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EXCESSIVE UPTAKE OF HEAVY METALS BY PLANTS FROM CONTAMINATED SOILS

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INTRODUCTION

Soils surrounding non-ferrous metal smelters are usually contaminated simultaneously with certain metals, and most often also with sulfur compounds. Trace metals might also simultaneously contaminate soils due to several other technological processes such as coal combustion, oil refiniing etc., as well as to agricultural use of various wastes.

Plant response to excesses of several metals can either differ from a summation of effects of individual metals or can be similar to simple additive effects. In most cases, however, synergic or antagonistic effects are present. These phenomena have been recently studied and reviwed by several authors [1, 2, 6, 9, 12]. Still mor experimental data and verifications are needed for better understanding and asseeement of threshold multiple metal toxicity to plants.

EXPERIMENTAL PROCEDURE AND METHODS

The experiment was conducted with corn *Zea mais* L, oats *Avena sativa* L. and lupine *Lupinus luteus* L. growing succesively (during two seasons) in the same pots, filled with 1 kg light loamy soil. Trace elements were added in both single and combined treatments: Cd, Cu and Zn as sulfates, and Pb as nitrate.

Plants were grown for about a month and were harvested before bud development. The first crop of corn suffered greatly, therefore corn was also grown as the last succesive crop the next summer (Fig. 1). There were four replicates of each treatments and results given are average of anlyses of mixed plant materials. Plants were washed with deionized water, dried, ignited in a furnace at 450°C, and prepared for analyses by ASA flame methods.

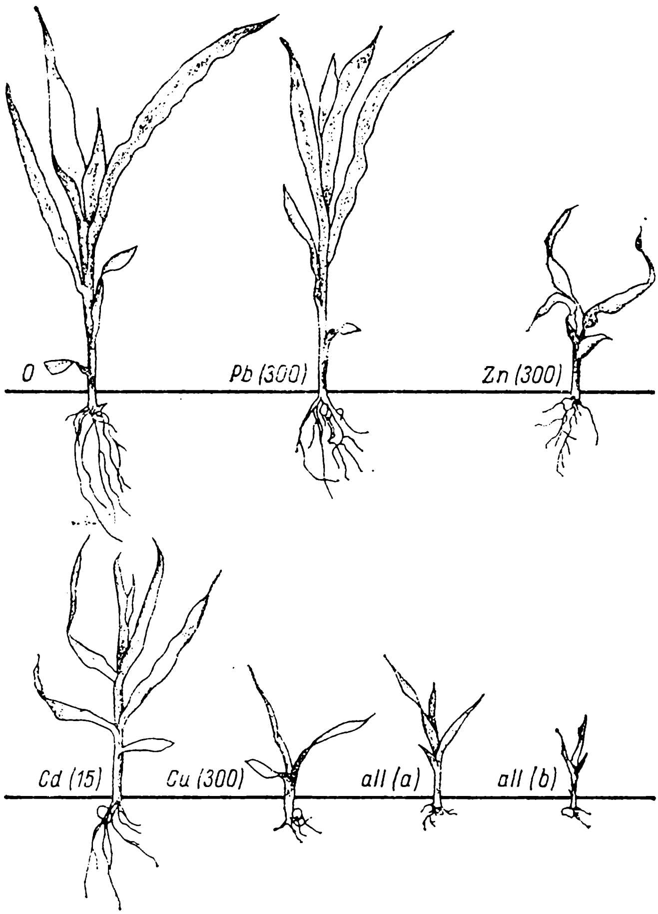

Fig. 1. Effects of singly- and simultaneously-added metals on growth of corn seedlings, 5 weeks old. Doses of the metals are given in ppm (in parentheses). Simultaneous doses

a — Cu, Zn, and Pb — 100 ppm, Cd — 5 ppm, b — Cu, Zn and Pb — 300 ppm, Cd — 15 ppm

Parallel to the pot experiment, soil samples were treated with similar doses of metals, and prepared for obtaining soil solutions by centrifugation [7].

