ACTA SOCIETATIS
BOTANICORUM POLONIAE
Vol. 56, nr 2: 271-280
1987

The uptake and transpiration of water and the accumulation of lead by plants growing on lead chloride solutions

MAREK BURZYŃSKI

Department of Plant Physiology, Institute of Botany, University of Wrocław, Kanonia 6/8, 50-328 Wrocław, Poland

(Received: May 1986. Revision accepted: September 16, 1986)

Abstract

The placement of approximately two week-old bean, cucumber and wheat plants in $PbCl_2$ solutions caused significant decreases in transpiration and uptake of water. The amount of transpiration and water uptake depended on the $PbCl_2$ concentration and length of treatment. Cucumber plants were the most sensitive to lead and accumulated the greatest amounts of it. Beans were the least sensitive, although they accumulated more lead than wheat. The lead taken up by cucumbers and beans accumulated mainly in the roots while the distribution of lead in wheat was rather uniform in the roots and above-ground parts. The removal of roots from bean plants caused high accumulation of lead in the lower stem parts.

Key words: lead, uptake and transpiration of water, accumulation of Pb

INTRODUCTION

It was found in previous studies (Burzyński and Jakób 1983, Burzyński 1985) that lead limits the uptake of water by sunflower hypocotyl segments and that the lead taken up by cucumber seedlings influenced chlorophyll synthesis and caused a decrease in the hydration of their tissues. It caused a decrease in transpiration of excised corn and sunflower leaves (Bazzaz et al. 1974, 1975). It can be concluded on the basis of these papers that lead has a significant influence on the water balance of plants. It can be supposed that the disturbances in the water balance

induced by lead are the causes of secondary metabolic disorders because the metabolic processes taking place in plants are dependent to a large degree on the state of tissue hydration. According to Hsiao (1973), low hydration of tissues causes growth arrest, inhibition of the synthesis of structural elements of the cell, chlorophyll and of many enzymes, as well as influences changes in enzymic activity. Further consequences of poor hydration of tissues are the closing of stoma and a decrease in the intensity of photosynthesis.

The aim of this study was to examine the influence of increasing lead concentrations in an external solution on the water balance of several species of plants, and to find the relationship between the uptake of water accumulation of lead in roots and above-ground plant parts.

MATERIAL AND METHODS

The experiments were conducted using 16 day-old *Phaseolus vulgaris* (var. Fana) plants, 21 day-old *Cucumis sativus* (var. Wisconsin SMR) plants and 10 day-old *Triticum aestivum* (var. Grana) plants growing in Hoagland's medium of the following composition (in mM): KNO_3 — 5.0, $Ca(NO_3)_2$ — 5, KH_2PO_4 — 1.0, $MgSO_4$ — 2.0, Fe-$C_6H_5O_7$ — 0.09; with the addition of microelements (in μM): H_3BO_3 — 46.0, $MnSO_4$ — 8.0, $CuSO_4$ — 1.0, $ZnSO_4$ — 0.5, Na_2Mo_4 — 0.1; the pH of the medium was 6.0. The plants were grown and the experiments themselves were carried out in a phytotron with a photoperiod of 18 hrs of light ($15.3\ Jm^{-2}\ s^{-1}$) and temp. 26°C and 6 hrs of darkness at 22°C with a relative humidity of 50%.

Transpiration and water uptake were determined volumetrically and on a weight basis. Similar plants, grown as described above, were placed in calibrated cylinders containing $PbCl_2$ solutions (Figs. 1, 2). NaCl solutions were used as controls. The amount of water taken up was read from the scale on the cylinder, while the amount of water transpired was calculated from the differences in the starting and final weights of the unit. Twenty-five plants in three replicates were measured.

Short-term experiments were run on potometres. The plants were transferred to 10^{-3} M solutions of $PbCl_2$ and after 4, 8 and 24 hours transferred again to potometers filled with $PbCl_2$. The uptake of water was measured every 15 min for 1 hour. Eight potometers were set up each time for each species. The experiment was repeated three times.

The amount of accumulated lead in the root and shoot dry mass was determined using an AAS 1N atomic absorption spectrophotometer (Carl Zeiss, Jena).

