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INTERACTION OF LEAD AND CADMIUM ON MAIZE ROOT GROWTH AND UPTAKE OF LEAD AND CADMIUM BY ROOTS

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ABSTRACT

Radicle elongation of soil-grown maize seedlings was depressed by concentrations of 25 μgCd/g of soil or 250 μgPb/g of soil when the metals were added singly. When Pb and Cd were added in combination inhibition of radicle elongation occurred at significantly lower concentrations. The effect of the metals when added in combination was greater than the sum of effects when the metals were added singly, thus strongly suggesting a synergistic interaction. The effect was partially attributed to elevated accumulation of the metals in combination treatments.

INTRODUCTION

A number of studies have indicated that Pb and Cd are accumulated by plants through their root systems (Ter Haar *et al.*, 1969; Baumhardt & Welch, 1972; Cox & Rains, 1972; John, 1972; John & Van Laerhoven, 1972; John *et al.*, 1972; Haghiri, 1973; Jones *et al.*, 1973; Lagerwerff *et al.*, 1973; Miller *et al.*, 1975*a,b*, 1976; Rolfe, 1973). With soil-grown plants high concentrations of Pb in the soil are necessary before sufficient accumulation occurs to cause an observable toxic response. For example, Pb acetate at over 1000 μgPb/g did not affect height or morphology of maize grown on a silt loam soil, while in sand culture levels as low as 240 μgPb/g severely retarded the growth of maize (Miller & Koeppe, 1971). The difference is probably due to the capacity of soil to bind Pb and/or the formation of relatively insoluble salts (Hassett, 1974; Miller *et al.*, 1975*a,b*). The situation with Cd is similar, but it is less readily immobilised by soil and thus more readily available to plants (Miller *et al.*, 1976).

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The majority of studies concerning the phytotoxicity of soil-applied metals have dealt with only single metal effects, yet in the natural state, the plant may be exposed to abnormally high concentrations of a number of metals. For example, elevated levels of Cd, Pb, Zn and Ni in soil bordering heavily travelled roads have been reported (Lagerwerff & Specht, 1970). In that study concentrations as high as 522 μgPb/g and 1·45 μgCd/g were found in the same soil close to the roadway. Although concentrations of Pb and Cd much higher than this have been observed in some situations, these values are probably representative of the conditions in the roadside fringes of some agricultural land.

In the work reported here the effects of Pb and Cd, added singly or together, on the elongation of maize roots and on the uptake of Pb and Cd by such roots were studied. In preliminary experiments it was determined that neither percent germination nor shoot growth were the most sensitive indicators of Pb or Cd toxicity, but that root elongation provided the earliest morphological evidence of injury.

METHODS

Maize (*Zea mays* L., Wf9 X M14) was grown in flats containing Bloomfield loamy sand (Psammentic Hapludalf) that had been treated with $PbCl_2$ and $CdCl_2$ at the indicated concentrations. The metals were added as solutions and allowed to react with the soil for a week before planting. The soil had 2·1 % organic matter, a cation exchange capacity of 2·3 me/100 g, a Bray P_1 test of 56 and a pH of 6·5. It had a binding capacity, as measured by absorption isotherms and leaching experiments, of 9·7 μmole Pb and 5·2 μmole Cd/g soil.

Fifty maize seeds were planted per treatment and watered daily with distilled water. On the third day and at daily intervals for four days thereafter, 10 seeds were removed from each flat and the length of the radicle measured. The roots were cleaned by rinsing in distilled water, detergent, distilled water, three times in 0·1N HNO_3 and then again in distilled water. This procedure has been shown effectively to remove surface-sorbed metals. The roots were dried, then dry-ashed in a muffle furnace at 490°C, allowing 4 h to heat from ambient to 490°C. The ash was taken up in 3N HCl that had been diluted from constant boiling HCl. Lead and Cd were determined by atomic absorption spectroscopy and background correction by measuring the absorption of close lying, non-selective alternate lines.

RESULTS AND DISCUSSION

The effects of Pb and Cd when added singly on the elongation of maize roots at the fifth day after germination are shown in Table 1. Measurements made on the four days prior to this showed a similar trend. Significant inhibition of root

TABLE 1

EFFECTS OF Pb AND Cd ON ELONGATION OF MAIZE ROOTS IN LOAMY SAND. VALUES ARE THE MEAN OF 10 MEASUREMENTS MADE ON THE FIFTH DAY AFTER GERMINATION WITH STANDARD DEVIATIONS

Pb		*Cd*	
Added Pb (*μg/g soil*)	*Root length* (*cm*)	*Added Cd* (*μg/g soil*)	*Root length* (*cm*)
0	12·00 ± 1·54	0	11·21 ± 2·05
100	11·61 ± 1·28	2	10·21 ± 1·48
250	9·74 ± 2·33	5	12·83 ± 2·09
500	6·28 ± 1·27	10	11·21 ± 1·45
1000	0·67 ± 0·23	15	10·07 ± 1·60
2000	0·21 ± 0·07	25	6·38 ± 1·83
		50	3·23 ± 0·67
	LSD(1%) = 1·09	100	1·50 ± 0·34
			LSD(1%) = 2·77

elongation did not occur at Pb concentrations below 250 μgPb/g soil nor at Cd concentrations below 25 μgCd/g soil. By use of non-toxic salts it was determined that osmotic inhibitions of root elongation did not occur except at the two highest Pb concentrations. In a separate experiment in the presence of both Pb and Cd (Fig. 1) there was a significant decrease in root elongation at levels of Pb and Cd that alone had little or no effect. A similar relationship was obtained for the dry

