Modeling the effect of multiple heavy metal contamination in soils on plants using nutrient solutions

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Capsule: Samples from heavy metal contaminated soils and nutrient solutions composed on the basis of the soil metal content were used for assessing the ecotoxicological risk at the sampling site. Measurements of plant physiological parameters were used for comparison between solution models and soils.

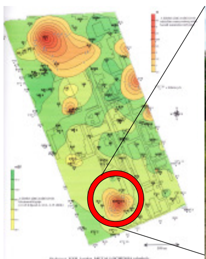
Background

Ecological hazard of contaminated sites are assessed by ecotoxicological tests. However, these tests are not reliable in all cases as plants may mobilize the otherwise biologically not available contaminants. The plants may take up e.g. heavy metals with or without showing (visible) toxicity symptoms. Thus, using plants in ecotoxicological tests is encouraged by different authors.

Contaminated site map of the abandoned industrial site of the Metallochemia Ltd. In Budapest, Hungary. The pollution came from the dismantling of used batteries with the waste disposed on site and the production of metallic paints such as red lead and lithopone for nearly a century.

Three soils samples were collected in the contaminated site and standardised ecotoxicological tests were conducted to evaluate the toxicity level.

On the basis of Pseudomonas fluorescens, Azotobacter agile and *Sinapis alba* germination tests the collected soil samples were evaluated as non-toxic.



Using plants in ecotoxicological tests can be time-consuming if soil samples are directly used as growth medium.

Objectives

The aim of this work was the
- ecotoxicological evaluation of soils by assessment of phytotoxicity parameters,
- evaluation of nutrient solution models to be used for risk assessment

Results

Total and bioavailable metal content of the soil samples was determined by ICP-AES.

mg/kg soil	Sample 1		Sample 2		Sample 3	
element	total	plant available	total	plant available	total	plant available
Pb	89610	14270	41360	4176	24510	6464
Cu	9268	916	52890	2129	2663	413
Zn	11620	760	13140	1118	11330	927
Cd	26	5	28	7	53	19
Fe	23600	87	21575	16	1758	25

Basic nutrient solution and treatments. The treatment concentrations were applied in 1x, 10x and 100x dilutions, respectively.

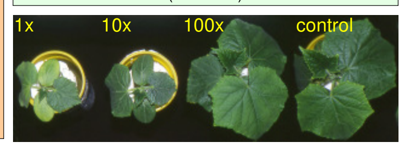
The basic, modified Hoagland nutrient solution contains:
- 1.25 m*M* KNO_3
- 1.25 m*M* $Ca(NO_3)_2x4H_2O$
- 0.5 m*M* $MgSO_4x7H_2O$
- 0.25 m*M* $KH_2(PO_4)$
- 11.6 *µM* H_3BO_3
- 4.6 *µM* $MnCl_2x4H_2O$
- 0.19 *µM* $ZnSO_4x7H_2O$
- 0.12 *µM* $Na_2MoO_4x2H_2O$
- 0.08 *µM* $CuSO_4x5H_2O$
- 10 µM Fe(III)-citrate

µM	Solution 1	Solution 2	Solution 3
$Pb(NO_3)_2$	440	700	680
$CuSO_4*5H_2O$	92.5	820	140
$ZnSO_4*7H_2O$	74.4	610	310
$CdSO_4$	0.27	2.23	3.67
Fe-citrate	10	10	10

Plants grown on the soil samples (4=control soil).

Heavy metal concentrations were defined on the basis of their plant available fraction in the soil samples. The Fe content was considered to be equal to 0.01 mM in all solutions and the heavy metal concentrations were calculated using their individual ratio to Fe.

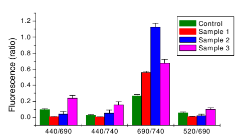
Plants grown on nutrient solutions. (Solution1)



Concentration of metals in the leaves of plants grown in the soil samples determined by ICP-AES.

mg/g	Sample 1	Sample 2	Sample 3
Pb	0.334	0.200	0.152
Cu	-	0.360	-
Zn	0.743	0.615	0.152
Cd	-	-	-
Fe	0.181	0.126	0.061

Fluorescence ratios derived from fluorescence images of the 2nd leaves of plants grown on soil samples.



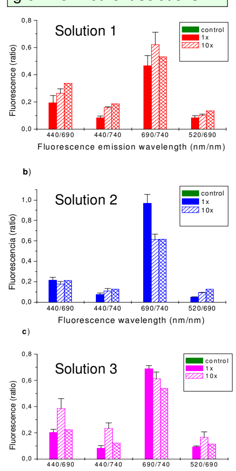
Fresh weight (Fw), Chlorophyll concentration (Chl) and stomatal conductance (Sc) of the 2nd leaves of plants grown in the nutrient solutions. (Control Fw=2069mg, Chl=2355 µg/g, Sc= 784 mmol/m²s)

	Solution 1		Solution 2		Solution 3	
	1x	10x	1x	10x	1x	10x
Fw (mg)	89	402	149	75	68	245
Chl (µg/g)	1550	2070	926	2120	1720	1935
Sc (mmol $H_2O/m^2.s$)	92.8	56.3	143.3	99.4	88.8	60.4

Concentration of metals in the leaves of plants grown in nutrient solution determined by ICP-AES. (Dilutions: 1x and 10X)

mg/g	Solution 1		Solution 2		Solution 3	
element	1x	10x	1x	10x	1x	10x
Pb	0.087	0.056	0.931		0.127	0.142
Cu	0.057	0.044	0.340		0.140	0.051
Zn	0.138	0.100	0.652		0.235	0.163
Cd	-	-	-		-	-
Fe	0.097	0.047	0.108		0.106	0.050

Fluorescence ratios derived from fluorescence images of the 2nd leaves of plants grown on nutrient solutions.



Fresh weight (Fw), Chlorophyll concentration (Chl) and stomatal conductance (Sc) of the 2nd leaves of plants grown in the soil samples. (Control Fw=552.6mg, Chl=2574 µg/g, Sc= 125 mmol/m²s)

	Sample 1	Sample 2	Sample 3
Fw (mg)	51.2	132.7	113.7
Chl (µg/g)	717	349	932
Sc (mmol $H_2O/m^2.s$)	66.9	40.5	67.3

Conclusions

- On the basis of the Pb, Zn, Fe and Cu concentrations compared in soil- and solution-grown plants the best correlation was found between Sample 3 solution diluted 10 times and the original soil sample followed by the undiluted solution of Sample 2. However the correlation for Sample 1 was poor.
- Chlorophyll concentration decreased similarly in soil- and solution-grown samples whereas F_v/F_m values (not shown) decreased only in Sample 2 compared to the control in both types. Transpiration (stomatal conductance) decreased much more in solution samples and correlation could not be established with the patterns of heavy metal content in the second leaf. F690/740 fluorescence ratio determined by fluorescence imaging proved to be a sensitive indicator and increased similarly in soil- and undiluted solution-grown samples. These findings imply that the established solution models can be reliable tools for the quick evaluation of the potential effect of soils contaminated by several heavy metals on plants.
- Iron can be used as reference point for setting metal ratios on condition that it is not a limiting factor.

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