RESULTS

Figure 1 shows the uptake of water by plants placed for 72 hrs in various lead concentrations. Lead at a concentration of 10^{-4} M only slightly lowered the uptake of water by cucumbers and wheat after 48 hrs, while not influencing at all the uptake by beans. A ten-fold greater concentration of lead caused a decrease in the uptake of water by all of the tested species, especially by cucumbers. In these plants, the uptake of water decreased by 50, 64 and 72 percent in comparison with the control after 24, 48 and 72 hours, respectively, of growth in solutions of lead. Lead chloride at a concentration of 10^{-2} M even more clearly inhibited the uptake of water by beans and wheat and killed the cucumbers. Concomitantly with the decreased water uptake, transpiration also declined (Fig. 2) in all of the studies species, starting from the lowest concentration of

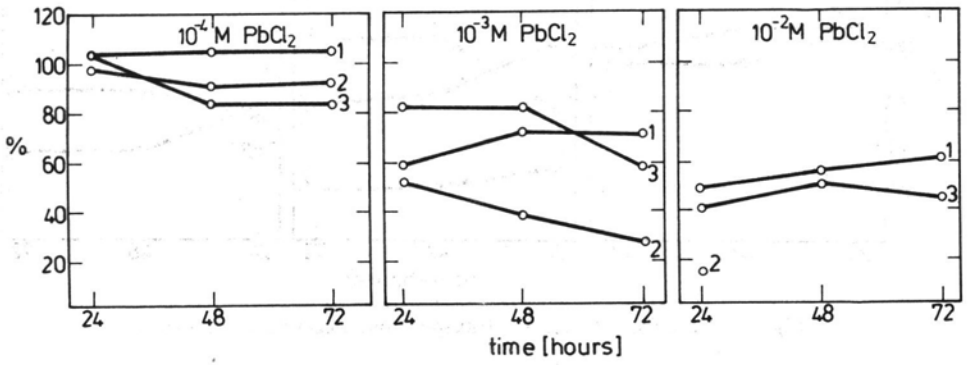

Fig. 1. The uptake of water from solutions with different concentrations of $PbCl_2$ (10^{-4}, 10^{-3} and 10^{-2} M) by bean plants (1), cucumbers (2) and wheat (3) expressed in percent of control

$PbCl_2$ (10^{-4} M) in the external solution. However, after 48 hrs, the transpiration of bean plants growing in the presence of 10^{-4} M Pb exceeded the transpiration of control plants. Higher concentrations of lead lowered the transpiration of water in all of the studied species, and the degree of reduction was similar to the changes in water uptake caused by lead.

Table 1 presents the fresh and dry weights and the hydration of plants after 72 hrs of treatment with lead. The fresh weight of all of the studied species was clearly lowered, which was already noticable in the plants treated with 10^{-4} M $PbCl_2$, whereas the dry weight did not differ from the dry weight of control plants. An exception was made by cucumbers growing in the presence of 10^{-3} M Pb. The dry weight of these plants attained only 32% of the weight of control plants. The hydration of plants treated with lead, in comparison with control plants, constantly decreased as the concentration of lead in the solution increased.

The placement of the plants for 72 hrs in solutions of $PbCl_2$ caused high accumulation of lead in their tissues. Differences in the lead content among the species also became apparent (Table 2). The highest lead content among the plants growing in the presence of 10^{-4} and 10^{-3} M $PbCl_2$ was found in beans and cucumbers, the lowest in wheat. A higher dose of lead in the external solution (10^{-2} M) caused the death of the cucumbers and, in relation to the lower Pb doses, brought about a 2.5- and 10-fold increase in the Pb content in beans and wheat, respectively, calculated for whole plants. The data in Table 2 indicate that in the presence of lower concentrations of $PbCl_2$ (10^{-4} and 10^{-3} M), about 80-90% of the Pb taken up accumulates in the roots of beans and cucumbers, while the

