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LITHIUM TOXICITY IN PLANTS

KEY WORDS: Lithium, trace metals, chelating agents, lime, metal interaction, tolerance to trace metals, metal toxicity, spectrographic analysis, plant analysis

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ABSTRACT

The toxicity of Li to three plant species was studied to determine if there were interactions with other elements and to determine if a chelating agent modified Li toxicity. Bush beans (Phaseolus vulgaris L. C.V. Improved Tendergreen), grown in solution culture, were sensitive to 0.5 $\times 10^{-3}$ M Li which resulted in 10 μg/g in leaves, 48 in stems, and 24 in roots. Higher concentrations of Li produced marked reductions in plant yield accompanied by increased Li concentrations in leaf, stem, and root tissues. For most treatments, root concentrations of Li were lower than those in shoots, but those in stems were higher than those in leaves. Higher levels of Li decreased Zn in leaves, increased Ca in stems, and generally increased Fe and Mn in all plant tissues. Ethylenediamine tetraacetic acid (EDTA) resulted in slightly increased Li levels in leaves, stems, and roots. Bush bean plants were injured slightly with 25 μg Li/g of Yolo loam soil applied as LiCl; 50 μg Li/g soil caused more severe injury. Leaf concentrations of about 200 μg Li/g resulted in significant yield reduction and around 600 μg/g of leaves resulted in severe toxicity. There were some interactions of Li with other elements which resulted in an increase of them in both leaf and stem tissues. Barley plants (Hordeum vulgare L. C.V. Atlas 57) were severely stunted when grown with 500 and 1000 μg Li/g soil as Li oxalate. Increasing the soil pH even further with lime and decreasing it with S had no influence on the toxicity. Shoot concentrations of Li ranged from 800 to over 2000 in the various treatments resulting in severe disruption of the Ca and K balance. Leaf concentrations of Li were higher than those for stems in cotton (Gossypium hirsutum L. C.V. Acala 442). Cotton was tolerant of a leaf concentration of 587 μg Li/g. High levels of Li increased concentrations of several elements in cotton leaves and in stems. Cotton leaves accumulated more Li than did bush beans.

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INTRODUCTION

Lithium is a widely used industrial chemical and the production of it and its compounds has greatly increased since the development of atomic energy. Lithium is ubiquitous in soils and plants although its concentration varies greatly[3]. Although it is not a really serious environmental hazard, its potential toxicity has been recognized for many decades and the literature on this subject, as well as that on its occurrence in soils and plants, was reviewed by Bradford[3]. Lithium toxicity has been described for citrus[1 2 6] and for avocado[3]. Accumulator and tolerant species do exist for Li[3 4 10]. The purposes of the present study were to ascertain toxic levels of Li in some plant species and to determine whether or not there were interactions with other elements.

MATERIALS AND METHODS

Previously germinated bush beans (Phaseolus vulgaris L. C.V. Improved Tendergreen) were transplanted in regular nutrient solution and grown for 14 days with different levels of Li (0.5×10^{-3} M to 5×10^{-3} M). The Li was supplied as $LiNO_3$ which made NO_3^- a variable also. In some cases extra $Ca(NO_3)_2$ was added to give more Ca. The solutions otherwise contained in me/liter, 10 $Ca(NO_3)_2$, 1 KNO_3, 4 K_2SO_4, 2 $MgSO_4$, 2 $NH_4H_2PO_4$ and trace metals. Ethylenediamine tetraacetic acid (EDTA) was also included as a variable to test possible interactions with Li. There were four replications for each treatment. After 24 days plants were separated into leaves, stems, and roots, washed in 1/10N HCl and deionized water, dried, weighed, and prepared for analysis by emission spectrography[9].

Lithium as Li oxalate was mixed into Yolo loam soil with and without 2% $CaCO_3$ or 1/2% as amendments at levels of 0, 500, and 1000 μg Li/g soil. Barley was transplanted four per each 500 g of soil and grown for 10 days. Nitrogen was added to soil at 200 μg N/g soil as NH_4NO_3 and soil moisture was kept near 1/3 bar. There were four replications. Plants were harvested by cutting 1 cm above the soil line, washed in 1/10N HCl and deionized water, dried, weighed, and prepared for analysis by emission spectrography[9].

