The Fe concentration in barley shoots decreased as pH was increased up to 7.8; above that it slightly increased for both with and without DTPA. In bush beans the Fe concentration remained more or less the same in minus DTPA while in plus DTPA, increased pH decreased Fe concentration. With DTPA, added Pb increased Fe up to pH 6.0. The pH effect was almost negligible at very high pH.

The Mn, Cu, and Zn concentrations in barley shoots and bush bean leaves were increased by DTPA. In both plant species, Mn concentration was very high at pH 4.0; after that it was decreased by increasing pH of the soil. The low pH tended to increase Cu concentration in barley and bush bean without DTPA. The Cu concentrations in bush bean leaves were increased with increasing pH in the DTPA treatment, but not without DTPA. In the presence of DTPA, Zn was increased in both species with increasing pH. The Zn, Mn, and Cu concentrations were not related to Pb levels.

The results of this study indicate that, even though Pb becomes primarily associated with the roots of plants, chelating agents facilitate movement of some of it to the shoots of plants. Since yield depressions were not always obtained from the presence of Pb in shoots at high concentrations, it can be expected that the Pb may not be located in metabolically active sites, but rather inactivated in conducting tissues[6].

In one of the experiments, DTPA also increased transport of Pb into bush bean seed pods (9 μg Pb/g dry weight for 100 μg DTPA/g soil at soil pH 8.5). Without DTPA essentially no Pb was found in pods.

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PHYTOTOXICITY AND SOME INTERACTIONS OF THE ESSENTIAL TRACE METALS IRON, MANGANESE, MOLYBDENUM, ZINC, COPPER, AND BORON

KEY WORDS: Iron, manganese, molybdenum, zinc, copper, boron

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ABSTRACT

The essential trace elements Fe, Mn, Zn, Cu, and B in high concentrations can produce phytotoxicities. Iron toxicity resulted from 5×10^{-4}M and 10^{-3}M $FeSO_4$, but not from equivalent amounts of FeEDDHA (ferric ethylenediamine di (o-hydroxyphenylacetic acid)). Leaf concentrations in bush beans of 465 μg Mn/g, 291 μg B/g, and 321 μg Zn/g all on the dry weight basis resulted in 27%, 45%, and 34% reduction in yields of leaves, respectively. Zinc was concentrated in roots while Mn and B concentrated in leaves. Solution concentrations of $MnSO_4$ of 10^{-3} and 10^{-2}M depressed leaf yields of bush beans by 63% and 83%, respectively, with 5140 and 10780 μg Mn/g dry weight of leaves. Copper concentrations were simultaneously increased and those of Ca were decreased. Bush bean plants grown in Yolo loam soil with 200 μg Cu/g soil had a depression in leaf yield of 26% (with 28.8 μg Cu/g leaf); plants failed to grow with 500 μg Cu/g soil. A level of 10^{-3}M H_2MoO_4 was toxic to bush beans grown in solution culture. Leaves, stems, and roots, respectively, contained 710, and 1054, and 5920 μg Mo/g dry weight.

INTRODUCTION

Literature for over 50 years has indicated that all of the essential trace metals for higher plants can be toxic to plants when in high concentrations except possibly Mo[1 2 5 7 13]. Even though usually not toxic to plants, high levels of Mo can be toxic to grazing animals[4]. Plants are very resistant to Mo toxicity even though animals are susceptible. Johnson[3] reported that 1000 to 2000 μg Mo/g could be toxic to plants under experimental conditions. A preliminary experiment was made with bush beans in which the highest level of H_2MoO_4 applied was 10^{-4}M, but there were no apparent adverse effects so an experiment was undertaken in which the level was increased to 10^{-3}M. Many trace metals interact with each other and the indication of chlorosis is a common phenomenon[2 6 6 7 11 12 13]. Chelating agents can modify the phytotoxicities of trace metals

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including the amounts taken up by plants; such effects have been noted for Fe, Cu, Co, Zn, Cd, and other elements[8 9 11].

The purpose of this study was to get a better definition of phytotoxicity levels for some of the essential trace metals and to obtain a quantitative assessment of some of their interactions.

