, A. ElGazzar, R.B.Clark
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ABSTRACT

Corn (*Zea mays* L.) hybrids WF9 and Ysi $\times$ Ysi, which are efficient and inefficient, respectively, in transport of iron were grown in soil and in solution culture with and without iron chelates to study aspects of the differential behavior. Especially in the iron-inefficient plant, additional iron uptake is used for new growth and iron concentration in shoots is not greatly increased. A level of 10 ppm iron as FeEDDHA [ethylenediamine di (o-hydroxyphenylacetic acid)] in nutrient solution was necessary for the inefficient hybrid to give maximum yield, but only 0.5 ppm was adequate for the efficient hybrid. FeDTPA (ferric diethylenetriamine pentaacetate) failed to supply iron to the plants. The iron-inefficient hybrid had a build-up of iron in roots with less iron in shoots. A saturation level of iron was reached when iron was transported to the shoots of iron-inefficient plants. The iron-inefficient transport was associated with a build-up of zinc, manganese, and copper in both roots and shoots of the iron-inefficient plants. Since the high iron level seemed to overcome this effect, at least in part, it may be that iron deficiency is a cause rather than the result. Calcium and phosphorous levels were higher in the shoots of the iron-inefficient plants and phosphorus may contribute to the iron deficiency. A high level of copper and zinc in nutrient solution coupled with a borderline level of iron intensified the iron-inefficient status of the Ysi $\times$ Ysi hybrid. The mechanism leading to iron inefficiency is different than in either of the PI54619-5-1 soybean and in the trifoliate orange rootstock.

INTRODUCTION

Hybrids and genetically different forms within a species of higher plants are being successfully used to elucidate some of the problems of mineral nutrition of plants much the same way that mutants are being used to elucidate

biochemical patterns in microorganisms. Mutants can be developed in microorganisms which do not have a specific enzyme or which do not have a series of enzymes. Two soybean varieties differing in 1 gene (PI54619-5-1 and Hawkeye) have resulted in much information concerning the nature of iron nutrition of plants (Brown et al., 1967; Brown et al., 1961a; Wallace et al., 1973). The PI54619-5-1 is inefficient in its ability to obtain and translocate iron. It has less ability to reduce Fe^{+++} to the Fe^{++} form which is necessary for its absorption by soybeans and by at least some other plants (Chaney et al., 1972). It has less ability to excrete H^+ which facilitates the mobility of soil Fe compared with other varieties. Interestingly enough, however, is that its impaired ability to obtain and transport iron also occurs for other micronutrients (Wallace et al., 1973). Although between species rather than within species, citrus rootstocks are examples of some of the same phenomena. For example, the trifoliolate orange rootstock imposes on the scions grown upon it stress for both adequate zinc and adequate iron (Khadr and Wallace, 1964).

Two pairs of corn hybrids have been studied which are capable of being very useful in the development of information on the iron nutrition of corn (Clark et al., 1973) and the magnesium nutrition of corn (Clark unpublished). The major purpose of the series of experiments reported in this paper is to develop additional information concerning the characteristics of the two corn hybrids used by Clark et al. (1973) which relate to the differences in efficiency with which they take up and translocate iron. These particular studies make use of an emission spectrograph in which the concentration of many elements can be simultaneously looked at.

The field of plant nutrition which Gerloff (1963) called "Comparative Mineral Nutrition of Plants" is an important one which can help solve many of the plant nutritional problems of the world. Within it are the possibilities for breeding resistance to deficiencies and toxicities. The plant hybrids are a special phase of the field and the present investigations represent but a small part of the data needed to be collected about them.

MATERIALS AND METHODS

Experiment 1: The two corn (*Zea mays* L.) hybrids (WF9 which is efficient in its ability to take up and translocate iron and Ysi X Ysi which is inefficient in its ability to take up and translocate iron) (Clark et al., 1973) were first grown in calcareous Hacienda loam soil (Wallace and Mueller, 1969). Two germinated seedlings were planted into each pot which contained 500 g of soil. Seven different treatments were used with each hybrid with four replications for each. These treatments were control, 2 and 5 ppm iron

(dry weight of soil basis) with either EDDHA [ethylenediamine di (o-hydroxy-phenyl acetate)] or DTPA [diethylene triamine pentaacetic acid] and each chelating agent without iron at a rate equivalent to the 5 ppm iron. The plants received 100 ppm nitrogen (dry weight soil basis) as NH_4NO_3 . The plants were grown for 14 days. Shoots were harvested by cutting 1 cm above the soil line. They were washed in 1/10N HCl then in deionized water, then dried, weighed, and prepared for mineral analysis by emission spectrography (Wallace et al., 1974).

