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# The effects of lead on photosynthesis, $^{14}C$ distribution among photoassimilates and transpiration of maize seedlings

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Abstract

Roots of whole 3 week-old seedlings of maize were exposed for 24 h to a solution of $PbCl_2$. The concentrations of Pb were: 0, 200, 400, 800, 1200, 2400 mg $dm^{-3}$. The amount of Pb taken up by roots was independent of the concentration of this element in the medium. The Pb taken up by shoots increased linearly with increasing treatment concentration. Pb caused: concentration-dependent inhibition of photosynthesis (PS), transpiration (T), $^{14}CO_2$ uptake and incorporation of label into photosynthetic products. The largest limitation by Pb of the flow of photoassimilated carbon occurred into starch and sugar phosphates. Among the water-soluble photoassimilates, the largest limitation of carbon flow occurred into organic acids and sugars and the smallest into amino acids.

*Key words*: *Zea mays L., lead, photosynthesis, photoassimilates, transpiration*

## INTRODUCTION

Numerous studies indicate the toxic effect of heavy metals on plants (see reviews: Woolhouse 1983, Clijsters and Van Assche 1985, Baszyński 1986). It has been reported that lead caused: disorganization of chloroplast ultrastructure (Rebechini and Hanzley 1974), inhibited the biosynthesis of chlorophyll (Hampp and Lendzian 1974, Burzyński 1985), reduced photosynthetic electron transport and photophosporylation (Miles et al. 1972), limited $CO_2$ fixation and activities of several enzymes of the reductive pentose phosphate cycle (Hampp et al. 1973a, b, Bazzaz et al. 1974, 1975, Carlson et al. 1975, Stribova et al. 1986) and reduced the growth of plants (Kacabova and Natr 1986). In a previous study (Poskuta et al. 1987) we observed that lead not only inhibited photosynthesis, photorespiration and transpiration in pea, but also altered the flow of photoassimilated carbon into the photosynthetic products. In literature there is a lack of information on the effects of lead on the photosynthetic carbon metabolism of $C_4$ plants, although such knowledge is important for deeper understanding the phytotoxicity of this pollutant. Therefore, in the study described below we examined the effects of the concentration of Pb on $CO_2$ uptake, distribution of $^{14}C$ among photosynthetic products and on transpiration of maize seedlings, i.e. in a $C_4$ type plant.

## MATERIALS AND METHODS

3-week-old seedlings of maize (*Zea mays* L.) cv. "Golden Bantham" were used as the experimental material. They were grown on Knop solution in 2 $dm^3$ plastic pots in a growth chamber with a 14 h photoperiod, 80% relative humidity and temperature of 26°C during the day and 18°C during the night. The solution in the pots was adjusted to pH 6.0 with 1 N KOH and continuously aerated. Photosynthetic photon flux density (PPFD 400-700 nm) was 15 W $m^{-2}$ provided by cool white fluorescent tubes. Similar sized seedlings in four replications were transferred for 24 h to the $PbCl_2$ solutions containing Pb at concentrations of: 0, 200, 400, 800, 1200 and 2400 mg $dm^{-3}$. In order to examine the possible effect of $Cl^-$, the seedlings were treated with the same concentration of KCl. These seedlings showed practically the same $CO_2$ exchange rates, as tested with an infra red $CO_2$ analyzer, as the control plants. The rates of photosynthesis, $^{14}CO_2$ uptake and transpiration were determined at PPFD 45 $Wm^{-2}$. The methods and procedure for measurements of photosynthesis, $^{14}CO_2$ uptake, transpiration and the distribution of $^{14}C$ among photoassimilates of 2 min. photosynthesis in $^{14}C$ (185 KBq) and content of Pb were described in a previous paper (Poskuta et al. 1987). Data were averaged and standard error calculated.

## RESULTS

### CONTENT OF Pb IN SEEDLINGS

There already was a rapid increase of Pb in roots at the concentration of 200 mg $dm^{-3}$ Pb in the solution. At this concentration, the content of lead in roots reached about 160 mg $kg^{-1}$ FW and then became independent of the concentration of this element in the medium of roots. In contrast the content of Pb in shoots increased almost linearly with increasing Pb concentration in the root medium (Fig. 1). As a result, the ratios shoot: root content of Pb in seedlings exhibited a straight-line relationship (Fig. 2). This provides evidence that the root was about a 20 to 50 times stronger sink for Pb than the shoot.