RESULTS AND DISCUSSION

Symptoms of injury and reduction of yield were observed in all plants grown in the soil contaminated with metals, and in the pots with Zn at 900 ppm plants did not germinate. Yield reduction varied highly for both crop and metal (Fig. 2). The greatest yield reduction was observed for the first crop of corn which decreased under treatment with Cu, Zn, Cd and Pb a factor (YR) of 0,1, 0,3, 05, and 0.6, respectively. The

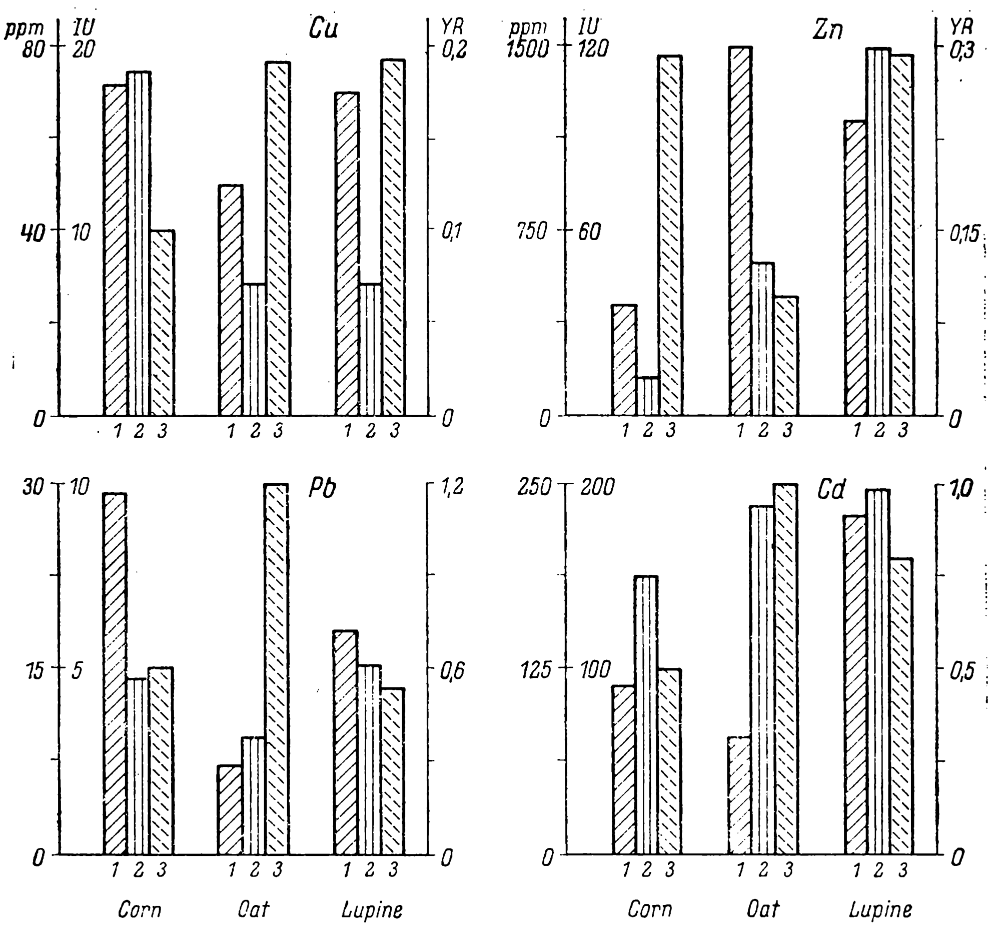

Fig. 2. Metal concentrations, relative uptake and yield reduction of various plants as influenced by addition of those metals to the soil at levels of 300 ppm for Cu, Zn, and Pb, and 15 ppm for Cd