MATERIALS AND METHODS

Bush bean plants (Phaseolus vulgaris L. C.V. Improved Tendergreen) were grown in 3700-ml nutrient solutions with different levels of $FeSO_4$ (10^{-6}, 10^{-5}, 10^{-4}, 2×10^{-4}, 5×10^{-4}, 10^{-3} M) and of FeEDDHA (ferric ethylenediamine di (o-hydroxyphenylacetic acid)) (10^{-5}, 10^{-4}, 10^{-3} M) for 15 days. The plants were then divided into leaves, stems, and roots, washed in 1/10 N HCl and deionized water and prepared for analysis by emission spectrography.

Bush beans were grown for 16 days in 3700-ml nutrient solutions with varying levels of Mn, B, and Zn to ascertain solution and plant concentrations of each which are conducive to phytotoxicity. The Zn series also received 5×10^{-4} M FeEDDHA to reduce any component of the phytotoxicity due to Fe[12]. The other plants received 10^{-4} M FeEDDHA. Plants were handled as in other experiments.

Bush bean plants were grown in 3700-ml nutrient solutions with either 10^{-5}, 10^{-4}, 10^{-3}, or 10^{-2} M $MnSO_4$. Solutions otherwise were as used elsewhere in these studies. After 21 days plants were divided into leaves, stems, roots and handled as previously in other experiments of this study.

Manganese as $MnSO_4$ was applied to 500-g quantities of Yolo loam soil at 0, 500, 1000, and 2000 μg Mn/g soil. Bush bean plants were then grown in the soil for 14 days and then harvested and analyzed as in other experiments. Nitrogen was supplied at 200 μg N/g soil as NH_4NO_3. Soil moisture was kept near -1/3 bar. There were 4 replications.

Bush bean plants were grown for 17 days in Yolo loam soil with 0, 50, 100, 200, and 500 μg Cu/g soil as $CuSO_4$. Conditions otherwise were like those for other soil experiments in this study.

Bush bean plants were grown for 14 days in 3700-ml solutions with levels of applied H_2MoO_4 of 0, 10^{-4}, 2×10^{-4}, and 10^{-3} M. It was known that all applied levels would be high. Plants were separated into leaves, stems, and roots, washed in 1/10 M HCl and then deionized water, dried, weighed, and prepared for analysis by emission spectrography. In some cases the Mo level was too high for the analytical system and such plant material was assayed after dilution with plant material containing little Mo.

RESULTS AND DISCUSSION

The 5×10^{-4} and 10^{-3} M levels of $FeSO_4$ resulted in Fe toxicity, but the 10^{-3} M FeEDDHA did not (Table 1). Leaf Fe concentrations at toxicity were 408 and 614 μg Fe/g leaves; those with 10^{-3} M FeEDDHA had only 124 μg Fe/g leaf. At 5×10^{-4} M $FeSO_4$, leaf levels of Zn, Cu, and Mn were decreased, but at 10^{-3} M $FeSO_4$ they were increased part of which effect could

TABLE 1

Effect of Fe levels on yields and mineral composition of bush beans grown in solution culture (dry weight basis).

Fe	Yield	Fe	Zn	Cu	Mn
M	g/plant	μg/g			
		Leaves			
10^{-6} FeEDDHA	1.21	61	36	9.2	139
10^{-5} $FeSO_4$	1.16	67	31	8.6	137
10^{-4} $FeSO_4$	1.24	76	26	6.8	133
2×10^{-4} $FeSO_4$	0.96	114	26	6.3	52
5×10^{-4} $FeSO_4$	0.38	408	15	5.8	26
10^{-3} $FeSO_4$	0.21	614	47	10.3	31
10^{-5} FeEDDHA	1.24	92	51	8.5	130
10^{-4} FeEDDHA	1.30	89	37	6.9	84
10^{-3} FeEDDHA	1.22	124	40	10.9	43
LSD .05	0.38	15	18	3.0	40
		Stems			
10^{-6} FeEDDHA	0.37	26	41	5.7	27
10^{-5} $FeSO_4$	0.33	28	32	6.1	17
10^{-4} $FeSO_4$	0.38	42	32	5.1	22
2×10^{-4} $FeSO_4$	0.30	66	35	6.0	17
5×10^{-4} $FeSO_4$	0.16	207	23	5.7	9
10^{-3} $FeSO_4$	0.12	270	72	4.9	17
10^{-6} FeEDDHA	0.34	40	57	6.3	18
10^{-4} FeEDDHA	0.36	94	44	7.4	17
10^{-3} FeEDDHA	0.29	83	56	10.2	9
LSD .05	0.13	57	NS	2.7	NS
		Roots			
10^{-6} FeEDDHA	0.26	348	392	28.1	2270
10^{-5} $FeSO_4$	0.27	1490	269	23.8	2050
10^{-4} $FeSO_4$	0.31	7943	384	26.8	1590
2×10^{-4} $FeSO_4$	0.32	>8000	373	26.8	590
5×10^{-4} $FeSO_4$	0.09	>8000	1275	30.0	28
10^{-3} $FeSO_4$	0.05	>8000	1410	65.8	80
10^{-5} FeEDDHA	0.25	1150	338	31.0	1850
10^{-4} FeEDDHA	0.30	3040	160	29.5	432
10^{-3} FeEDDHA	0.28	3750	134	59.8	600
LSD .05	0.12	1040	395 and 50	21.1	769

