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EXCESS TRACE METAL EFFECTS ON COTTON: 6. NICKEL AND CADMIUM IN YOLO LOAM SOIL

KEY WORDS: Nickel, cadmium, phytotoxicity, cotton cultivars, trace metals.

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ABSTRACT

Two cultivars of cotton (Gossypium spp.) were grown in Yolo loam soil in a glasshouse to determine phytotoxicity effects of excesses of Ni and Cd. A 200 μg/g level of Ni in soil reduced yield by 60% in Acala SJ-2 and by 83% in Giza 45. The leaf Ni concentrations, respectively, were 146 and 165 μg/g. The 300 μg/g level of Cd decreased leaf yields by 60% and 75% for the two cultivars, respectively. Leaf concentrations of Cd, respectively, were 43 and 63 μg/g. There was a stem to leaf gradient of Cd for all cases. High Cd did not depress Mn concentrations in plants as in other species but there were many mineral element interactions.

INTRODUCTION

Considerable studies have been made in recent years of phytotoxic effects of trace metals (1, 2, 3, 4, 6). Most of these have been directed towards food chain relationships while most non-food chain crops such as cotton have been overlooked. The objective of this study was to determine the relative tolerance of two cotton cultivars to excesses of Ni and Cd when grown in soil.

MATERIALS AND METHODS

Cotton plants (Gossypium hirsutum L. cultivar Acala SJ-2 and Gossypium barbadense L. cultivar Giza 45) were grown in a glasshouse at the University of California, Los Angeles in the year 1977. The seeds were

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grown in sand flats for two weeks then transplanted to plastic pots containing 2000-g Yolo loam soil of pH 6.8. The soil was mixed before transplanting with different rates of Ni and Cd, each supplied as the sulfate salt and mixed throughout the soil. The different treatments for Ni were control, 100 μg/g and 200 μg/g soil and for Cd were control, 300 μg/g and 600 μg/g soil. Nitrogen was applied to the soils at 100 μg N/g soil as NH_4NO_3. The replications were two pots from each treatment and two plants in each pot. Plants were harvested after 5 weeks by cutting the stem 1 cm above the soil line, leaves and stems were separated, washed in 0.1N HCl and deionized water, dried, weighed and prepared for analysis by emission spectrography (7).

RESULTS AND DISCUSSION

Total vegetative growth (leaves and stems) of cotton plants was significantly reduced by application of Ni and Cd to the soil as found by others for other plants (3, 5, 9, 10, 11) (Table 1). On a percent basis (control = 100%) with Ni at 100 μg/g and 200 μg/g, the dry weights of the leaves were

TABLE 1

Yields and Mineral Composition of Cotton Plants cv. Acala SJ-2 Grown in Yolo Soil with Different Levels of Ni and Cd (dry weight basis).

Treatment μg/g soil	Yield g/plant	P %	Na μg/g	K %	Ca %	Mg %	Zn μg/g	Cu μg/g	Fe μg/g	Mn μg/g	B μg/g
					LEAF						
Control	1.20	0.29	935	1.77	2.74	0.52	21.4	6.9	141	43	42
100 Ni	0.67	0.18	1560	1.99	3.28	0.67	18.6	5.6	189	49	73
200 Ni	0.25	0.24	2045	1.27	3.19	0.94	28.3	6.1	277	53	152
300 Cd	0.48	0.24	2548	1.67	4.41	0.91	34.4	3.6	236	80	116
600 Cd	0.19	0.23	2215	1.14	3.64	1.15	18.4	4.9	258	169	125
F value	95.5**	1.0	20.3**	8.4**	8.4**	17.2**	21.3**	9.6**	5.9**	17.8**	39.7**
LSD 0.05	0.13	NS	429	0.38	0.69	0.18	4.7	1.2	70	38	21
LSD 0.01	0.18	NS	602	0.53	0.97	0.26	6.5	1.7	97	54	30
					STEM						
Control	0.49	0.26	788	2.28	0.92	0.47	27.2	6.0	48	7	25
100 Ni	0.20	0.15	1528	2.19	0.98	0.59	24.8	3.2	68	10	28
200 Ni	0.12	0.15	1720	1.02	0.63	0.40	20.2	2.4	84	15	30
300 Cd	0.11	0.20	2540	2.23	1.06	0.82	55.7	3.4	104	11	35
600 Cd	0.07	0.25	5690	1.96	0.89	0.53	32.3	3.6	123	91	47
F value	84.3**	8.5**	9.3**	7.5**	4.8*	11.1**	24.0**	13.2**	8.6**	5.1*	5.1*
LSD 0.05	0.05	0.05	1928	0.58	0.22	0.14	7.9	1.2	31	48	12
LSD 0.01	0.07	0.08	2705	0.81	NS	0.19	11.5	1.6	43	NS	NS