Lithium as LiCl was mixed into Yolo loam soil with and without 2% $CaCO_3$ at levels of 0, 10, 25, and 50 μg Li/g soil. Bush bean plants were grown for 16 days in the soil after transplanting under the same cultural conditions as above. There were four replications. Harvested plants (1 cm above soil line) were separated into leaves and stems and handled as above.

Cotton plants were grown for 21 days in 500-g quantities of Yolo loam soil with different levels of Li as $LiNO_3$. The highest level (100 μg/g) was with and without 2% $CaCO_3$. Nitrogen application was held constant at 200 μg/g soil with the addition of NH_4NO_3. Plants were harvested 1 cm above soil line, separated to leaves and stems, washed and prepared for analysis as above. There were four replications.

RESULTS AND DISCUSSION

Vegetative yields of bush beans were decreased slightly by 0.5 and 1.0×10^{-3} M Li and more so by 2.0 and 5.0×10^{-3} M Li (Table 1). Leaf

TABLE 1

Yields and Mineral Composition of Bush Beans Grown in Solution Culture.

Treatments Li (M)	Other (M)	Yield (g/plant)	Li	Fe	Zn	Mn	Cu	Ca
			μg/g dry weight					%
		Leaf						
0		3.24	0	92	59	42	4.0	2.87
0.5×10^{-3}		2.72	19	96	87	59	6.2	2.66
1×10^{-3}		2.56	49	95	77	54	5.0	2.79
2×10^{-3}		1.84	112	104	43	79	5.3	2.77
2×10^{-3}	2×10^{-3} $Ca(NO_3)_2$	2.89	78	106	40	82	5.0	2.54
2×10^{-3}	10^{-4} EDTA	1.69	167	91	32	47	1.3	3.11
5×10^{-3}		0.87	295	139	69	102	7.3	2.62
5×10^{-3}	5×10^{-3} $Ca(NO_3)_2$	1.03	247	83	33	68	6.0	2.46
5×10^{-3}	10^{-4} EDTA	0.77	364	101	28	63	3.0	3.61
LSD 0.05		0.45	20	22	25	13	1.1	0.82
LSD 0.01		0.59	27	NS	35	17	1.4	NS
		Stem						
0		0.79	0	40	66	9.2	3.6	0.42
0.5×10^{-3}		0.55	48	48	78	9.2	4.4	0.44
1×10^{-3}		0.52	117	50	74	11.7	4.2	0.55
2×10^{-3}		0.35	170	65	59	13.3	5.5	0.29
2×10^{-3}	2×10^{-3} $Ca(NO_3)_2$	0.50	150	77	61	11.1	4.7	0.59
2×10^{-3}	10^{-4} EDTA	0.33	296	64	30	13.4	2.1	1.48
5×10^{-3}		0.17	516	121	121	28.8	17.2	2.41
5×10^{-3}	5×10^{-3} $Ca(NO_3)_2$	0.19	479	87	99	16.0	14.3	2.42
5×10^{-3}	10^{-4} EDTA	0.18	567	118	48	22.9	4.0	2.89
LSD 0.05		0.10	44	18	21	5.0	1.6	0.30
LSD 0.01		0.13	58	23	28	6.5	2.1	0.39
		Root						
0		0.75	0	541	174	193	8.8	0.62
0.5×10^{-3}		0.62	24	1138	208	242	11.5	0.38
1×10^{-3}		0.51	50	907	222	233	9.8	0.54
2×10^{-3}		0.43	57	1358	153	389	13.0	0.55
2×10^{-3}	2×10^{-3} $Ca(NO_3)_2$	0.62	65	1054	130	344	10.2	0.50
2×10^{-3}	10^{-4} EDTA	0.41	99	219	43	112	3.7	0.58
5×10^{-3}		0.21	126	1689	278	598	27.3	0.65
5×10^{-3}	5×10^{-3} $Ca(NO_3)_2$	0.27	113	718	133	228	9.4	0.47
5×10^{-3}	10^{-4} EDTA	0.24	154	198	44	125	4.4	0.64
LSD 0.05		0.14	19	532	61	90	2.9	NS
LSD 0.01		0.18	25	702	81	118	3.8	NS