Experiment 2: The two corn hybrids were grown in nutrient solution at five different levels of FeEDDHA (0.0, 0.5, 1.0, 5.0, and 10.0 ppm iron). There were four replicates. The composition of the nutrient solution otherwise was: 200 ppm calcium, 195 ppm potassium, 24 ppm magnesium, 96 ppm sulfur, 62 ppm phosphorus, 28 ppm $\text{NH}_4\text{-N}$, 154 ppm $\text{NO}_3\text{-N}$, 0.5 ppm manganese, 0.05 ppm boron, 0.125 ppm zinc, 0.03 ppm molybdenum. The plants were grown with 3700 ml solution which was not renewed during the period of test. The plants were grown for 14 days as in Experiment 1. The plants were separated into roots and shoots and each plant was handled as in Experiment 1.

Experiment 3: Each hybrid was again grown in solution culture as above except with micronutrient modifications. There were six treatments with 10 ppm iron as FeEDDHA and the same six treatments were supplied with 0.5 ppm iron. The treatments were: (a) 1/100 level of zinc, copper, and manganese; (b) the regular level; (c) regular except 10^{-4} M ZnSO_4 ; (d) 1/100 level with 10 g CaCO_3 in the nutrient solution; (e) regular with CaCO_3 , and (f) regular except 2×10^{-6} M CuSO_4 . There were four replications in 3700 ml containers. The plants were grown for 14 days in the solution without change and they were subsequently handled as in Experiment 2.

RESULTS AND DISCUSSION

Experiment 1: The iron inefficient hybrid failed to transport sufficient iron to the shoots for adequate chlorophyll formation (Table 1). The EDDHA with or without iron corrected the apparent iron deficiency. The variability in iron concentrations in the shoots of these plants was so great that none of the differences could be proved significant. On the per plant basis, however, the EDDHA increased the iron transported to shoots, but DTPA did not. The rough nature of the iron concentration data appears to be related to the fact that entire shoots were assayed rather than new leaves (Clark et al., 1973). This experiment failed to show a significant difference between iron concentrations in the two hybrids.

Interesting, and perhaps important, differences were observed in

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concentrations of some of the other micronutrients in these two hybrids grown in soil. Zinc, manganese, phosphorus, and calcium levels were elevated in the iron-inefficient plants. The latter two may be related to the fact that many of them were yellow with iron deficiency (DeKock et al., 1960). Whether or not the fairly large zinc differential contributed to the iron inefficiency was tested in Experiment 3.

Experiment 2: The iron found in plants at the zero-iron level was essentially that in the plants before they were transplanted plus any present as contaminants (Table 2). FeEDDHA generally is not considered to be a good source of iron for corn and other grasses (Brown et al., 1960; Brown et al., 1961b). Ten ppm iron as FeEDDHA appeared necessary for maximum yield with the iron inefficient hybrid. Only 1/2 ppm iron as EDDHA, in contrast, was needed to produce maximum yield with the iron-efficient hybrid. As iron uptake increased in both hybrids, the additional new growth appeared to dilute the iron concentrations in the shoots. More iron was found on virtually all of the roots for the inefficient hybrid compared with respective treatments of the efficient hybrid. Clark et al. (1973) have suggested that xylem transport failure is a dominant reason for the inefficiency and the present data for iron in roots appears to substantiate that conclusion. When iron in roots of the inefficient plant reached a saturation point, iron was effectively transferred to shoots.

The iron-efficient transport was associated with a build-up of zinc, manganese, and copper in both roots and shoots of the iron-inefficient plants. In the shoots the differences largely disappear on the per plant basis, but not with the roots. The effects seemed to be less pronounced with the high iron level which would indicate that iron deficiency was at least one cause of the effects observed. Whether or not some of these heavy metals are a reason for iron transport failure was tested in Experiment 3.

The phosphorous levels in shoots were sufficiently greater for the iron-inefficient plants to be a possible factor in the iron deficiency (Brown et al., 1959). Again, the calcium differential between the shoots of the two hybrids was indicative of iron deficiency in the inefficient one (DeKock et al., 1960).