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56% and 20.4% respectively for Acala SJ-2 cultivar and 54% and 17.1% for Giza 45 cultivar respectively (Table 2). Toxicity symptoms were the same in the two cultivars which were very slow growth and yellowish-green leaves especially between the veins.

Adding Cd also decreased the yield of dry leaves significantly. On a percent basis (control =100%) the leaf dry weights of Acala SJ-2 cultivar were 39.6% and 15.4% and for Giza 45 cultivar were 24.8% and 14% grown in soil with 300 μg/g and 600 μg Cd/g soil respectively. In addition to the reduction in growth caused by Cd toxicity the petioles were red and the whole leaf was greenish yellow.

There was also a significant decrease of dry weight of stems of cotton plants in soils with Ni and Cd (3, 5, 9, 10, 11). With plants in soil with 100 and 200 μg Ni/g soil, the dry weight of stems were 40.6% and 24.4% respectively (control =100%) for Acala SJ-2 cultivar, and for Giza 45 cultivar they were 72.7% and 18.8% respectively. Added Cd to the soil at 300 and 600 μg/g soil reduced also the dry weight of cotton stems

TABLE 1 (Continued)

SJ-2 Grown
asis).

Mn μg/g	B μg/g	Al μg/g	Si μg/g	Ti μg/g	V μg/g	Co μg/g	Ni μg/g	Mo μg/g	Cr μg/g	Sr μg/g	Ba μg/g	Li μg/g	Cd μg/g
							LEAF						
43	42	51	350	11.5	2.9	1.5	0.0	1.7	0.3	153.0	43.4	1.6	2.8
49	73	114	663	16.0	3.5	1.5	48.8	0.8	0.4	204.0	29.1	3.9	1.5
53	152	262	1513	26.5	3.5	0.0	146.0	0.8	0.4	276.5	32.6	6.6	<3.0
80	116	188	1538	22.9	4.2	0.4	0.0	1.1	0.7	307.3	26.8	8.2	42.4
169	125	294	1590	33.2	3.3	1.1	0.0	0.7	0.6	301.3	30.8	7.9	77.4
*	**	**	**			**	**		**	**	*	**	**
17.8	39.7	11.1	17.6	2.3	1.6	8.2	356.7	2.6	8.7	22.5	5.7	29.5	45.1
38	21	93	426	NS	NS	0.8	10.4	NS	0.2	43.6	8.2	1.6	15.6
54	30	130	597	NS	NS	1.1	14.6	NS	0.3	61.2	11.6	2.3	21.8
							STEM						
7	25	12	70	10.2	2.3	0.0	0.0	0.0	0.0	95.1	37.5	0.7	<3.0
10	28	26	115	55.0	1.8	0.0	26.0	0.0	0.0	148.5	23.2	0.7	<3.0
15	30	37	235	42.9	1.5	0.0	67.5	0.0	0.0	133.0	11.3	0.2	<3.0
11	35	43	253	36.9	3.0	0.0	1.0	0.0	0.0	206.7	22.9	1.0	98.5
91	47	81	449	41.1	2.3	0.0	0.6	0.0	0.0	200.3	20.3	0.8	440.8
**	*	**	**				**			**	**	*	**
5.1	5.1	16.7	9.3	1.0	1.8	--	16.9	--	--	8.7	17.2	3.5	16.8
48	12	20	148	NS	NS	NS	21.7	NS	NS	47.1	7.0	0.5	142.5
NS	NS	28	208	NS	NS	NS	30.4	NS	NS	66.1	9.8	NS	199.9