concentrations of Li at mild toxicity were 18 to 49 μg/g and at more severe toxicity they ranged from 112 to 364 μg/g. The EDTA slightly increased the Li concentration in leaves, stems, and roots. Stems generally contained more Li than did leaves, but root concentrations were lower than in either leaves or stems.

Some interesting phenomena were illustrated in this experiment. The Li concentration in solution necessary to cause severe disruption of plant growth was about two orders of magnitude higher than for some other non-essential trace metals. This indicates a lower affinity of the plants for Li than for elements like Cd or Ni. The observation that EDTA increased uptake of Li is not likely the result of chelation of Li, but more likely the result of chelation of other elements which may compete with Li for uptake. The distribution of Li among leaves, stems, and roots was more uniform than for most trace metals. Lithium was not bound in roots, but was very mobile in plants.

High Li levels were associated with increased concentrations of Fe, Mn, and Cu which could easily be the result of concentration due to decreased yields[8]. Some of the high levels of Li resulted in high Ca concentrations in stems. The highest levels of Li, especially with EDTA, decreased Zn concentrations in leaves and stems.

The Li oxalate applications made the soil alkaline, greatly depressed yields of barley, and resulted in levels of Li in the plants of from 800 to over 2000 μg/g (Table 2). The 2% $CaCO_3$ had little effect on uptake or toxicity of Li as expected[5]. The increased Fe levels as result of Li toxicity may be, in part, related to severe stunting of plants and, therefore, a concentration effect[8]. Potassium and Ca levels in barley were depressed considerably by the high levels of Li. This could be evidence of a loss of membrane permeability and may be related to the high soil pH caused by the oxalate.

In bush bean plants which were grown with much lower levels of Li than was barley, a soil application rate of 10 μg Li/g soil resulted in no visible or measurable Li toxicity (Table 3). The 25 μg Li/g soil application resulted in some slight chlorosis and mottled leaf edges. Leaf yields were depressed significantly at the 5% level without $CaCO_3$, but less so with $CaCO_3$. The Li concentration of leaves was lower with $CaCO_3$ than without (152 μg/g vs 226 μg/g). The 50 μg Li/g soil resulted in severe toxicity of bush beans and in 600 μg Li/g dry weight in leaves. The toxicity appeared to be almost equal with and without $CaCO_3$.

Bush bean stem material consistently contained more Li than did leaves. At low levels of Li the stem-leaf ratios for Li were 6:1 and 11:1, but at the highest Li level it was about 1.3:1. With citrus, Aldrich et al. (1951) obtained less Li in stems than in leaves. Although Li resulted in some significantly different K and Ca concentrations in bush bean leaves, there was no consistent depression in either as the Li was increased. Differences in Fe concentrations were erratic. With added $CaCO_3$ the same increase of Fe with Li found for barley was also present. No such trend appeared without presence of $CaCO_3$.

TABLE 2

Yields and Mineral Composition of Barley Plants Grown in Yolo Loam Soil of Different pH Values and with Different Levels of Applied Li Oxalate (dry weight basis).