Experiment 3: The purpose of this particular experiment was to test the hypothesis that iron transport failure in the Ysi x Ysi hybrid is related to some micronutrient other than iron present in excess. At 10 ppm iron the micronutrient treatments made no difference on the green color of leaves although the yield of the high copper treatment plants was decreased for the iron-inefficient hybrid (Table 3). With the 0.5 ppm iron level, differential results were obtained for yields and leaf color when regular micronutrients

or high zinc or high copper were applied. The iron inefficient hybrid was iron deficient in each case. Both hybrids were iron deficient when CaCO_3 was in the nutrient solution when only 0.5 ppm iron was supplied.

When upper leaves had iron concentrations of 40 ppm or less on the dry weight basis, iron chlorosis was observed, but iron concentrations in the leaves were not consistently related to treatments. The low level of micro-nutrients appeared to result in increased iron in the iron-inefficient hybrid, but not in the iron-efficient hybrid. The results further indicate that increased levels of both zinc and copper can intensify the iron-inefficient nature of the Ysi $\times$ Ysi hybrid, but especially if the iron level is borderline. In this particular experiment, the iron levels in roots were not always higher in the inefficient hybrid than in the efficient. With high copper they were. Although the leaf color and yield data suggested that manganese may be high, the manganese concentrations in leaves and roots do not easily suggest that manganese toxicity is a cause of any of the iron transport failure. The aspect could be studied in more detail.

It is perhaps too early to draw definite conclusions about the similarities or differences between the two corn hybrids used in this study, and the two soybeans, PI54619-5-1 and Hawkeye, which have been intensively used in studies of iron nutrition. The iron inefficiency in the Ysi $\times$ Ysi corn hybrid seems to be more related to failure of iron transport to and through the xylem while both uptake and transport failure seem to be involved with the PI54619-5-1 soybean (Brown et al., 1967; Brown et al., 1961a; Tiffin, 1972; Wallace et al., 1973). The decreased ability of the soybean to accumulate iron appears not to be specific, but includes zinc, copper, manganese and even some other elements. Some of these elements, in contrast, are increased in the Ysi $\times$ Ysi corn hybrid simultaneously with a decrease of iron in shoots. It then does appear that there are differences in mechanisms for the two pairs of different plants which result in the iron inefficiency.

In the case of the citrus rootstocks where two different species used for rootstocks have been compared (Khadr and Wallace, 1964) the species trifoliolate orange (Poncirus trifoliata) which is inefficient in its ability to take up and translocate iron is also the same way for zinc. Translocation to shoot is equally an important problem as is the initial uptake. Rough lemon (Citrus jambhiri) is efficient towards iron and zinc. It appears then that there are fewer differences between the soybeans and citrus in iron efficiency than between soybeans and corn.

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Table 1. Yields and mineral composition of shoots of 2 corn hybrids grown in Hacienda loam soil (Experiment 1).

Treat- ment*	Leaf	Yield	Fe	Fe	Mn	Cu	Zn	Ni	Mo	K	P	Ca
ppm Fe & source	color	<u>mg</u> plant	<u>μg</u> plant	ppm						%		
Fe inefficient (Ysi × Ysi)												
1.	G	218	16.6	76	92	7.3	37	1.5	5.5	2.02	0.11	1.74
2.	G	331	20.9	63	76	7.9	29	1.4	4.9	1.66	0.11	1.82
3.	Y	114	3.9	34	111	11.0	44	1.7	7.8	1.44	0.14	2.56
4.	Y	172	5.3	31	78	9.1	50	3.5	7.6	1.54	0.12	2.17
5.**	G	212	18.4	87	133	13.5	37	3.0	5.2	1.68	0.16	2.10
6.**	Y	118	13.6	115	93	11.7	38	5.8	6.8	1.45	0.14	2.29
7.	Y	120	8.3	69	97	9.2	66	7.3	6.5	1.22	0.13	2.93
Fe efficient (WF9)												
1.	G	187	13.1	70	56	9.0	13	2.0	4.1	1.70	0.09	1.51
2.	G	227	21.3	94	47	8.0	18	1.5	3.1	1.77	0.11	1.85
3.	G	286	20.9	73	63	10.6	19	2.6	2.9	1.87	0.09	1.38
4.	G	226	13.8	61	68	12.1	24	3.4	4.5	2.31	0.09	1.57
5.**	G	230	10.8	47	61	13.1	14	1.8	4.7	2.28	0.09	1.34
6.**	G	206	10.3	50	65	11.0	27	3.9	4.0	1.96	0.07	1.59
7.	G	182	14.6	80	65	9.6	16	2.8	3.8	2.24	0.10	1.48
LSD .05		66	6.8	NS	23	3.4	13	NS	NS	0.36	0.02	0.45
LSD .01		88	9.0	NS	33	NS	17	NS	NS	0.47	0.03	0.63
Main effects for hybrids												
Mean inefficient		184	12.4	71	97	10.0	43	3.5	6.3	1.57	0.13	2.23
Mean efficient		221	14.9	68	61	10.5	19	2.6	3.9	2.02	0.09	1.53
LSD .05		NS	NS	NS	11	NS	7	0.4	0.5	0.19	.010	0.24
LSD .01		NS	NS	NS	15	NS	9	NS	0.6	0.25	.043	0.31