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TABLE 2

Yields and Mineral Composition of Cotton Plants cv. Giza 45 Grown in Yolo Soil with Different Levels of Ni and Cd (dry weight basis).

Treatment μg/g soil	Yield g/plant	P %	Na μg/g	K %	Ca %	Mg %	Zn μg/g	Cu μg/g	Fe μg/g	Mn μg/g	B μg/g
LEAF											
Control	0.79	0.24	634	2.26	2.89	0.34	19.2	6.3	110	26	32
100 Ni	0.43	0.23	549	2.25	3.58	0.49	23.2	7.0	146	44	50
200 Ni	0.14	0.27	1272	1.63	3.55	0.74	20.1	6.3	181	63	118
300 Cd	0.20	0.29	498	2.49	5.15	0.81	15.1	2.7	108	73	64
600 Cd	0.11	0.37	1243	1.92	6.52	1.02	17.3	6.7	303	75	123
F value	52.2**	1.3	5.6	0.9**	11.2**	11.4	0.4	4.6*	5.2*	1.1	92.9**
LSD 0.05	0.15	NS	500	NS	1.36	0.24	NS	2.3	108	NS	13
LSD 0.01	0.22	NS	702	NS	1.91	0.34	NS	NS	NS	NS	18
STEM											
Control	0.29	0.19	934	3.05	0.84	0.26	17.4	5.8	53	8	21
100 Ni	0.21	0.12	1713	2.06	0.76	0.29	10.1	3.2	66	9	20
200 Ni	0.06	0.13	5375	1.35	1.07	0.52	14.6	3.4	157	20	25
300 Cd	0.05	0.12	9377	2.38	1.20	0.43	14.3	2.9	101	10	26
600 Cd	0.04	0.22	7255	1.97	1.28	0.63	34.9	4.5	137	25	36
F value	59.7**	7.3**	3.3*	4.2*	4.0*	14.2**	6.9**	16.8**	21.0**	3.0	11.4**
LSD 0.05	0.05	0.05	6071	0.94	0.34	0.13	11.3	0.9	30	NS	6
LSD 0.01	0.07	0.07	NS	NS	0.48	0.18	15.8	1.3	42	NS	9

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significantly. The relative dry weight of stems on a percent basis (control = 100%) was 21.3% and 14.7% for Acala SJ-2 cultivar and 18% and 12.8% for Giza 45 cultivar respectively. The decrease in dry weight in Giza 45 cultivar in general was greater than the decrease in Acala SJ-2 cultivar. This means that the Acala SJ-2 cultivar is more tolerant than Giza 45 cultivar to both Cd and Ni. This result is not unusual because they are actually different species.

Adding Ni to the soil with Acala SJ-2 cultivar increased Na, Zn, Fe, B, Al, Si, Ni, Sr and Li in the leaves and decreased K, Ba and Co. In stems Ni increased Fe, Al, Si, Ni, Sr and Mg (for 100 μg/g); it decreased P, K, Ca, Cu, Ba and Li. In Giza 45 Ni increased Na, Mg, B, Al, Si, Ni, Sr and Li and decreased Mo and Ba in leaves. In Giza 45 stems there was increased Mg, Fe, Al, Si, Ni, V, Cr, Sr and Li while there was decreased P, K, Cu and Ba for Ni.