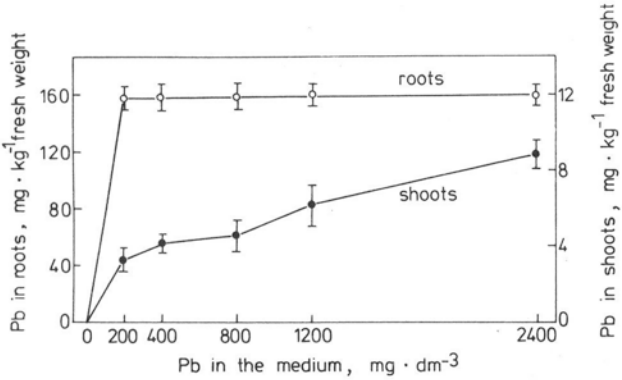


Fig. 1. The relationship between the amount of Pb accumulated by shoots and roots of maize seedlings and the concentration of Pb in the medium of roots. Bars represent SE of the means

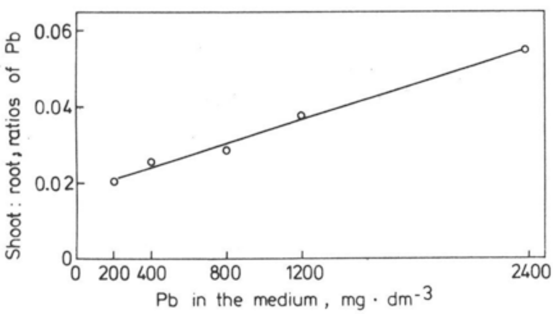


Fig. 2. The relationship between the Pb shoot:root ratios and the concentration of Pb in the medium of roots

THE EFFECTS OF Pb ON PHOTOSYNTHESIS, TRANSPIRATION, $^{14}CO_2$ UPTAKE AND ON DISTRIBUTION OF $^{14}C$ AMONG PHOTOSYNTHETIC PRODUCTS

It is evident that the percentages of inhibition by lead of both the $CO_2$ uptake rate as determined by an infra red $CO_2$ analyzer and of $^{14}CO_2$ uptake, were very similar. The inhibition of transpiration followed the pattern of photosynthesis but the magnitudes of inhibition of transpiration were markedly lower as compared with those of photosynthesis (Fig. 3, Table 1). The data of Table 1 indicate that there was markedly lower inhibition of $^{14}C$ incorporation into the water-soluble photoassimilates by lead as compared with water-insoluble ones. An exception was the magnitudes of inhibition by Pb at the concentration of 2400 mg $dm^{-3}$. As seen in Fig. 4, within the water-soluble photoassimilates after 2 min. of photosynthesis, the gross of radioactivity (45%) was located in organic acids whereas in sugars and amino acids, the percentages of label were similar (27.2 and 27.8% respectively). The

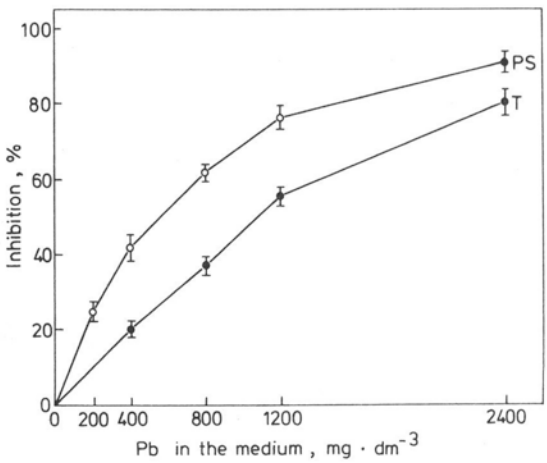


Fig. 3. The relationship between inhibition of photosynthesis (PS) and transpiration (T), and the concentration of Pb in the medium of roots. The processes are expressed as percentages of inhibition of the control values: PS — $6.9 \pm 0.3$ mg $CO_2 g^{-1}$ fresh weight $h^{-1}$, T — $160 \pm 12.3$ mg $H_2O$ $g^{-1}$ fresh weight $h^{-1}$

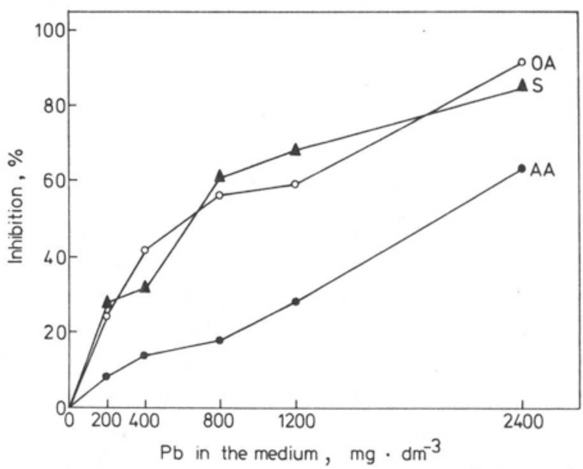


Fig. 4. The relationship between the inhibition of distributions of $^{14}C$ among organic acids (OA), sugars (S) and amino acids (AA) of shoots and the concentration of Pb in the medium of roots. The distributions are expressed as percentages of inhibition of control values (in KBq $g^{-1}$ fresh weight): OA — 112.3, S — 70.6, AA — 69.0