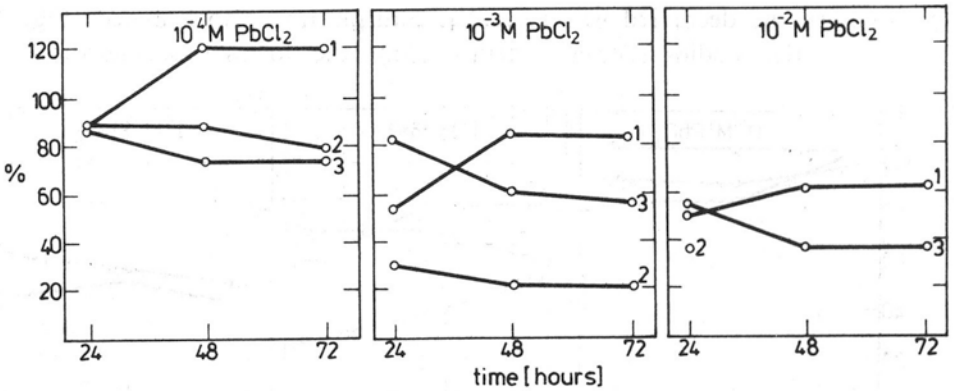

Fig. 2. The effect of lead on transpiration. Legends as in Fig. 1

higher concentration of $PbCl_2$ (10^{-2} M) caused the abrupt translocation of lead to the above-ground parts of the bean plants. In wheat, approximately 40% of the lead taken up by the whole plant accumulated in the stems, regardless of the concentration of lead in the external solution.

The concentration of $PbCl_2$ in the solution also had an influence on the extent of accumulation of lead in roots and stems. While in beans and cucumbers the concentration of lead in stems in the presence of 10^{-4} and 10^{-3} M $PbCl_2$, calculated on a dry weight basis, was from 70 to 200 times less than that in the roots, in wheat stems it was only 10 times less than that in the roots. The dose of 10^{-2} M $PbCl_2$ caused a significant rise in the content of Pb in the dry matter of bean and wheat shoots, while for cucumbers it was lethal.

The potometric measurements of the effect of lead on the uptake of water (Table 3) showed that after only 4 hrs, lead at a concentration of 10^{-3} M lowered the uptake of water by wheat seedlings by 46% and slightly (9%) by bean and cucumber seedlings. After 8 hrs the fall in water

Table 1

The fresh and dry weights and hydration of plants treated for 72 hrs with $PbCl_2$, expressed as a percentage of values of control plants

Pb concentration, M	Bean			Cucumber			Wheat		
	fresh weight	dry weight	hydration	fresh weight	dry weight	hydration	fresh weight	dry weight	hydration
10^{-4}	89 ± 8.3*	106 ± 5.2	83 ± 7.3	88 ± 4.7	98 ± 4.2	81 ± 4.1	77 ± 5.3	93 ± 3.1	91 ± 4.1
10^{-3}	78 ± 7.4	107 ± 5.6	71 ± 9.7	40 ± 9.3	32 ± 9.9	43 ± 9.4	78 ± 5.2	100 ± 6.2	75 ± 5.3
10^{-2}	61 ± 9.2	94 ± 8.6	53 ± 9.4	–**	–	–	52 ± 9.1	96 ± 7.4	45 ± 8.6

* Mean ±SE. ** Cucumbers died after 24 hrs of treatment with lead.

Table 2

The accumulation of lead in plants treated for 72 hrs with $PbCl_2$

Plant	Organ	Concentration of lead in the solution, M		
		10^{-4}	10^{-3}	10^{-2}
		mg Pb gram $^{-1}$ dry weight		
Bean	root	16.80 ± 1.2*	75.50 ± 1.4	97.52 ± 1.7
	shoot	0.10 ± 0.04	0.83 ± 0.06	23.44 ± 0.08
Cucumber	root	54.55 ± 1.3	228.00 ± 7.2	–**
	shoot	0.25 ± 0.6	3.29 ± 0.5	–
Wheat	root	5.65 ± 0.2	16.90 ± 0.3	104.50 ± 3.3
	shoot	1.22 ± 0.1	1.56 ± 0.1	42.50 ± 2.1
		µg Pb per organ		
Bean	whole	1083 ± 61 (100)***	4213 ± 82 (100)	11747 ± 115 (100)
	root	924 ± 44 (85)	3926 ± 93 (93)	4973 ± 168 (42)
	shoot	159 ± 18 (15)	288 ± 33 (7)	5774 ± 177 (58)
Cucumber	whole	1151 ± 63 (100)	2058 ± 91 (100)	–
	root	1091 ± 77 (95)	1824 ± 62 (88)	–
	shoot	60 ± 5 (5)	244 ± 7 (12)	–
Wheat	whole	61 ± 4 (100)	156 ± 5 (100)	1562 ± 90 (100)
	root	35 ± 3 (59)	101 ± 3 (65)	935 ± 88 (60)
	shoot	26 ± 3 (42)	55 ± 4 (35)	627 ± 72 (40)

* Mean ±SE. ** Cucumber died. *** Percentage.