TABLE 2 (Continued)

n	B	Al	Si	Ti	V	Co	Ni	Mo	Cr	Sr	Ba	Li	Cd
n 'g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g	μg/g
						LEAF							
3	32	30	284	20.7	2.9	1.5	1.2	4.7	1.0	170.5	72.8	4.7	<3.0
4	50	47	495	15.4	2.8	1.5	49.3	1.5	1.0	217.8	28.6	5.6	<3.0
3	118	130	1105	36.1	3.5	1.5	165.0	1.5	1.2	236.0	22.4	8.4	<3.0
3	64	81	889	37.7	2.9	1.5	1.7	1.6	1.3	289.3	25.0	9.3	62.9
5	123	490	2123	64.0	4.8	1.5	3.3	1.5	1.9	374.3	27.8	11.4	411.8
1	92.9**	5.1*	10.8**	2.7	3.6*	00	151.2**	4.6*	5.4**	9.5**	26.7**	18.1**	93.0**
3	13	259	669	NS	1.4	NS	17.7	2.0	0.5	77.5	12.5	2.0	56.8
3	18	NS	938	NS	NS	NS	24.8	NS	0.8	108.7	17.6	2.8	79.7
						STEM							
8	21	18	106	8.1	2.1	1.5	1.7	2.0	0.7	91.7	58.0	2.5	<3.0
9	20	28	157	16.0	1.8	1.5	13.2	1.4	0.5	100.2	24.4	2.6	<3.0
0	25	79	396	62.5	3.7	1.5	84.5	1.0	0.9	178.3	24.5	3.9	<3.0
0	26	72	348	150.7	3.0	1.5	2.9	1.8	0.8	178.5	28.6	4.9	113.9
5	36	107	444	120.9	3.8	1.5	3.7	0.8	0.7	226.5	26.6	7.5	806.8
0	11.4**	11.8**	11.2**	2.8	9.0**	00	29.6**	2.1	3.7*	17.3**	17.9**	125.2**	29.6**
S	6	33	138	NS	1.0	NS	20.2	NS	0.2	42.6	10.5	0.6	199
S	9	47	193	NS	1.3	NS	28.3	NS	NS	59.7	14.6	0.8	278

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The Cd resulted in increases in Na, Ca, Mg, Zn, Fe, Mn, B, Al, Si, Cr, Sr, Li and Cd in leaves of Acala SJ-2, while there was decreased K, Cu, Co and Ba. In Acala SJ-2 stems there was an increase in Na, Mg, Zn, Fe, Mn, B, Al, Si, Sr and Cd, while there was a decrease in K, Cu and Ba. Giza 45 cultivar analysis indicated that in leaves there was an increase in Na, Ca, Mg, Fe, B, Al, Si, V, Cr, Sr, Li and Cd, while there was a decrease in Cu (for 300 μg Cd/g soil only) Mo and Ba. The Giza 45 stem analyses indicated increased Na, Ca, Mg, Zn, Fe, B, Al, Si, V, Sr, Li and Cd, while there was a decrease in P (in low Cd), K, Cu and Ba. Mn in these plants was not depressed by Cd like it has been reported for some other species (9, 11) or in solution culture (5).

The differential effect of the added soil Ni and Cd was estimated by determination of the value of Y in the expression: $\left(\frac{C1}{C2}\right)^Y$ = uptake ratio (8). Values of Y near ln 2 (0.693) indicate possible barriers to uptake while values of 1.0 indicate no barrier to uptake (8).

For Ni the values of Y for leaves of stems combined were 1.43 and 1.87 for Acala SJ-2 and Giza 45 respectively. For Cd they were 1.78 and 2.83 for the 2 cultivars respectively. These values are all well over 1.0. These high values may indicate non-metabolic uptake factors, very high affinity for transport to leaves, or most likely, differential soil fixation of the metals according to concentration applied. This latter is surmised because when these metals were applied in solution culture with cotton (5) the values of Y were about 0.62.

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