1 — metal concentrations in plants tops (ppm dried weight), 2 — index of metal uptake by plants (IU) expressed as the ratio of metal content of plants to the control value, 3 — yield reduction (YR) expressed as the ratio of plant yield from the contaminated soil to that of the control

severely harmful effect of a 300 ppm Cu dose on the growth of corn was also observed (Fig. 1). Only the yield of oats did not decrease in soil treated with Pb and Cd. However, the yield reductions might also reflect an influence of SO_4^{2-} and NO_3^- anions introduced with metal compounds into the soil. Doses of associated anions affected the pH of both soil and soil solution (Table 1 and 2). Only the highest dose of $ZnSO_4$, increasing the SO_4^{2-} content of the soil up to 0.1 percent, brought a significant acidification of soil and soil solution to about 5.2 pH. Chemical reagents used as additives to the soil obscured effects of metals on plant yield. However, soils contaminated with metals by industrial emissions are most often also polluted with sulfur and its compunds. Thus, conditions of the experimental soil might be comparable with those occuring in other contaminated soils.

Table 1

Effects of heavy metal addition into the soil on their solubility and concentrations in various plants /before bud stage/

Metal	Treatment		Metal added ppm	Soil pH 1 N KCl	Metal concentrations			
					soil solution	corn	oat	lupine
					µg/l	ppm		
Zn	Zn	sgl	300	5.4	105 500	450	1500	1200
		sgl	900	5.[illegible]	1 500 000	n.y.	n.y.	n.y.
		sml	a	[illegible]	1[illegible]5 000	1700	160	1162
		cnt	0	6.1	500	40	48	99
Cu	Cu	sgl	100	6.0	133	21	19	44
		sgl	300	5.7	671	72	50	70
		sml	a	5.2	100	46	28	14
		cnt	0	6.1	250	3.8	6.4	9.4
Pb	Pb	sgl	100	6.3	31	12	3.5	10
		sgl	300	6.0	31	29	7	18
		sml	a	5.2	40	25	5	2
		cnt	0	6.1	29	6.9	3.7	3
Cd	Cd	sgl	5	6.2	6	80	44	205
		sgl	15	6.2	12	112	74	245
		sml	a	5.2	1750	330	156	90
		cnt	0	6.1	7	0.5	0.4	1.3
Fe	Zn	sgl	300	5.4	6[illegible]	1[illegible]8	110	110
	Cu	sgl	300	6.3	1[illegible]7	94	69	106
	Pb	sgl	300	6.6	63	74	74	147
	Cd	sgl	15	7.2	63	98	72	105
	All	sml	a	6.4	120	74	106	106
		cnt	0	6.1	353	84	77	124
Mn	Zn	sgl	300	6.2	1300	700	330	76[illegible]
	Cu	sgl	300	6.3	1200	920	930	1160
	Pb	sgl	300	6.6	67	134	690	2100
	Cd	sgl	15	7.2	31	166	520	1650
	All	sml	a	6.4	4636	520	800	1000
		cnt	0	6.1	266	200	390	316

a - doses of all metals in ppm: Zn - 300, Cu and Pb - 100, Cd - 5
Treatments: sgl - single, sml - simultaneous, cnt - control

The Cd, Cu, Pb and Zn, when applied singly, resulted in a slightly smaller reduction of yield than when applied simultaneously, but the variation was not significant. $Pb(NO_3)_2$ resulted in a slight yield increase of oats only, but also was not significantly (Fig. 2).

Table 2

Effects of heavy metal compounds on major cations in the soil solution

Metal and dose		Associated anion added		Soil solution				
				pH	Ca	Mg	K	Na
mg/kg		mg/kg			mg/l			
Cd	5	SO_4^{2-}	4	7.3	117	1.7	29	3.8
	15		13	7.3	128	2.0	33	4.3
Cu	100	SO_4^{2-}	150	6.3	254	5.9	53	4.2
	300		454	6.6	388	12.2	85	6.3
Zn	300	SO_4^{2-}	440	6.2	363	11.6	80	5.7
	900		1322	5.2	383	16.0	100	6.0
Pb	100	NO_3^{2-}	29	6.6	188	2.7	33	3.7
	300		87	6.7	344	5.7	57	3.4
Simultaneous	a	SO_4^{2-}	558	6.4	400	12.7	90	6.2
		NO_4^{2-}	29					
Control - 0				6.0	370	7.5	34	7.4
Control - NPK				7.0	109	1.8	262	4.7