be due to concentration. Root analyses indicated that low Zn in leaves caused by $FeSO_4$ may be a translocation failure of Zn, but the effect on Mn may be an uptake failure.

The value of Y for uptake to leaves and stems when $(C_1/C_2)^Y$ = uptake ratio[10] which expresses uptake ratio for two different concentrations (C) was 0.876 for Fe from $FeSO_4$ between 10^{-4} and 10^{-3} M. The coefficient of variation (C.V.) was high, however, at 34.7%. The value of Y for Fe from EDDHA was much lower, only about 0.355.

A leaf concentration of 465 μg Mn/g leaf in bush beans when grown in solution culture with 10^{-4} M $MnSO_4$ resulted in a 27% reduction in leaf yield (Table 2). Leaf yields decreased further (52%) for 5×10^{-4} M $MnSO_4$ with 1508 μg Mn/g dry weight and 64% for 10^{-3} M with 2550 μg Mn/g dry weight. More Mn was in leaves than in stems and more in roots than in stems. The mean value of Y in the expression, uptake ratio = $(C_1/C_2)^Y$ [10], was 0.778 (C.V. = 26.4%) for leaves and 0.689 (C.V. = 26.4%) for the whole plant. The value of Y for leaves seemed to be slightly higher than ln2. There were interactions of Mn with Zn, Cu, Fe, B, and Pb, especially in leaves.

A leaf concentration of 291 μg B/g dry weight decreased leaf yields 45% with 5×10^{-4} M H_3BO_3 in solution. The 10^{-3} M H_3BO_3 level decreased leaf yields by 61% and resulted in a leaf concentration of 552 μg B/g. Stem and root concentrations of B were much lower than those in shoots even at the very high level. The mean value for Y in the expression, uptake ratio = $(C_1/C_2)^Y$ was 0.825 (C.V. = 25.7%) for leaves and 0.758 (C.V. = 29.0%) for the whole plant. These values also seemed to be greater than ln2 but the variation was great enough to create uncertainty. The interactions of B with other elements were minimal, but decreased growth with high B resulted in some increases in concentrations of other metals.

The 10^{-4} M solution concentration of $ZnSO_4$ resulted in a 34% yield reduction for leaves and in a leaf concentration of 321 μg Zn/g dry weight. The 2.5×10^{-4} M Zn resulted in a 68% yield reduction and in 605 μg Zn/g dry weight in leaves. The 5×10^{-4} M Zn resulted in a 76% reduction in leaf yields and in 820 μg Zn/g dry weight. The Zn concentrations increased from leaves, to stems, to roots at all levels of applied Zn. The value of Y (uptake ratio $=(C_1/C_2)^Y$) was 0.583 (C.V. = 14.0%) for leaves and 0.627 (C.V. = 16.7%) for the whole plant. Both were reasonably near the value for ln2[10]. The Mn concentrations in plants decreased with some high levels of Zn while Fe and Cu increased in roots with high Zn.

