GROWTH REDUCTION IN AMERICAN SYCAMORE (PLANTANUS OCCIDENTALIS L.) CAUSED BY Pb-Cd INTERACTION

ROGER W. CARLSON & F. A. BAZZAZ
Department of Botany and Institute of Environmental Studies,
University of Illinois, Urbana, Illinois 61801, USA

ABSTRACT

Seedlings of American sycamore (Plantanus occidentalis L.) were grown in Drummer silty clay loam soil treated with various concentrations of Pb, Cd, or Pb plus Cd. Plant growth and heavy metal content were measured at the end of 90 days. Heavy metal accumulation by plant parts increased with soil treatment levels but was much lower than values previously reported in the literature. Root growth, woody stem diameter increment, new stem growth and foliage growth were found to be synergistically affected by the Pb–Cd treatment. Whilst treatment with Pb or Cd alone caused a reduction in photosynthesis and transpiration, the addition of Cd to Pb-treated plants did not reduce rates of photosynthesis and transpiration below that observed for plants treated with Pb alone. A method is proposed to quantitate the concept of synergism.

INTRODUCTION

Pb and Cd are two important environmental contaminants which arise from certain mining and manufacturing operations (Buchauer, 1973; Cox, 1974), as well as from the combustion of fossil fuels used in transportation and other energy conversion processes (Cannon & Bowles, 1962; Singer & Hanson, 1969; Chow, 1970; Daines et al., 1970; Lagerwerff & Specht, 1970; Motto et al., 1970; Page et al., 1971; Smith, 1971; MacLean & Langille, 1973; Noller & Smythe, 1974). A wide variety of plants have been shown to be sensitive to contamination with Pb (Lagerwerff, 1971; Bazzaz et al., 1974a, 1975; Huang et al., 1974; Rolfe & Bazzaz, 1975) and Cd (Allaway, 1968; Lagerwerff, 1971; John et al., 1972; Lagerwerff & Bierdsorff, 1972; Page et al., 1972; Haghiri, 1973; John, 1973; Turner, 1973; Bazzaz et al., 1974a, b; Huang et al., 1974; Carlson et al., 1975).
amount of Pb translocated to leaves of maize and soybean plants during a longer treatment period of 2-4 weeks was significant and caused substantial reduction in photosynthesis (Bazzaz et al., 1974c) as well as several other metabolic processes (Huang et al., 1974). Pb has also been found to reduce photosynthesis in seedlings of loblolly pine (Pinus taeda L.) and autumn olive (Elaeagnus umbellata Thunb.) grown for 7 weeks in a Pb-contaminated medium of 1 part soil, 1 part sand and 1 part peat moss (Rolfe & Bazzaz, 1975).

All these studies have dealt with single element effects. However, since Pb and Cd are both frequently found in high concentrations at the same location (Lagerwerff & Specht, 1970; Lagerwerff, 1971; Buchauer, 1973; Natusch et al., 1974), it is necessary to determine the extent of any interaction that might exist between the two heavy metals as it affects plant growth. Furthermore, other environmental contaminants, e.g. ozone and sulphur dioxide, have been found to act synergistically in combined treatment (Menser & Heggestad, 1966; Dochinger & Heck, 1969; Dochinger et al., 1970; MacDowall & Cole, 1971; Banfield, 1972; Costonis, 1973).

The only examples of a synergistic interaction between heavy metals and plant growth are those published by Miller et al. (1974) and Hassett et al. (1976), who found root growth to be synergistically reduced by treatment with Pb and Cd.

In this study we examine the effect of Pb and Cd both separately and together on the growth and photosynthesis of American sycamore (Platanus occidentalis L.) seedlings grown for 90 days in a rich agricultural soil. The species is a common urban tree in several areas of the eastern and midwestern United States.

METHODS

Dormant two- to three-year-old saplings of American sycamore were obtained from the Union Tree Nursery in Jonesboro, Illinois, selected for uniformity in size of root system and prepared for experimental use by trimming off terminal and lateral branches to leave a single stem approximately 30 cm long.