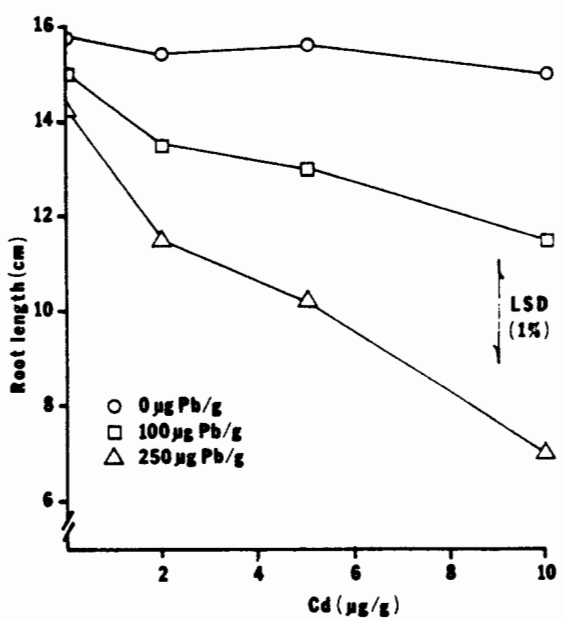

Fig. 1. Combined effects of Pb and Cd on elongation of maize roots. Values are the mean of ten measurements made on the fifth day after germination.

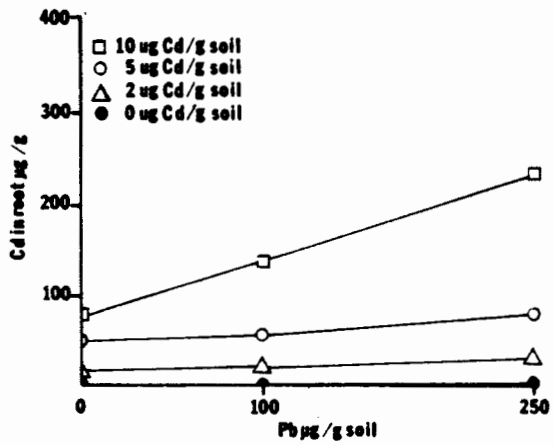

Fig. 2. The effect of added Pb on the concentration of Cd in maize roots at different Cd levels on the fifth day after germination.

weight of the roots versus metal concentration. When the metals were added together the magnitude of inhibition was greater than the sum of the inhibitions when the metals were added separately, thus suggesting a synergistic interaction.

The effect of the interaction of Pb and Cd on their concentration in maize roots is shown in Figs. 2 and 3. Combinations of 100 μgPb/g or 250 μgPb/g with 10 μgCd/g resulted in an increase in the concentration of Cd (Fig. 2). Combinations of 5 and 10 μgCd/g with 250 μgPb/g doubled the concentration of Pb in the young

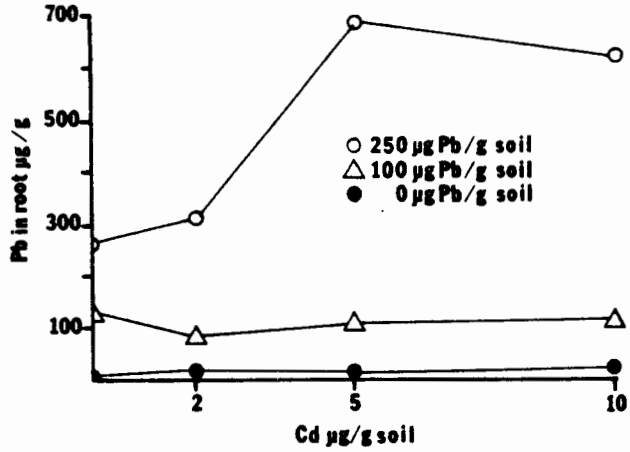

Fig. 3. The effect of added Cd on the concentration of Pb in maize roots at different Pb levels on the fifth day after germination.

maize roots (Fig. 3). Cadmium had little effect at the other Pb levels even though the combination of 10 μgPb/g had increased the Cd concentration.

The reasons for the apparent interaction of Pb and Cd on maize root elongation appear to be, at least in part, due to the elevated metal concentrations found in the roots at the higher treatment combinations. It is possible that at the higher metal concentrations the selectivity of the cell membranes was reduced, thus allowing more rapid entry of the metals. Both Pb and Cd affect mitochondrial membrane permeability (Bittel *et al.*, 1974). In addition, recent results show that both Pb and Cd reduce the respiration rates of root tip segments (D. E. Koeppe, details to be published later). Although the interaction of Pb and Cd on root elongation may be primarily due to the observed effects on metal uptake, the possibility of physiological interactions cannot be overlooked. The synergistic inhibition of respiration of *Chorella vulgaris* by fluoride and copper was attributed to effects on separate metabolic pathways (Hassall, 1967), since the inhibition of either pathway separately did not impair the rate of respiration. Regardless of the reasons for the observed Pb–Cd interactions, it is apparent in studies of heavy metal toxicity related to environmental effects that possible metal interactions need to be considered.

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