When bush beans were grown in solution with 10^{-3} M $MnSO_4$ a 63% reduction in leaf yield resulted (leaf concentration of Mn was 5140 μg/g) (Table 3). When 10^{-2} M $MnSO_4$ was used, the yield reduction was 83% (10790 μg/g dry weight). The high Mn levels did not result in changes in Fe and Zn concentrations of leaves, but Cu was increased in leaves, stems, and roots at the highest Mn concentration while Ca was depressed in all plant parts at the two highest levels of Mn. Manganese is known to interact with some other elements[6].

TABLE 2

Bush bean yields and trace metal concentrations for bush beans grown at different levels of Mn, B, and Zn.

Treatments	Yield	Zn	Cu	Fe	Mn	B	Pb
M	g/plant	μg/g					
			Leaves				
10^{-5} Mn	1.29^{d}	33^{e}	7.9^{ef}	127^{bcd}	66^{e}	17^{d}	4^{c}
10^{-4} Mn	0.94^{d}	38^{e}	10.5^{de}	87^{cd}	465^{d}	25^{d}	5^{c}
5×10^{-4} Mn	0.62^{bc}	51^{d}	16.2^{ab}	88^{cd}	1508^{b}	33^{cd}	18^{b}
10^{-3} Mn	0.46^{ab}	48^{d}	16.9^{a}	79^{d}	2550^{a}	43^{c}	27^{a}
10^{-5} B	1.29^{e}	33^{d}	7.9^{ef}	127^{bcd}	66^{e}	17^{d}	4^{c}
10^{-4} B	1.38^{e}	24^{e}	6.5^{f}	89^{cd}	48^{f}	54^{c}	5^{c}
5×10^{-4} B	0.71^{cd}	33^{e}	10.1^{de}	128^{bcd}	70^{e}	291^{b}	19^{b}
10^{-3} B	0.50^{abc}	39^{e}	11.7^{cd}	139^{bc}	100^{e}	552^{a}	6^{c}
10^{-6} Zn	1.33^{e}	29^{e}	9.8^{de}	110^{bcd}	595^{c}	22^{d}	3^{c}
10^{-5} Zn	1.26^{e}	83^{c}	10.1^{de}	132^{bcd}	72^{e}	19^{d}	7^{c}
10^{-4} Zn	0.88^{d}	321^{a}	9.6^{de}	121^{bcd}	67^{e}	22^{d}	3^{c}
2.5×10^{-4} Zn	0.42^{ab}	605^{a}	13.9^{bc}	145^{b}	63^{ef}	47^{c}	5^{c}
5×10^{-4} Zn	0.32^{a}	820^{a}	11.5^{cd}	208^{a}	39^{f}	40^{cd}	5^{c}
			Stems				
10^{-5} Mn	0.34^{ab}	39^{d}	6.1^{ef}	55^{g}	12^{de}	13^{d}	11^{b}
10^{-4} Mn	0.24^{cd}	54^{cd}	10.7^{c}	39^{g}	98^{c}	14^{d}	14^{b}
5×10^{-4} Mn	0.23^{cde}	82^{c}	14.1^{b}	53^{g}	346^{b}	16^{cd}	19^{b}
10^{-3} Mn	0.23^{cde}	71^{cd}	17.7^{a}	45^{g}	1100^{a}	15^{d}	50^{a}
10^{-5} B	0.34^{ab}	39^{d}	6.1^{ef}	55^{g}	12^{e}	13^{d}	11^{b}
10^{-4} B	0.40^{a}	25^{d}	5.4^{f}	45^{g}	9^{e}	15^{d}	9^{b}
5×10^{-4} B	0.30^{bc}	28^{d}	6.9^{ef}	40^{g}	15^{e}	33^{b}	8^{b}
10^{-3} B	0.22^{de}	59^{cd}	8.7^{cde}	57^{g}	23^{d}	59^{a}	9^{b}
10^{-6} Zn	0.37^{ab}	46^{cd}	10.0^{cd}	71^{cd}	13^{e}	16^{cd}	27^{ab}
10^{-5} Zn	0.38^{a}	115^{c}	7.1^{ef}	73^{cd}	13^{e}	14^{d}	8^{b}
10^{-4} Zn	0.22^{cde}	360^{b}	7.3^{def}	99^{bc}	15^{e}	13^{d}	12^{b}
2.5×10^{-4} Zn	0.16^{f}	1290^{a}	14.7^{b}	127^{b}	13^{e}	20^{c}	11^{b}
5×10^{-4} Zn	0.14^{f}	1590^{a}	10.7^{c}	180^{a}	11^{e}	17^{cd}	9^{b}
			Roots				
10^{-5} Mn	0.31^{ab}	107^{e}	23.4^{f}	1128^{def}	401^{d}	14^{cd}	38^{cd}
10^{-4} Mn	0.24^{bc}	86^{e}	46.1^{cde}	844^{ef}	3405^{b}	15^{cd}	43^{cd}
5×10^{-4} Mn	0.19^{cd}	174^{d}	78.1^{a}	1340^{cd}	7320^{a}	19^{c}	13^{a}
10^{-3} Mn	0.17^{cd}	189^{d}	73.5^{ab}	1160^{de}	7038^{a}	15^{cd}	88^{b}
10^{-5} B	0.31^{ab}	107^{e}	23.4^{f}	1128^{def}	401^{d}	14^{cd}	38^{cd}
10^{-4} B	0.35^{a}	95^{e}	21.9^{f}	760^{f}	406^{d}	19^{c}	28^{d}
5×10^{-4} B	0.20^{cd}	108^{e}	39.8^{de}	977^{def}	517^{d}	65^{b}	36^{cd}
10^{-3} B	0.12^{de}	224^{d}	55.1^{cd}	1373^{cd}	803^{c}	98^{a}	51^{cd}
10^{-4} Zn	0.34^{a}	112^{e}	49.4^{cde}	1217^{de}	83^{e}	12^{cd}	43^{cd}
10^{-5} Zn	0.37^{a}	229^{d}	33.9^{ef}	1208^{de}	95^{e}	11^{d}	25^{d}
10^{-4} Zn	0.19^{cd}	1898^{c}	49.2^{cde}	1748^{b}	61^{e}	12^{cd}	58^{c}
2.5×10^{-4} Zn	0.12^{de}	3233^{b}	61.8^{bc}	1647^{bc}	29^{f}	10^{d}	53^{cd}
5×10^{-4} Zn	0.06^{e}	4490^{a}	73.8^{ab}	2135^{a}	54^{ef}	16^{cd}	63^{bc}