Treatments	Yields	Soil pH	Li	Fe*	Ca	K	Mg	Zn	Cu	Mn
μg Li/g soil	g/plant		μg/g		%			μg/g		
			No soil amendments							
0	0.254	6.3	2	81	1.04	4.30	0.41	80	13.1	39
500	0.087	7.7	1131	2188	0.29	1.01	0.66	73	15.0	70
1000	0.073	8.5	1733	812	0.20	0.93	0.46	96	16.6	76
			+ 2% $CaCO_3$							
0	0.262	7.2	1	85	1.20	3.30	0.37	83	10.1	40
500	0.076	8.9	806	540	0.30	0.68	0.47	61	7.9	36
1000	0.091	9.0	1717	406	0.27	0.90	0.41	60	14.5	28
			+ 1/2%S							
0	0.281	5.5	11	148	1.11	3.39	0.44	50	9.5	90
500	0.075	7.4	2058	495	0.38	0.95	0.62	98	15.6	55
1000	0.091	7.8	1729	472	0.27	1.21	0.48	88	16.4	72
F value	78.2	-	54.2	22.0	101.1	8.4	17.1	4.9	17.6	13
LSD.05	.092	-	319	386	0.116	1.33	0.065	17	1.5	16
LSD.01	.132	-	459	555	0.167	1.91	0.094	24	2.2	23

*Analysis for Ti may indicate some soil contamination on some of the plants.

The levels of Li which caused toxicity in bush beans grown in soil (about 200 μg/g in dry leaves) corresponds with the literature[3] for some species, but for other species it has been reported to be as low as 40 μg/g. For bush beans in solution culture, a Li concentration above 1000 μg/g in leaves was very toxic. Very severe injury occurred in the present study for bush beans when Li was around 600 μg/g leaves and from 800 to 2000 μg/g leaves in barley. These may be much higher levels than those previously reported in the literature. In a Li-accumulating plant in the Mojave Desert[4] we have observed levels of 1100 μg Li/g leaves on the dry weight basis. The species is completely tolerant of this level of Li.

The ability of $CaCO_3$ to partially overcome mild toxic effects of Li may be related to the ability of Ca to compete with Li for uptake[5,7].

Twenty-five μg Li/g soil did not decrease vegetative yield of cotton although it increased the leaf concentration to 587 μg/g leaves (Table 4). Leaf yield was decreased 33% by 50 μg Li/g soil and 78% by 100 μg/g. Leaf concentrations were 1120 and 2385 μg/g, respectively. The $CaCO_3$

TABLE 3

Leaf Yield and Composition of Bush Beans Grown in Yolo Loam Soil with Different Levels of LiCl (dry weight basis).

Treatments μg Li/g soil	Yield leaf g/plant	Leaf Li μg/g	Stem Li μg/g	Leaf Ca %	Leaf K %	Leaf Fe μg/g	Stem Fe μg/g	Leaf Cu μg/g	Stem Cu μg/g	Leaf Zn μg/g	Stem Zn μg/g	Leaf Mn μg/g	Stem Mn μg/g
						Yolo loam soil							
0	0.522	0	0	2.11	4.13	313	49	11.6	4.8	53	59	135	26
10	0.526	30	186	2.32	3.63	192	51	10.5	4.1	68	76	166	32
25	0.357	226	519	2.68	3.93	252	63	12.0	9.5	80	116	164	42
50	0.136	612	842	2.22	4.08	95	83	10.3	20.4	68	140	132	68
						Yolo loam soil + $CaCO_3$							
0	0.517	0	0	2.19	3.59	58	16	7.9	3.0	62	57	73	16
10	0.489	8	90	2.51	2.13	61	21	7.6	4.1	51	56	67	10
25	0.413	152	413	3.00	3.20	83	43	12.3	7.2	67	91	107	15
50	0.168	631	730	2.70	4.51	197	105	12.0	17.1	55	123	89	33
F value	13.5**	71.0**	182.1**	5.0**	7.0**	30.6**	12.7**	8.7**	110.1**	2.1	14.9**	30.5**	35.8**
LSD .05	0.118	57	68	0.43	0.77	62	23	1.7	1.7	NS	23	10	9
LSD .01	0.160	75	89	NS	1.01	84	31	2.3	2.3	NS	32	13	12

TABLE 4

Effect of $LiNO_3$ on Yield and Mineral Composition of Cotton Grown on Yolo Loam Soil (dry weight basis).

