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Interactions of Lead and Cadmium on Metal Uptake and Growth of Corn Plants[1]

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ABSTRACT

Short term plant accumulation and growth effects of Pb and Cd added to soil separately and in combination were investigated with corn (*Zea mays* L., Wf9 × M14) grown in a loamy sand under greenhouse conditions. A tendency for soil Pb to increase both the plant Cd concentration and the total Cd uptake of the corn shoots was observed. Conversely, soil Cd reduced the total Pb uptake and in some cases the Pb concentration in the corn shoots. Both Pb (125 and 250 μg/g soil) and Cd (2.5 and 5 μg/g soil) reduced the vegetative growth of the corn shoots, and a positive interaction of the two metals on growth was noted.

Additional Index Words: ion uptake, plant toxicity.

Accumulation of the elements Pb (Cox and Rains, 1972; John and Van Laerhoven, 1972) and Cd (Page et al., 1972; Turner, 1973) has been documented for numerous plant species. Of the two elements, Cd is more readily taken up by plants from soil as indicated by the studies of Giordano et al. (1975) with corn (*Zea mays* L.) and Lagerwerff (1971) with radish (*Raphanus sativus* L.). That Cd is more readily translocated than Pb from root to shoot is also apparent by comparison of the work of Root et al. (1975) on Cd uptake by corn and Broyer et al. (1972) on Pb uptake by bean (*Phaseolus vulgaris* L.), barley (*Hordeum vulgare* L.) and tomato (*Lycopersicon esculentum* L.). Lagerwerff (1971) made similar observations with a root crop (radish).

The potential for plant toxicity is probably as great for Pb as for Cd as illustrated by its effects on isolated mitochondria (Bittell et al., 1974); however, the tendency for Pb to be immobilized in the soil (Hassett, 1974) and plant (Malone et al., 1974) reduces the hazard of Pb to plants.

With the exception of recent studies dealing with Cd and Zn interaction (Haghiri, 1974) and the uptake of trace metals from sewage sludge (Dowdy and Larson, 1975; Giordano et al., 1975; Sabey and Hart, 1975), the majority of published reports deal with the uptake and effects of a single metal. It is rare in cases of trace element contamination of soil that only a single metal is observed to be elevated. Knowledge of the behavior and effects of the individual metals is an integral part of understanding their importance as environmental contaminants; however, in view of the known interactions of mineral nutrients (Gauch, 1972) and elements in sewage sludge (Hinesly et al., 1974)[3] with regard to uptake, it is important that studies be undertaken to reveal possible interactions.

Earlier work concerning a Pb and Cd interaction on corn root growth (Hassett et al., 1976) suggested that a study of possible interactions of these metals with regard to uptake and plant growth was warranted.

METHODS AND MATERIALS

Corn plants (*Zea mays* L., Wf9 × M14) were planted in 15.2 by 15.2 cm plastic pots containing Bloomfield loamy sand (Psammentic Hapludalf) which had a cation exchange capacity of 2.3 meq/100 g soil, a Bray P1 test of 140 kg P/ha, and a pH of 6.0. After emergence the plants were thinned to 10 per pot. The plants were grown in a greenhouse with a 14-hour controlled daylength, and were watered daily with a measured amount of distilled water taking care that the metals were not leached from the soil.

The experiment was a factorial design with added soil Cd concentrations of 0, 2.5, and 5 μg/g of soil and soil Pb concentrations of 0, 125, and 250 μg/g of soil. Each treatment was replicated three times. The metals were added as solutions of the chloride salts and were thoroughly mixed with the soil. The soils were brought close to field capacity and allowed to dry four times to allow reaction of the metals with the soil prior to planting.

The corn shoots were harvested at 10, 17, 24, and 31 days after emergence and washed with deionized water to remove any surface contamination. At 10 days, four plants were harvested and two were harvested at the remaining time periods. Plants were dried at

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Table 1—The effects of two levels of soil-applied Pb on the concentrations of Cd and the uptake of Cd in corn shoots at 10, 17, 24, and 31 days after emergence

Soil Pb	Soil Cd	1A Days 10	17	24	31	1B Days 10	17	24	31
μg/g	μg/g	plant Cd, μg/g							
0	2.5	53	47	24	14	4	12	15	16
	5	107	102	58	34	9	24	28	33
125	2.5	96	32	47	30	8	18	22	24
	5	264	169	85	52	17	29	30	43
250	2.5	90	72	49	29	7	15	21	27
	5	159	127	76	41	14	20	24	41

50C, weighed and ashed at 450C for 4 hours, allowing 4 hours for the oven to heat from the ambient room temperature. Previous experiments by Root et al. (1975) established that wet ashing gave similar results. The ash was dissolved in 10 ml of 3N HCl prepared from constant boiling HCl. Metal concentrations were determined by atomic absorption by the procedure of Root et al. (1975).