Values followed by a common letter are not statistically significant at the 0.05 level; leaf, stem, and root statistics were calculated separately.

TABLE 3
Effect of different levels of $MnSO_4$ in solution culture on growth and mineral composition of bush beans (dry weight basis).

$MnSO_4$ M	Yield mg/plant	Mn	Fe	Cu	Zn	Ca	Soln. pH
		μg/g				%	
			Leaves				
10^{-5}	1420	167	153	11.0	24	2.80	4.2
10^{-4}	1175	993	124	11.7	25	2.55	4.2
10^{-3}	524	5140	116	19.4	28	1.88	4.5
10^{-2}	235	10790	178	39.6	30	0.68	4.5
LSD .05	180	2730	43	6.9	NS	0.27	-
			Stems				
10^{-5}	358	38	64	6.9	20	1.33	
10^{-4}	308	193	67	9.0	23	1.45	
10^{-3}	147	2500	63	17.7	45	1.18	
10^{-2}	54	19770	99	39.1	34	0.52	
LSD .05	81	3330	16	2.4	8	0.28	
			Roots				
10^{-5}	330	788	905	23.9	56	0.70	
10^{-4}	292	1870	1196	33.0	58	0.79	
10^{-3}	156	7870	1550	61.6	84	0.54	
10^{-2}	39	11640	1850	97.9	82	0.36	
LSD .05	95	1734	323	13.6	24	0.13	

The average value of Y [$(C_1/C_2)^Y$ = uptake ratio] in this experiment for Mn was 0.582 with a coefficient of variation of 20.1%.

A level of 200 μg Cu/g soil was necessary to decrease growth of bush beans, as measured by leaf yield, by 26% (Table 4). The leaf concentration of Cu was 28.8 μg/g. When 500 μg Cu/g soil was used, plants failed to grow. Iron in leaves was depressed slightly by the highest level of Cu while Ni, Mn, and Al were increased slightly by the high Cu levels, an effect possibly associated with a slight change in soil pH.