Table 3

The effect of 10^{-3}M $PbCl_2$ on the uptake of water (μl plant^{-1} 15 min^{-1}.) measured in potometers

Plant		Duration of lead action		
		4	8	24
Bean	control	137±17.2*	93±4.0	182±6.3
	Pb	124±13.2 (93)**	73±3.7 (77)	106±4.3 (59)
Cucumber	control	95±11.4	110±7.1	127±11.3
	Pb	87±13.2 (91)	64±11.4 (58)	38±4.2 (30)
Wheat	control	5.9±0.2	6.1±0.7	15.7±0.3
	Pb	3.2±0.2 (54)	3.4±0.4 (55)	6.6±0.1 (42)

After 4, 8 or 24 hrs of growth on solutions of lead or on 5×10^{-3}M NaCl (control), the plants were transferred to potometers. The uptake of water was measured for 1 hour from the time the plants were placed in the potometers.
* Mean ±SE. ** Percent of control is given in parentheses.

uptake was clear in all of the species and equalled: beans — 23%, cucumbers — 42% and wheat — 45%. The extension of the time of Pb action to 24 hrs lowered the water uptake even more visibly.

The removal of the roots from been plants lowered the water uptake by 30% (Table 4). The same decrease in water uptake was observed in

Table 4

The effect of Pb (10^{-3}M $PbCl_2$, 72 hrs) on the uptake of water by beans with and without excised roots

	Amount of water taken up, cm^3	
	plant with roots	plant without roots
Control	25.7±1.2*	18.1±0.7
Pb	18.0±0.6 (70)**	15.1±0.2 (83)

* Mean ±SE. ** Percent of control values.

plants with intact roots but treated with 10^{-3} M $PbCl_2$. The lowest water uptake was observed in plants having their roots removed and treated with lead. This uptake amounted to 59% of that of control plants. In plants with intact roots, 75% of the lead taken up accumulated in the roots (Table 5), the remainder of this lead accumulated in the stem. No accumulation of lead was observed in petioles and leaves. In the plants whose roots had been removed, the entire accumulated lead was located in the stem. The accumulation of lead in the stem was dependent on the distance from the root or place of excision. The greatest amounts of lead accumulated at the base of the stem, the smallest — in the upper parts of the stem.

Table 5

The accumulation of lead by beans with and without excised roots treated for 72 hrs with 10 ^{3}M $PbCl_2$

	μg Pb 100 mg ^{1} dry weight					μg Pb per organ	
	root	parts of the stem			leaves	root	stem
		lower	middle	upper			
Plant with roots	8100 ± 112*	2000 ± 85	368 ± 33	150 ± 18	0	2925 ± 118	944 ± 82
Plant without roots	–	7650 ± 185	1675 ± 74	945 ± 98	0	–	2918 ± 92

* Mean ± SE.

DISCUSSION

Previous papers (Burzyński and Jakób 1983, Burzyński and Grabowski 1984, Burzyński 1985) have suggested that lead lowered the water uptake and hydration of several day-old seedlings or isolated fragments of plant tissues. The results presented in this study show that lead also affects the water balance of well-developed plants which were transferred for 72 hrs to $PbCl_2$ solution. As shown by the experiments, the magnitude of the effect of lead on the water balance of plants was dependent on its concentration in the external solution and on the plant species.