a - dose of metals as given in Table 1

Trace element content of plant tops show a strong relation to the concentrations of these elements in the soil (Table 1). The highes index of uptake (IU) of metals was calculated for Cd and all plants (IU values range from 150 to 200), whereas a much lower IU value (from 3 to 5) was obtained for Pb, being the lowest for oast (Table 3). In each case, however, higher contents of metals were in roots than in tops (Fig. 3). The high doses of Cd and Pb resulted also in elevated concentrations of these metals in leaves and nodes of corn (Fig. 3).

The uptake of metals by plants seems to be related to the metal content in soil solution, although it is not a linear relationship (Table 1). The highest relative solubility is observed for Zn, whereas all other metals entered into the soil solution in variable amounts.

A strong mobilization of heavy metals in acid soils, particularly in soils acidified due to sulfur deposition, has already been observed [8, 11]. Itoh and Yomura [5] reported the relationship between Cd, Cu, Zn, Cr, Ni and Pb concentrations in the soil solution, and the absorption of these metals by plants. Although the authors did not relate the metal availability to the soil and the solution pH, increasing acidity due to applied sulfates of Cu, Cr and Zn (and also Pb nitrate) was most probably an important factor.

Table 3

Concentrations of heavy metals in corn grown in soil contaminated with these elements

/second year of the experiment/

Metal	Treatment		Metal added	Metal content of corn - ppm	
			ppm	leaves	roots
Zn	Zn	sgl	300	1850	5000
		sgl	900	2375	8500
		sml	a	650	1850
		cnt	0	40	186
Cu	Cu	sgl	100	23	360
		sgl	300	40	380
		sml	a	30	240
		cnt	0	3	6
Pb	Pb	sgl	100	3.5	78
		sgl	300	7.0	281
		sml	a	3.8	33
		cnt	0	2.3	5
Cd	Cd	sgl	5	82	125
		sgl	15	128	155
		sml	a	102	83
		cnt	0	0.5	0.8
Fe	Zn	sgl	300	116	1150
	Cu	sgl	300	53	795
	Pb	sgl	300	72	975
	Cd	sgl	15	120	675
	All	sml	a	56	335
		cnt	0	75	596
Mn	Zn	sgl	300	300	440
	Cu	sgl	300	205	250
	Pb	sgl	300	440	625
	Cd	sgl	15	540	495
	All	sml	a	500	240
		cnt	0	233	254

a - dose of metals as given in Table 1

Interactions of simultaneously-added trace metals are known to cause either additive and synergistic or antagonistic response in plant tissues or adjacent to the roots. The most pronounced antagonism observed in this experiment was between Fe and trace metals. However, a slight Fe deficiency occurred also in control plants (Table 1). A significant reduction of Fe solubility in the soil solution under the influence of trace metals might be also responsible for a reduction in Fe uptake by plants. Such an antagonistic effect of trace metals on Mn solubility and uptake was not observed in this experiment, although this interaction has been often reported for both plant tissues and root surroundings [6]. All well confirmed antagonisms reported by F o y et al. [3] between trace metals occurred in this experiment but at different degrees, depending on plant species.