Table 1

The effect of Pb concentration on the distribution of $^{14}C$ among the products of 2 min. photosynthesis of maize shoots (in KBq $g^{-1}$ fresh weight)

| $^{14}C$ incorporation | Pb mg $dm^{-3}$ | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 200 | 400 | 800 | 1200 | 2400 |
| Total | 505.5±40.2 | 388.3±31.0 (23.2) | 295.2±20.6 (41.7) | 202.2±14.6 (60.0) | 163.6±12.3 (67.7) | 59.3±4.6 (88.3) |
| Water-soluble material | 253.5±18.6 | 215.0±19.6 (15.2) | 174.9±15.3 (31.0) | 133.2±10.2 (47.5) | 113.9±8.1 (55.1) | 32.0±2.9 (87.4) |
| Water-insoluble material (starch) | 221.5±20.5 | 152.4±10.8 (31.2) | 110.7±9.4 (50.1) | 62.5±5.1 (71.8) | 44.9±5.5 (79.8) | 27.3±1.8 (87.7) |
| Sugar phosphates | 30.5±2.9 | 20.8±1.9 (31.9) | 9.6±0.8 (68.8) | 6.4±0.4 (79.0) | 4.8±0.3 (84.3) | 0.0 (100.0) |

Percent of inhibition given in parentheses.

data of Fig. 4 and Table 1 indicate that there was a much stronger inhibition by lead of labeling of organic acids, sugar phosphates and sugars as compared with that of amino acids.

## DISCUSSION

The results of the present study show that Pb exerts a stronger inhibitory effect on photosynthesis than on transpiration of whole maize seedlings. The pattern of inhibition of both processes however was similar (Fig. 3). These results contradict the earlier observation of Bazzaz et al. (1975) who noticed higher sensitivity of transpiration to lead as compared with photosynthesis in maize leaves. We assume that the discrepancy is due to the different experimental approaches applied by the mentioned authors and in this study. In the experiment of Bazzaz et al. (1975), detached leaves were immersed with their cut ends in a solution of $PbCl_2$ for a relatively short period of time, whereas in the present study, the roots of whole seedlings were submerged in the lead solution for 24th. Furthermore, our data indicate that the roots of maize present an extremely large sink for Pb (Fig. 2). The straight line relationship between the shoot:root content of Pb and concentration of this element in the medium of roots, indicates that lead was transported from the root to shoot by an active mechanism. This conclusion is supported by the observation that the content of Pb in roots reached maximal values at the lowest root medium Pb concentration (Fig. 1). This observation can be interpreted as absorption of Pb by roots via passive diffusion (Foy et al. 1978). The inhibition of photosynthesis by lead was associated with considerable changes in the flow of photoassimilated carbon into photosynthetic products (Table 1, Fig. 4). The flow of carbon into photoassimilates was restricted at all of Pb concentrations used, with the greatest reduction occurring at the higher treatment levels. The lowest suppression of carbon flow by lead occurred into amino acids. It is reasonable to assume that the metabolism of amino acids represent a more resistant mechanism for Pb toxicity as compared with that of organic acids and carbohydrates. This supposition is consistent with recent observations which indicate only a slight effect of Pb on the content of protein in barley shoots (Stiborova et al. 1986). The alteration of Pb of the flow of photosynthetic carbon during its prolonged action should affect the transport and distribution of photoassimilates among plant organs. As a consequence not only growth can be suppressed but also the quality of plant yield as recently observed by Kacabova and Natr (1986).

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## *Wpływ ołowiu na fotosyntezę, rozdział znakowanych węglem-14 produktów fotosyntezy i na transpirację siewek kukurydzy*

### Streszczenie

Korzenie całych 3-tygodniowych siewek kukurydzy (*Zea mays* L.) odm. Golden Bantham zanurzono na 24 godz. w roztworach $PbCl_2$ w stężeniach Pb: 200, 400, 800, 1200 i 2400 mg $dm^{-3}$. Stwierdzono gromadzenie się ołowiu w korzeniach niezależnie od stężenia Pb w roztworze zewnętrznym. Gromadzenie się ołowiu w części nadziemnej siewek było prawie liniową funkcją stężenia tego pierwiastka w roztworze, w którym były zanurzone korzenie. Wykazano, że Pb hamował w tym samym stopniu fotosyntezę mierzoną przy użyciu analizatora $CO_2$ w podczerwieni, jak i za pomocą pobierania $^{14}CO_2$ i hamowanie było zależne od stężenia Pb. Hamowanie transpiracji w swoim przebiegu było podobne do hamowania fotosyntezy, ale rozmiary hamowania były mniejsze w porównaniu z fotosyntezą. Gromadzenie się ołowiu w pędach spowodowało także zmiany w metabolizmie węgla w fotosyntezie, polegające na mniejszym hamowaniu przepływu zasymilowanego węgla do kwasów aminowych w stosunku do kwasów organicznych, cukrów, fosforanów cukrów i skrobi.