*1 = 2 FeEDDHA; 2 = 5 FeEDDHA; 3 = 2 FeDTPA; 4 = 5 FeDTPA; 5 = NaEDDHA**; 6 = NaDTPA**; 7 = Control.

**Equivalent to 5 ppm Fe.

Table 2. Yield and mineral composition of two corn hybrids grown at different levels of FeEDDHA.

Fe in nutrient solution (as EDDHA) ppm	SOLUTION CULTURE									
	Yield		Fe		Fe		Zn		Cu	
	mg/plant		ppm		µg/plant		ppm		ppm	
	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*
TOP										
0	121	544	52	29	6.3	15.8	97	50	13.5	9.4
1/2	93	929	31	27	2.9	25.1	141	32	15.5	7.1
1	181	978	30	34	5.4	33.3	109	34	12.8	8.3
5	372	893	27	49	10.0	43.8	54	13	10.6	7.4
10	1126	890	46	58	51.9	51.6	42	19	13.6	10.1
LSD .05	165		NS		4.0		23		3.0	
LSD .01	218		NS		5.3		30		4.0	
ROOT										
0	97	194	130	74	12.6	14.4	219	36	43.3	20.7
1/2	80	264	873	175	69.8	14.4	233	35	64.3	21.2
1	113	264	1480	334	167.2	88.2	119	33	40.0	20.1
5	193	246	1073	412	207.1	101.4	107	24	34.6	17.0
10	336	235	861	559	289.3	131.4	73	35	32.0	26.6
LSD .05	65		390		35.1		78		13.9	
LSD .01	88		383		46.3		103		18.4	
MEANS										
Main effects for hybrids										
Top	379	847	37	39	15.3	33.9	89	30	13.2	8.4
LSD .05	294		NS		15.8		23		1.1	
LSD .01	388		NS		NS		30		1.5	
Root	164	241	883	310	149.2	76.3	150	33	42.8	21.1
LSD .05	69		276		41.7		37		6.9	
LSD .01	NS		364		55.2		49		9.1	

*In. is inefficient for Fe hybrid YsiX Ysi; Eff. is efficient for Fe hybrid WF9.

Table 2 (continued from previous page)

Fe in nutrient solution (as EDDHA) ppm	SOLUTION CULTURE									
	Mn		Mo		P		Ca		K	
	ppm		ppm		%		%		%	
	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*	In.*	Eff.*
TOP										
0	194	112	3.7	3.1	0.60	0.52	1.33	0.67	3.79	5.82
$\frac{1}{2}$	217	103	5.7	2.7	0.63	0.46	1.24	0.48	4.40	4.72
1	200	89	9.8	2.4	0.55	0.43	1.20	0.54	4.33	4.82
5	151	74	5.4	1.7	0.54	0.38	0.78	0.49	4.03	3.81
10	110	72	6.6	1.8	0.47	0.38	0.58	0.55	4.68	4.21
LSD .05	46		2.65		0.11		0.20		1.08	
LSD .01	63		3.50		0.15		0.27		NS	
ROOT										
0	603	170	5.3	19.7	0.69	0.40	0.43	0.75	3.95	3.73
$\frac{1}{2}$	386	150	14.9	13.8	1.01	0.43	0.57	0.66	4.15	3.97
1	204	126	21.8	12.6	0.61	0.39	0.38	0.79	3.25	3.84
5	242	54	11.5	9.0	0.93	0.37	0.52	0.74	4.53	3.87
10	234	70	15.3	9.4	0.78	0.44	0.60	0.77	5.04	4.24
LSD .05	151		5.4		0.26		0.19		0.66	
LSD .01	201		7.2		0.35		0.25		NS	
MEANS										
Main effects for hybrids										
Top	174	90	6.2	2.3	0.56	0.43	1.03	0.54	4.24	4.68
LSD .05	25		1.2		0.04		0.21		NS	
LSD .01	32		1.6		0.06		0.28		NS	
Root	334	114	13.8	12.9	0.80	0.41	0.50	0.75	4.18	3.93
LSD .05	92		NS		0.09		0.14		NS	
LSD .01	122		NS		0.12		0.19		NS	