The addition of metal sulfates (and Pb nitrate) into the soil resulted in variable mobility of Ca, Mg and K. Major cation concentrations in the

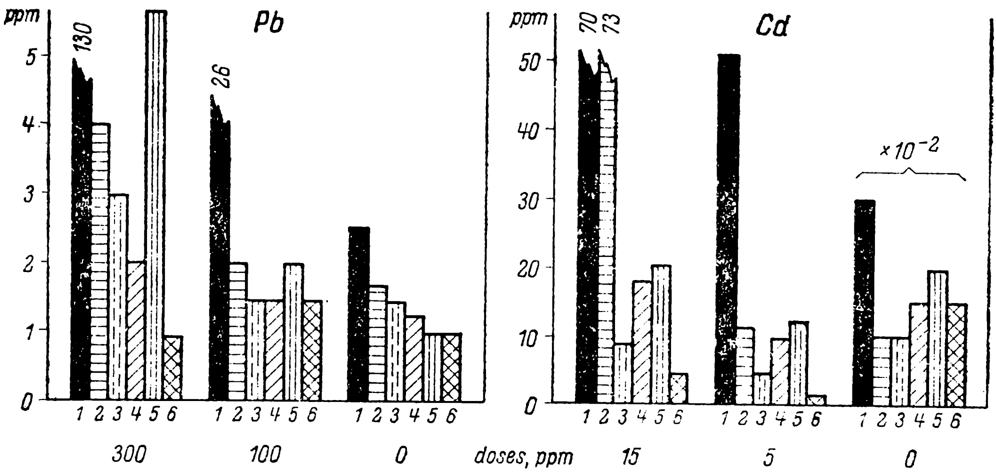

Fig. 3. Lead and cadmium distribution within corn plants as influenced by high doses of these metals

1 — roots, 2 — leaves, 3 — stems, 4 — sheaths, 5 — nodes, 6 — male inflorescences

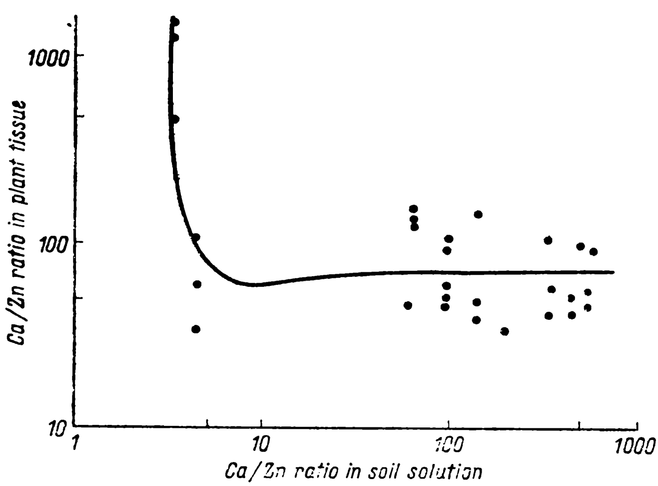

Fig. 4. Relationship between the Ca/Zn ratio in the plant tissues and this value for the soil solutions

soil selutions do not show any regular effect of the metal addition (Table 2). However, the ratio of Ca to micro-cations in the soil solution and in the plants tissues indicates that Ca is involved in the uptake processes of trace metals. The Ca/Zn ratio in the plants show a negative relation to that value in the soil solution (Fig. 4). On the other hand, the relationship between the Ca/Pb ratio in plants and solutions indicates positive actions of Ca on relative uptake of Pb. Such a phenomena have been often reported by various authors [4, 10]. The values of the Ca/Cu and Ca/Cd ratios were quite variable, depending on the metal concentrations and on plant species, but general trends indicated a positive function between these pairs of elements occurring in plant tissues and in soil solutions.

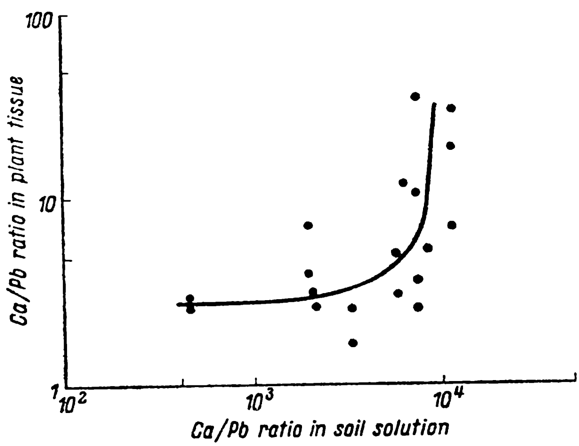

Fig. 5. Relationship between the Ca/Pb ratio in the plant tissues and this value for the soil solutions

An additive nature of simultaneous trace metal effects in soils acidified by sulfate anions is of considerable importance, especially, for a proper assessment of threshold toxicity of metals contaminating soils in industrial regions.