Soil was collected from the A-horizon of a Drummer silty clay loam on the University of Illinois experimental farms at Urbana. After being air-dried it was processed with a soil shredder-grinder to break up large clumps and then passed through a 0.96-cm mesh screen. A preweighed amount of heavy metal was added to 2.5-kg portions of a soil mixture containing 1 part 'Perlite' and 6 parts of soil by volume and placed in free-draining 3-litre plastic pots. The addition of heavy metal to soil was done for each pot separately to give treatment levels of 0, 50, 100, 250, 500 and 1000 μg/g Pb as PbCl₂, 0, 5, 10, 25, 50 and 100 μg/g Cd as CdCl₂ and a combined treatment of 50 + 5, 100 + 10, etc. for Pb + Cd, respectively. After metal addition the pots were wetted to saturation and allowed to air-dry for 6 cycles over the following 3 weeks. The sycamore saplings were transplanted into the pots on 18 July. Over the course of the experiment, glasshouse daytime air temperature...
The amount of Pb in new stems increased with treatment concentration in plants treated with Pb alone. However, in plants treated with both Pb and Cd, new stem Pb content increased with soil concentration at low treatment levels but declined at higher levels. For plants treated with Cd alone, the Cd content of new stems increased to 4 μg/g at a treatment level of 25 μg Cd/g soil and did not change with higher treatment concentration. A similar trend was observed for the amount of Cd in new stems at the lower concentrations of the combined treatment. However, at the highest treatment level the amount of new stem Cd for the combined treatment was more than twice that of the plants treated with Cd alone.

The Pb content of woody stems was greater at high treatment levels for plants treated with Pb alone than for the combined treatment. Conversely, the relationship between Cd content of woody stems and treatment concentration of plants treated in Cd alone was similar to that of the combined treatment.
experiment died and were therefore excluded from the data analysis. Standard deviations varied from 17 to 38% of the mean, indicating a large variability between individual plants. A high degree of variability was also present in the data for plants treated with heavy metals and has, to a certain extent, hampered data interpretation by obscuring some treatment effects.

To enable direct comparison between growth parameters, the growth datum for each observation was expressed as a per cent of the average value obtained for control plants. The data are summarised in Fig. 2, where each point represents the mean of 3 to 5 replications.

Inspection of Fig. 2 reveals a general pattern for all growth parameters in the relationship between treatment concentration and growth reduction. That is, treatment with either Pb or Cd alone caused a reduction in each growth parameter to

![Graph](image)

**Fig. 3.** Relationship between soil heavy metal concentration and gas exchange rates of leaves having a leaf plastochron age (LPA) of 2 (see text for discussion of LPA). Treatments are identified and Gx Pb + Cd calculated as for Fig. 2.
The value of \( G_{e} \) is plotted in Fig. 2 for each growth parameter. Diameter growth, foliage growth and new stem growth of sycamore seem to be synergistically affected by the combined Pb plus Cd treatment at Pb/Cd soil concentrations greater than 250/25. Root growth follows the same trend except for the 500/50 Pb/Cd treatment. A synergistic response of Pb and Cd has been observed by Miller et al. (1974) for maize root elongation at much lower soil treatment levels. However, in their study they used a sandy soil having a much lower binding capacity for Pb than the silty clay loam soil used in the present study.

The measured effect of the combined Pb plus Cd treatment on photosynthesis is either less than, or equal to, the expected effect calculated from the effect of each heavy metal alone (Fig. 3). However, photosynthesis of sycamore treated with Pb plus Cd combined is approximately equal at all soil concentrations to the rate of photosynthesis of plants treated with Pb alone. It thus appears that photosynthesis is reduced by Pb treatment to some lower level which is not reduced further by the addition of Cd to the soil. The addition of Cd to Pb-treated plants does, however, synergistically lower biomass accumulation in all plant parts. These results suggest whilst separate treatments with Pb or Cd alone cause some reduction in both carbon dioxide uptake and growth, the synergistic action of the combined Pb/Cd treatment takes place in biochemical steps converting the assimilated CO\(_2\) into dry matter.

In previous studies we have found a high degree of correlation between the rate of photosynthesis and leaf heavy metal content for both excised leaves (Bazzaz et al., 1974a, 1975) and whole plants (Bazzaz et al., 1974c, 1975; Carlson et al., 1975). We have found that a linear relationship is adequate to describe this relationship for intact plants. In this study photosynthesis was related to leaf heavy metal content by the following expression:

\[
P_{s} = 17.4 - 1.59X_{1} - 0.18X_{2} \quad r = 0.806
\]

where \( P_{s} \) is in units of mg CO\(_2\) dm\(^{-2}\) h\(^{-1}\), \( X_{1} \) = leaf Pb content in \( \mu \)g/g and \( X_{2} \) = leaf Cd content in \( \mu \)g/g. Thus only small amounts of Pb or Cd in leaf tissue can result in large reductions in the rate of photosynthesis.

**SUMMARY**

We have examined the effects of Pb and Cd in individual as well as combined treatment on various aspects of sycamore growth and have found:

1. That there is a low rate of heavy metal accumulation in shoots even at high treatment levels for silty clay loam soil.
2. That there is a significant reduction in root growth, diameter increment of new stems, new stem growth, foliage growth and photosynthesis at higher heavy metal concentrations for all treatments.
3. That a synergistic action of Pb and Cd exists on root growth, diameter rowth, new stem growth and foliage growth.
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