RESULTS AND DISCUSSION

The concentrations of Cd in corn shoots (μg/g dry weight) were increased at all harvest times by Pb amendment of the soil (Table 1A). In most cases the highest shoot Cd concentrations occurred at the 125 μg Pb/g soil level. Variance analysis indicated significance for the soil Pb effect on shoot Cd concentrations for all time periods, while the interaction of soil Pb and Cd was significant at 10, 17, and 24 days (Table 3). Shoot Cd concentrations declined with time even though total Cd uptake (μg/shoot) was greater at each successive harvest (Table 1B). This is an indication that Cd uptake was not keeping pace with plant growth or Cd was becoming less available with time, since it was determined that soil Cd concentrations were not substantially reduced by the plants during the course of the experiment.

Since the soil Pb concentrations used in this experiment caused stunting of the corn shoots (Table 4), it might be inferred that the Pb effect on plant Cd concentrations was only the result of decreased plant size resulting in greater concentrations of Cd in the tissue. That this is not the total explanation is illustrated by the fact that soil Pb tended to increase Cd uptake on an individual plant basis (Table 1B). This effect of soil Pb was significant at the 10-, 17-, and 31-day harvest periods, while the interaction of soil Pb and Cd was significant at 10, 24, and 31 days (Table 3).

Conversely, when considering the effect of soil Cd on plant Pb uptake and concentration a general reduction is evident (Table 2). The reduction in Pb uptake due to soil applied Cd (Table 2) was significant at all harvest times, while the soil Pb and Cd interaction was significant at 17 and 31 days (Table 3). This effect of soil Cd was probably, in large part, a secondary effect due to Cd stunting of corn shoot growth and the concomitant reduction of ion uptake. However, when shoot Pb was expressed on a concentration basis the tendency for lower tissue Pb concentrations was still evident in the 250 μg Pb/g soil treatments (Table 2A). Variance analysis of these data alone showed significance at the 5% level for the 10, 17, and 31 day harvest periods. This is especially interesting since

Table 2—The effects of two levels of soil-applied Cd on the concentration of Pb and the uptake of Pb in corn shoots at 10, 17, 24, and 31 days after emergence

Soil Cd	Soil Pb	2A Days 10	17	24	31	2B Days 10	17	24	31
μg/g	μg/g	plant Pb, μg/g							
0	125	359	294	242	152	43	107	200	217
	250	266	396	372	452	24	80	210	413
2.5	125	310	355	225	185	25	76	107	150
	250	168	365	374	282	14	75	157	267
5.0	125	401	350	180	142	26	59	64	116
	250	154	331	362	299	11	51	128	260

stunting of plant growth often leads to a concentration of mineral elements in plant tissues (Gauch, 1972). No consistent effect of soil Cd on shoot Pb concentrations was evident in the 125 μg Pb/g soil treatments (Table 2A). Analysis of the data from both soil Pb treatment levels within harvest times indicated significance of the Cd effect only at 31 days, and significance for the Pb and Cd interaction at 17 and 31 days (Table 3). It is interesting to note that plant size across soil Cd levels was more uniform with the 250 μg Pb/g soil treatment and, thus, the Cd effect at this Pb level may have a more direct bearing on the consideration of Cd effects on Pb uptake.

Plant Cd concentration and uptake were not significantly affected by Pb in soils not amended with Cd, nor did Cd affect plant Pb levels in soils not amended with Pb. The Cd concentrations ranged between 0.4 and 1.8 μg/g dry weight, and Pb between 2.5 and 5.1 μg/g dry weight in plants grown on soils not amended with the metals. Also, it should be noted that the concentrations of the metals in the plants grown on metal-amended soils are higher than those commonly reported in the literature. One reason for this is that the loamy sand used in this experiment had a relatively low cation exchange capacity (2.3 meq/100 g soil) which results in greater plant uptake of Pb and Cd at a given metal concentration than would occur from finer textured soils (Miller et al., 1975; Miller et al., 1976).