Stems contained less Cu than did leaves. The same trends for other metals in leaves were also expressed in roots.

The value of Y in the expression $(C_1/C_2)^Y$ = uptake ratio for different concentrations of Cu was 0.558 with a coefficient of variation of 42.5%.

TABLE 4
Yields and mineral concentration of bush bean plants grown in Yolo loam soil with added levels of $CuSO_4$ (dry weight basis).

Cu μg/g soil	Yield mg/plant	Cu	Fe	Ni	Mn	Al
		μg/g				
			Leaves			
0	990	7.4	162	<2.0	78	21
50	835	10.0	135	3.4	80	20
100	874	17.8	139	7.4	128	23
200	729	28.8	132	12.5	186	32
500*	173	34.3	115	17.3	110	47
LSD .05	216	3.5	20	2.1	27	11
			Stems			
0	367	3.7	60	1.5	20	10
50	363	5.0	47	2.0	16	8
100	364	9.5	49	3.6	28	8
200	314	11.7	42	4.9	30	11
500*	114	20.3	47	7.8	13	21
LSD .05	91	1.6	9	0.9	6	3

*Plants never grew, but remained same size as when treatments started.

In the Yolo loam soil experiment with $MnSO_4$, the Mn concentration in leaves and stems was almost in direct proportion to that applied. The Y value in $(C_1/C_2)^Y$ = uptake ratio[10] was 0.96. This may be related to the acute toxicity with loss of regulation of the uptake. The leaves were dead or dying for the treated plants. Some of the small apparent weight differences were due to the fact that plants grew little during the 14 days of the experiment. Iron, Cu, Zn, Al, Co, Ni, Mo, Sn, Ag, Pb, and K increased in leaves at the high Mn level as if there were no barrier to transport for substances from soil. The Mn concentrations were very high, up to 28,000 μg/g (Table 5). This is almost 3% of dry weight.

The 10^{-3}M H_2MoO_4 inhibited plant growth (Table 6) and resulted in slightly yellow plants. This very high level of Mo resulted in 710 μg Mo/g of leaves, 1054 μg Mo/g stems, and 5920 μg Mo/g roots. There was no interaction of Mo with Fe in shoots; others had observed that Mo did cause Fe deficiencies[29]. Manganese, Zn, K, Ca, and Mg levels of leaves, stems, and roots were decreased by the highest level of Mo.

On the whole plant basis the value of Y in the expression $(C_1/C_2)^Y$ = uptake ratio where C is concentration [10] was only 0.263 as the mean for the values between 10^{-4} and 10^{-3} M Mo. In the preliminary experiment between 10^{-7} and 10^{-4} M H_2MoO_4 the Y value was 0.904. The implication is that this experiment gave a fair amount of scatter in amounts of Mo taken up and also that the value of Y changes with increasing concentration of Mo.

TABLE 5

Yields and mineral composition of bush beans plants grown in Yolo loam soil with different levels of $MnSO_4$.

Mn µg/g soil	Soil pH	Yield mg/plant	Mn	Fe	Cu	Zn	B	Al	Co	Ni
			µg/g							
			Leaves							
0	6.1	363	79	110	6.8	20	122	18	0.0	1.0
500	5.8	347	9460	130	16.3	23	118	25	0.9	3.1
1000	5.6	300	16450	164	20.2	31	98	38	3.1	7.0
2000	5.5	242	28350	211	28.2	53	68	68	5.1	10.7
LSD .05	-	84	5190	34	3.2	13	26	8	0.8	1.5

Mn µg/g soil		Yield mg/plant	Mo	Ag	Sn	Pb	P	K	Ca	Mg
			µg/g				%			
			Leaves							
0	6.1	363	0.6	0.6	0.0	0	0.26	1.87	3.14	0.48
500	5.8	347	1.4	3.8	1.4	23	0.40	2.34	3.90	0.85
1000	5.6	300	2.1	8.7	7.9	87	0.58	2.91	2.73	0.68
2000	5.5	242	3.3	21.1	19.3	254	0.74	3.03	1.60	0.88
LSD .05		84	0.6	3.3	2.3	39	0.10	0.39	0.52	0.27

Mn µg/g soil	Yield mg/plant	Mn µg/g
	Stems	
0	180	14
500	137	2415
1000	107	11800
2000	66	34350
LSD .05	36	5910

TABLE 6

Yields and metal concentrations of bush bean plants grown in solution culture with varying levels of Mo (dry weight basis).