Treatments μg Li/g soil	Vegetative yield g/plant	Li μg/g	Fe μg/g	Zn μg/g	Mn μg/g	Cu μg/g	Al μg/g	P %	K %	Ca %	Mg %	Sr μg/g	Ba μg/g	Na μg/g
						Leaves								
0	.695	1	45	36	84	7.5	10.2	0.46	1.60	2.44	0.41	29	64	135
25	.797	587	69	29	76	8.1	30.3	0.54	1.98	2.93	0.50	38	89	132
50	.467	1120	265	32	118	11.4	339	0.54	1.99	3.81	0.54	36	140	128
100	.155	2385	1108	54	157	15.1	1564	0.98	2.05	3.10	0.76	66	153	866
100 + 2% $CaCO_3$	.202	1498	440	37	102	13.1	588	0.44	1.48	3.24	0.57	50	65	132
LSD .05	.294	422	270	NS	22	3.3	431	0.17	NS	0.48	0.13	15	21	34
LSD .01	.396	570	365	NS	30	4.5	582	0.23	NS	0.63	0.17	20	28	433
						Stems								
0	.245	0	17	37	10	7.5	4.5	0.28	1.96	0.26	0.28	16	62	71
25	.234	65	9	29	10	6.6	6.6	0.29	2.22	0.34	0.32	22	94	106
50	.107	184	12	28	11	4.6	4.6	0.21	2.68	0.25	0.31	17	84	220
100	.029	1634	33	50	31	29.6	29.6	0.35	1.73	2.36	0.55	44	141	1361
100 + 2% $CaCO_3$	.043	781	13	36	18	16.9	16.9	0.15	2.50	1.14	0.35	30	66	951
LSD .05	.085	678	NS	NS	4	9.5	9.5	NS	0.71	0.80	0.20	14	41	470
LSD .01	.115	916	NS	NS	6	12.9	12.9	NS	NS	1.08	NS	NS	NS	635

treatment decreased the toxicity only slightly, but the difference was not statistically significant. $CaCO_3$ did, however, decrease the Li concentration in leaves and stems. Lithium concentrations were higher in leaves than in stems of these plants in contrast to bush beans.

High levels resulted in increased Fe, Mn, Cu, Al, Sr, and Ba in cotton plant parts which may be due to concentration effects resulting from decreased yields[8]. High Ca was found in stems at the highest two Li levels and this is most likely independent of the concentration effect.

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CALCIUM DEFICIENCY AND $CaCO_3$ ON MICRONUTRIENT STATUS OF PLANTS GROWN IN SOLUTION CULTURE

KEY WORDS: Copper, iron, nickel, zinc, manganese, aluminum, titanium

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ABSTRACT

Plants were grown in solution culture with different levels of Ca to further evaluate Ca relationships to trace metal uptake and to toxicity of trace metals. When tomato plants (Lycopersicon esculentum L., Tropic) were grown at a low level of Ca, the Zn, Cu, Fe, Mn, Al, and Ti concentrations of leaves, stems, and roots were considerably increased. The use of an excess of $CaCO_3$ which increased pH did not influence the trace metal concentrations of plants any more than did Ca^{++}. In a factorial experiment with bush beans (Phaseolus vulgaris L. C.V. Improved Tendergreen) with Ca (10^{-4}, 10^{-3}, 10^{-2} N) and Ni (0, 2×10^{-6} M, 2×10^{-5} M), Ni phytotoxicity and Ni uptake were decreased somewhat at the highest Ca level. High Ni tended to decrease the Ca concentration in leaves. High Ca and Ni both tended to decrease Fe, Cu, Zn, and Mn concentrations in leaves. The Ni had some interactions on the P concentrations of shoots.

INTRODUCTION

In determining possible phytotoxicity levels of various trace metals, it is necessary also to consider the Ca status of the plants[1 2 3 4 5 7]. It is generally accepted that one of the functions of Ca in plant nutrition is that of preventing trace metals from being toxic. The most expressed evidence of such an effect is the decreased uptake of trace metals caused by an increased supply of Ca. The purpose of this study was to further evaluate the effect of Ca on trace metal uptake by plants.

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