*In. is inefficient for Fe hybrid Ysi x Ysi; Eff. is efficient for Fe hybrid WF9.

Table 3. Yields and leaf color and mineral composites of two corn hybrids grown in solution culture at different micronutrient concentrations.

Treatments	Leaf color		Shoots		Roots	
	WF9	Ysi X Ysi	WF9	Ysi X Ysi	WF9	Ysi X Ysi
g/plant						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	G	G	0.91	0.88	0.32	0.25
Regular micronutrients	G	G	0.97	0.84	0.35	0.27
10^{-4} M Zn + regular micro.	G	G	0.55	0.67	0.17	0.23
1/100 micronutrients + CaCO ₃	G	G	0.84	0.79	0.33	0.34
Regular + CaCO ₃	G	G	0.87	0.70	0.31	0.23
2×10^{-6} M Cu	G	G	1.07	0.62	0.30	0.17
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	G	G	0.90	0.77	0.30	0.26
Regular micronutrients	G	Y	0.78	0.25	0.27	0.13
10^{-4} M Zn + regular micro.	G	Y	0.76	0.19	0.27	0.13
1/100 micronutrients + CaCO ₃	VY	VY	0.31	0.16	0.14	0.12
Regular + CaCO ₃	VY	VY	0.25	0.14	0.14	0.11
2×10^{-6} M Cu	G	Y	0.63	0.21	0.24	0.12
LSD .05			0.27		0.11	
LSD .01			0.36		0.14	

(Table 3 continued)

Treatments	Upper leaves		Lower leaves		Roots	
	WF9	Ysi X Ysi	WF9	Ysi X Ysi	WF9	Ysi X Ysi
Fe ppm of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	67	124	48	77	487	547
Regular micronutrients	82	102	55	48	665	411
10^{-4} M Zn + regular micro.	56	75	59	47	1067	509
1/100 micronutrients + CaCO ₃	88	61	40	46	292	492
Regular + CaCO ₃	65	99	51	65	1142	964
2×10^{-6} M Cu	77	84	47	46	902	1200
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	68	129	39	58	148	447
Regular micronutrients	58	40	42	25	217	596
10^{-4} M Zn + regular micro.	45	41	42	39	363	465
1/100 micronutrients + CaCO ₃	25	19	32	35	415	172
Regular + CaCO ₃	21	16	32	40	231	183
2×10^{-6} M Cu	49	27	34	29	527	882
LSD .05		26		16		122
LSD .01		34		21		161
P% of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	0.37	0.79	0.36	0.82	0.39	1.39
Regular micronutrients	0.45	0.64	0.40	0.76	0.51	1.16
10^{-4} M Zn + regular micro.	0.30	0.69	0.25	0.76	0.30	1.22
1/100 micronutrients + CaCO ₃	0.30	0.34	0.27	0.35	0.29	0.30
Regular + CaCO ₃	0.29	0.24	0.25	0.30	0.21	0.68
2×10^{-6} M Cu	0.42	0.55	0.42	0.54	0.62	0.83

(Table 3 continued on next page)