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ЧРЕЗМЕРНОЕ УСВАИВАНИЕ ТЯЖЕЛЫХ МЕТАЛЛОВ РАСТЕНИЯМИ ИЗ ЗАГРЯЗНЕННЫХ ПОЧВ

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Резюме

В засоренных почвах в результате как воздействия промышленных эмиссий так и вследствие использования разных отходов в земледелии в почве обычно происходит накапливание одновременно нескольких тяжелых металлов. Растения реагируют различно на чрезмерную концентрацию металлов.

Взаимодействие повышенных концентраций тяжелых металлов и биологические последствия до сих пор не изучены.

Сосудные опыты с тремя растениями (Zea mais L., *Arena satira* L. и *Lupinus luteus* L.) на почвах с высокими дозами Cd, Cu, Zn и Pb симулировали природные условия роста растений на почвах сильно загрязненных тяжелыми металлами.

Установлена сильная зависимость концентрации тяжелых металлов в растениях (их надземных частей и корней) от содержания этих металлов в почве, а в первую очередь от их растворимости в почвенном растворе. Все растения наиболее интенсивно усваивали кадмий (150–200 раз больше в сравнении с контролем), а наиболее слабо свинец (3–5-кратно больше в сравнении с контролем).

Закисление почвы и почвовенного раствора в результате внесения анионов SO_4^{2} и NO_3^- вместе с солями тяжелых металлов приводило к заметному повышению растворимости металлов и их усваивание растениями. Концентрация калця в почвенном растворе оказывала также влияние на интенсивность усваивания тяжелых металлов и зависела от вида металлов и их концентрации, а также от вида растений.

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NADMIERNE POBIERANIE METALI CIĘŻKICH PRZEZ ROŚLINY Z GLEB ZANIECZYSZCZONYCH

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Streszczenie

W zanieczyszczonych glebach, zarówno w wyniku oddziaływania emisji przemysłowych, jak i wskutek stosowania różnych odpadów w rolnictwie, następuje najczęściej równoczesne nagromadzenie kilku metali ciężkich. Reakcje roślin na nadmierne stężenia metali są zróżnicowane.

Wzajemne oddziaływanie podwyższonych zawartości metali ciężkich oraz skutki biologiczne nie są poznane.

Doświadczenia wazonowe z trzema roślinami: *Zea mais* L., *Avena sativa* L. oraz *Lupinus luteus* L., na glebach z dużymi dawkami Cd, Cu, Zn i Pb naśladowały warunki naturalne rozwoju roślin na glebach silnie zanieczyszczonych metalami ciężkimi.

Wykazano dużą zależność stężenia metali ciężkich w roślinach (w nadziemnych częściach i korzeniach) od ich zawartości w glebie, a przede wszystkim od ich rozpuszczalności w roztworze glebowym. Wszystkie rośliny pobierały najintensywniej kadm (150- do 200-krotnie więcej od kontroli), a najsłabiej ołów (3- do 5-krotnie więcej od kontroli).

Zakwaszenie gleby i roztworu glebowego w wyniku wprowadzenia anionów SO_4^{2-} i NO_3^- wraz z solami metali ciężkich wyraźnie zwiększyło rozpuszczalność metali oraz ich pobieranie przez rośliny. Stężenie wapnia w roztworze glebowym wpływało także na intensywność pobierania metali ciężkich wykazując zależność od rodzaju metali i ich stężenia oraz od gatunku roślin.

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Wpłynęło do redakcji w czerwcu 1984