The early stage at which the plants were sampled was also a consideration, as it can be seen that Pb and Cd concentrations within the plants generally declined with time (Tables 1 and 2).

Although it is not true for all metal levels or growth periods it appears that there is a tendency for soil Cd to reduce the shoot concentration of Pb and for soil Pb to increase the shoot concentration of Cd in soils amended with Pb and Cd. Elucidation of the mechanisms resulting in these observations is difficult in that events in the soil,

Table 3—Significance of soil Pb, soil Cd, and their interaction on Pb and Cd uptake, concentration, and the dry weight of corn shoots

	Time period, days 10 Pb	Cd	Pb × Cd	17 Pb	Cd	Pb × Cd	24 Pb	Cd	Pb × Cd	31 Pb	Cd	Pb × Cd
Cd uptake	*	**	*	*	**	–	–	**	*	**	**	*
Cd concentration	**	**	**	**	**	**	**	**	**	**	**	–
Pb uptake	**	*	–	**	**	**	**	**	–	**	**	**
Pb concentration	**	–	–	**	–	**	**	–	–	**	**	**
Dry weight	–	**	–	**	**	*	**	**	**	**	**	**

*, ** Significant at 5% and 1% level, respectively.

at the soil-root interface and within the plant are all relevant considerations. It is not difficult to understand the effect of one metal in reducing the uptake of the other due to competition for uptake, as this is well documented (Gauch, 1972). Although Cd was present in the soil at much lower concentrations than Pb, it would likely be an effective competitor with Pb for uptake due to its greater soil "availability" (Lagerwerff, 1972). Also, Cd has been shown to reduce transpiration of corn leaves (Bazzaz et al., 1974), which may result in less translocation of Pb from the soil and roots to the shoots.

The reasons for the observed tendency for soil Pb to increase corn shoot Cd concentrations and uptake are less obvious and only speculative. One might speculate that Cd concentrations in the soil solution, and thus in the plant, are elevated by Pb as it has been shown that Pb more effectively competes for exchange sites on colloidal surfaces than Cd (Bittell and Miller, 1974). Previous experimentation with Pb-Cd interactions on growth and metal accumulation by 5-day-old corn plants indicated that both metals had a tendency to increase the other's concentration in the roots (Hassett et al., 1976). If that were the case in these experiments, it would be reasonable to expect greater Cd concentrations in the shoot due to Pb treatment, in that Cd is relatively mobile in the plant. One would not expect Pb concentrations to be similarly higher in the shoot, even though it may be in the roots, due to its known immobility in the plant. Unfortunately, metal analysis on root material were not obtained in the experiment since previous experience indicated serious errors due to surface contamination of the roots.

With the exception of Pb at the 10-day period, both Pb and Cd significantly (1% level) reduced the growth of corn shoots (Table 4). The negative interaction which was previously observed in the case of corn root elongation (Hassett et al., 1976) was not found with corn shoot growth. In fact, positive interactions (5% level) on shoot growth were observed at 17, 24, and 31 days. It might be inferred that the soil Cd reduction of Pb uptake is related to the apparent positive interaction on growth, except that shoot Cd was elevated by soil Pb. It is more likely that the explanation lies in the fact that plant growth was severely retarded by either of the metals singly, and the added burden of the other metal did not cause a growth inhibition comparable to its effects on a healthy plant. The response of plant growth to heavy metals is rarely a linear function of metal concentration, over an extended range of concentrations (Root et al., 1975). One might also speculate, in view of observed similarities in the mechanisms of physiological action of Pb and Cd (Bittell et al., 1974), that there is a competition between the two metals for physiologically active sites.

Table 4—The influence of Pb and Cd on the dry weight of corn shoots over time

Metal, Pb-Cd	Time period, days			
	10	17	24	31
— μg/g soil—	dry weight, g/plant†			
0–0	0.11	0.44	1.19	1.56
0–2.5	0.08	0.26	0.83	1.12
0–5	0.08	0.24	0.49	0.83
125–0	0.12	0.36	0.84	1.35
125–2.5	0.08	0.21	0.47	0.82
125–5	0.06	0.17	0.36	0.84
250–0	0.09	0.20	0.54	0.91
250–2.5	0.08	0.21	0.43	0.97
250–5	0.07	0.15	0.32	0.37
L.S.D. (0.01)	±0.02 g	±0.07 g	±0.17 g	±0.21 g

† Values are the means of three replicates.

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