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Treatments	Upper leaves		Lower leaves		Roots	
	WF9	Ysi x Ysi	WF9	Ysi x Ysi	WF9	Ysi x Ysi
P % of dry weight						
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	0.47	0.67	0.50	0.62	0.52	1.04
Regular micronutrients	0.61	0.53	0.60	0.51	0.58	0.77
10^{-4} M Zn + regular micro.	0.59	0.54	0.50	0.69	0.64	1.10
1/100 micronutrients + CaCO_3	0.55	0.16	0.47	0.12	0.34	0.16
Regular + CaCO_3	0.45	0.62	0.40	0.52	0.94	1.01
2×10^{-6} M Cu	0.49	0.55	0.49	0.63	0.51	0.83
Mo ppm of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	0.6	2.8	0.5	2.8	2.6	4.3
Regular micronutrients	3.1	9.5	2.9	6.8	12.1	17.0
10^{-4} M Zn + regular micro.	1.0	6.3	1.2	6.8	11.1	17.3
1/100 micronutrients + CaCO_3	0.7	2.6	0.7	2.0	1.5	2.3
Regular + CaCO_3	2.7	3.2	2.4	3.2	4.9	4.0
2×10^{-6} M Cu	2.5	9.7	2.0	6.8	11.7	20.2
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	0.7	3.3	0.9	2.1	3.1	4.0
Regular micronutrients	3.6	7.8	3.3	5.0	14.4	26.8
10^{-4} M Zn + regular micro.	3.4	9.2	4.0	9.1	13.6	20.8
1/100 micronutrients + CaCO_3	1.1	2.1	1.1	2.0	1.8	1.1
Regular + CaCO_3	3.1	4.6	3.1	4.5	6.0	4.8
2×10^{-6} M Cu	3.4	7.1	3.2	6.2	18.8	25.6
LSD .05	0.09		0.10		0.19	
LSD .01	0.12		1.13		0.25	
Mn ppm of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	3	5	1	4	1	4
Regular micronutrients	27	43	17	51	3	91
10^{-4} M Zn + regular micro.	11	32	9	33	1	8
1/100 micronutrients + CaCO_3	14	7	4	6	2	7
Regular + CaCO_3	53	19	51	28	430	218
2×10^{-6} M Cu	30	70	29	80	11	203
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	7	3	4	6	1	4
Regular micronutrients	50	105	48	112	13	141
10^{-4} M Zn + regular micro.	18	92	16	46	5	15
1/100 micronutrients + CaCO_3	12	23	9	25	21	16
Regular + CaCO_3	163	80	84	81	225	302
2×10^{-6} M Cu	57	123	53	161	13	222
LSD .05	26.3		17.2		84.1	
LSD .01	34.7		22.7		111.0	
Zn ppm of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	39	57	45	55	51	99
Regular micronutrients	58	65	56	57	73	114
10^{-4} M Zn + regular micro.	66	170	99	179	175	427
1/100 micronutrients + CaCO_3	70	63	48	54	68	105
Regular + CaCO_3	61	39	50	47	85	79
2×10^{-6} M Cu	48	53	51	50	78	124

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Treatments	Upper leaves		Lower leaves		Roots	
	WF9	Ysi x Ysi	WF9	Ysi x Ysi	WF9	Ysi x Ysi
Zn ppm of dry weight						
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	53	58	68	53	67	75
Regular micronutrients	70	75	88	100	109	124
10^{-4} M Zn + regular micro.	197	243	258	262	358	353
1/100 micronutrients + CaCO ₃	98	83	122	80	125	74
Regular + CaCO ₃	77	98	79	108	114	138
2×10^{-6} M Cu	75	77	82	108	101	115
LSD .05	22.7		33.8		43.5	
LSD .01	30.0		44.6		57.4	
Cu ppm of dry weight						
10 ppm Fe as FeEDDHA						
1/100 micronutrients	6.5	7.3	6.3	8.2	13.2	17.3
Regular micronutrients	7.6	7.3	7.3	7.4	13.1	22.1
10^{-4} M Zn + regular micro.	8.2	9.5	6.9	10.1	19.4	28.9
1/100 micronutrients + CaCO ₃	8.2	9.2	5.9	7.1	15.2	16.1
Regular + CaCO ₃		6.3	6.5	7.3	18.5	15.2
2×10^{-6} M Cu	12.0	9.9	12.2	10.1	80.0	65.0
0.5 ppm Fe as FeEDDHA						
1/100 micronutrients	7.5	8.4	8.9	8.6	11.8	31.1
Regular micronutrients	8.9	11.3	10.5	10.5	24.0	41.0
10^{-4} M Zn + regular micro.	8.2	14.3	11.5	16.4	27.7	66.4
1/100 micronutrients + CaCO ₃	10.9	7.9	11.5	8.0	21.6	16.1
Regular + CaCO ₃	12.7	10.1	11.2	10.0	20.2	22.0
2×10^{-6} M Cu	22.1	15.3	22.0	19.6	131.5	100.0
LSD .05	2.6		2.4		12.3	
LSD .01	3.5		3.2		16.2	