It can be assumed on the basis of these experiments that the primary reaction of plants after being transferred to $PbCl_2$ solutions is shock, the effect of which is the fall in transpiration. This shock was shown to be short in beans, and after 48 hrs transpiration clearly increased. However, the experiments done using potometers showed that lead inhibits the uptake of water, with this already occurring only 8 hrs after the plants had been placed in the $PbCl_2$ solution. It would seem then that the fall in transpiration was not caused by the accumulation of lead in the stoma observed by Bazzaz et al. (1975), but rather by the lower water uptake and the effect of Pb on the root system. As shown by Lane and Martin (1977), Lane et al. (1978) and Sieghardt (1984), the lead accumulated in the roots is localized mainly in the cell walls, especially of the endodermis and vessels. This fact can be of primary importance in the uptake and transport of water by plants contaminated with this metal. The fact that bean plants treated with lead took up similar amounts of water as plants with their roots removed but not treated with lead clearly suggests that the lead accumulated in the roots limits the uptake of water and probably makes its transport to leaves more difficult. Analysis of the lead content of the individual parts of the bean plant showed that the lead taken up accumulated mainly in the roots (70-80%) while no lead was found in the leaves.

The results of our experiments show that lead quickly enters into plants and accumulates mainly in the roots, and that during the 72hr treatment of plants with lead, its translocation to the above-ground parts is small, especially in beans and cucumbers. This fact is supported by the studies of Broyer et al. (1972), Jones et al. (1973) and Kabata-Pendias (1977). Only in wheat in our experiments was about 40% of the lead taken up translocation to the leaves. It is not excluded that the shorter distance between the roots and leaves in wheat plants, as compared with bean and cucmber plants, was the reason for the greater accumulation of lead in these organs.

Acknowledgment

This study was supported by a grant from the Institute of Soil Cultivation and Fertilization in Puławy, Problem No. 09.4.06.

REFERENCES

Bazzaz F. A., Carlson R. W., Rolfe G. L., 1974. The effect of heavy metals on plants. Part. I. Inhibition of gas exchange in sunflower by Pb, Cd, Ni and Tl. Environ. Pollut. 7: 241-246.

Bazzaz F. A., Carlson R. W., Rolfe G. L., 1975. Inhibition of corn and sunflower photosynthesis by lead. Physiol. Plant. 34: 326-329.

Broyer T. C., Johnson C. N., Paull R. E., 1972. Some aspect of lead in plant nutrition. Plant and Soil 36: 301-313.

Burzyński M., 1985. Influence of lead on chlorophyll content and on initial steps of its synthesis in greeninig cucumber seedlings. Acta Soc. Bot. Pol. 54: 95-105.

Burzyński M., Grabowski A., 1984. Influence of lead on NO_3^- uptake and reduction in cucumber seedlings. Acta Soc. Bot. Pol. 53: 77-86.

Burzyński M., Jakób M., 1983. Influence of lead on auxin-induced cell elongation. Acta Soc. Bot. Pol. 52: 231-239.

Hsiao T. C., 1973. Plant responses to water stress. Ann Rev. Plant Physiol. 24: 519-570.

Jones L. H. P., Clement C. R., Hopper M. J., 1973. Lead uptake from solution by perenial ryegrass and its transport from root to shoot. Plant and Soil 38: 403-414.

Kabata-Pendias A., 1977. Wpływ ołowiu w pożywce wodnej na skład chemiczny stokłosy. Rocz. Nauk. Roln. 102-A: 29-38.

Lane S. D., Martin E. S., 1977. A histochemical investigation of lead uptake in *Raphanus sativus*. New Phytol. 79: 281-286.

Lane S. D., Martin E. S., Garrod J. F., 1978. Lead toxicity effects on indole-3-ylacetic acid-induced cell elongation. Plants 144: 79-84.

Sieghardt H., 1984. Eine anatomisch-histochemische Studie zur Bleiverteilung in Primärwurzeln von *Pisum sativum* L. Mikroskopie 41: 125-133.

Pobieranie i transpiracja wody oraz akumulacja ołowiu przez rośliny rosnące na roztworze chlorku ołowiawego

Streszczenie

Stwierdzono istotne zmniejszenie transpiracji i pobierania wody, zależne od stężenia oraz od czasu działania $PbCl_2$ u fasoli, ogórka i pszenicy. Najbardziej wrażliwy na ołów był ogórek, który akumulował jednocześnie największą ilość Pb. Najmniej wrażliwa była fasola chociaż akumulowała więcej ołowiu niż pszenica. Ołów pobrany przez ogórki i fasolę akumulował się głównie w korzeniach, natomiast u pszenicy rozmieszczenie ołowiu było dość równomierne w korzeniu i w częściach nadziemnych. Pozbawienie fasoli korzeni powodowało duże gromadzenie Pb w dolnej części łodygi.