Mo M	Yield g/plant	Mo	Fe	Mn	Zn	Cu	Ca	K	Mg
		µg/g					%		
		Leaves							
0	2.28	0.2	112	59	31	7.5	2.04	5.83	0.27
10^{-4}	1.48	189	100	117	38	8.6	2.48	5.73	0.42
$2x10^{-4}$	1.64	322	96	94	45	8.0	2.09	5.31	0.44
10^{-3}	0.42	710	100	36	12	9.1	1.26	3.45	0.37
LSD .05	0.35	133	NS	22	16	NS	0.30	1.66	0.06
		Stems							
0	0.57	0.7	61	11	47	5.4	0.71	4.40	0.12
10^{-4}	0.39	414	64	18	53	7.0	0.97	4.69	0.14
$2x10^{-4}$	0.46	954	47	12	65	6.9	0.67	4.64	0.15
10^{-3}	0.24	1054	50	12	25	7.3	0.54	2.95	0.13
LSD .05	0.11	372	NS	NS	22	1.3	0.30	0.94	NS
		Roots							
0	0.44	3.3	901	283	109	13.0	0.64	7.21	0.26
10^{-4}	0.39	3990	1068	756	109	29.3	0.81	7.11	0.21
$2x10^{-4}$	0.38	3250	890	871	175	31.0	0.74	6.00	0.22
10^{-3}	0.10	5920	1440	54	45	43.2	0.54	3.94	0.14
LSD .05	0.10	2120	179	89	58	5.7	0.14	1.54	0.02

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PHYTOTOXICITY OF COBALT, VANADIUM, TITANIUM, SILVER, AND CHROMIUM

KEY WORDS: Cobalt, vanadium, titanium, silver, chromium, toxicity

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ABSTRACT

The phytotoxicity of five nonessential elements (Co, V, Ti, Ag, Cr) to higher plants was studied in solution culture experiments with bush beans (Phaseolus vulgaris L. C.V. Improved Tendergreen). All, but in varying degrees, tended to concentrate in roots with a decreasing gradient to stems and leaves. Cobalt was one of the more mobile of the five trace metals. Its toxicity was expressed as severe chlorosis; 43 (with 10^{-5}M) and 142 (with 10^{-4}M) μg Co/g dry weight in leaves resulted in severe chlorosis. Vanadium as 10^{-4}M vanadate resulted in smaller plants but not in chlorosis. Leaf, stem, and root V, respectively, were 13, 8, and 881 μg/g dry weight. Titanium was somewhat mobile with considerable yield decrease at 10^{-4}M; leaf, stem, and root Ti concentrations, respectively, were 202, 48, and 2420 μg/g. Symptoms were chlorosis, necrotic spots on leaves, and stunting. Silver was very lethal at 10^{-4}M $AgNO_3$; at 10^{-5}M yields were greatly decreased, but plants were grown without symptoms. Leaf, stem, and root concentrations of Ag for this treatment, respectively, were 5.8, 5.1, and 1760 μg/g dry weight. Plants grown with 10^{-5}N Cr_2O_7 were decreased in yield by about 25% with or without EDTA (ethylenediamine tetraacetic acid) while the same level of $Cr_2(SO_4)_3$ was essentially without effect. For the two salts, the leaf, stem, root concentrations for Cr, respectively were 2.2 and 1.3, 0.7 and 0.7, and 140 and 104 μg/g. Most of the trace metals studied here had interactions in the uptake and/or distribution of other elements.

INTRODUCTION

The five elements investigated at this time have the common characteristic of easy assay in routine emission spectrography[6]. Each has been the subject of considerable past study[1] although phytotoxicity of Ag and Ti has not really been explored while that of Cr, Co, and V have been studied considerably. A recent excellent study of Cr, Co, and other elements was made by Petterson[2]. The objectives of this study were to determine

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