Effect of Heavy Metals on Wheat and Maize Crop on Brown Forest Soil

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Introduction

Gyöngyös and its neighbourhood are becoming more and more loaded with toxic elements and heavy metals, caused by the Mátra Power Station, M3 Motorway, Toka Brook, etc. The critical limit values of phytotoxicity can be evaluated reliably for different soils and plants in field experiments. KÁDÁR (1995) and SZABÓ (1995, 1996) initiated the establishment of this kind of long-term field trial earlier.

The present paper aims to give data on the phytotoxicity and uptake of wheat and maize crops grown on an acidic brown forest soil with clay illuviation treated with different toxic salts. Results of soil analysis carried out in this field experiment are presented by SZABÓ (1998).

Material and Methods

The field trial of split-plot design includes 8 elements with 3 loading levels, i. e. 24 treatments all in triplicate (72 plots). Plot sizes were 35 m² each.

The main characteristics of the ploughed layer of the acidic brown forest soil with clay illuvation are: $pH_{(KCl)}$ 6.2; humus content 3%; clay content: 30-35%.

The treatments, forms of the salts applied are given in Table 1.

The cultivated experimental plants were: wheat in 1995 and maize in 1996. In the wheat experiment plant samples were taken at the end of shooting (5 May, 1995) and at harvest (4x1 m above ground part per plot). In the maize experiment 20 plants per plot were taken at 4-6 leaf stage, 30-30 leaves per plot before flowering and 20-20 plants with cob per plot at harvest. After weighing, drying and grinding the element content was determined by cc. HNO_3 + H_2O_2 digestion and ICP technique.

Table 1

Treatments in the field experiment on brown forest soil with clay illuviation (Salt applied in November 1994, Gyöngyös)

Element	Load, kg element/ha			The form of the salt applied
	1.	2.	3.	
Al	0	90	270	$Al(NO_3)_3 \cdot 9H_2O$
As	30	90	270	$NaAsO_2$
Cd	30	90	270	$3CdSO_4 \cdot 8H_2O$
Cr (VI)	30	90	270	K_2CrO_4
Cu	30	90	270	$CuSO_4 \cdot 5H_2O$
Hg	30	90	270	$HgCl_2$
Pb	30	90	270	$Pb(NO_3)_2$
Zn	30	90	270	$ZnSO_4 \cdot 7H_2O$

Table 2

Effect of treatments resulting in the phytotoxicity of wheat (Acidic brown forest soil with clay illuvation, Gyöngyös, 5 May, 1995)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
	Visual assessment (1=very weak, 5=well developed stand)					
As		5.0	4.3	3.0		4.1
Cr	5.0	4.7	3.3	1.7	1.1	3.2
Cu		4.7	4.0	3.0		3.9
Zn		4.3	3.3	2.7		3.4
	Green shoot, kg/4 linear metres (0.5 m²)					
As		1.29	0.91	0.89		1.03
Cr	1.36	1.02	0.50	0.16	0.40	0.56
Cu		0.90	0.80	0.76		0.82
Zn		0.98	0.60	0.40		0.66
	Percentage of dry matter in shoot					
As		15.2	14.8	15.0		15.0
Cr	14.6	14.6	15.1	17.8	1.9	15.8
Cu		15.4	15.1	17.7		16.1
Zn		14.4	16.7	16.0		15.7
	Dry weight of shoot, g/0.5 m²					
As		196	135	133		155
Cr	197	150	76	29	59	85
Cu		137	117	111		122
Zn		143	102	61		102

Results and Discussion

Wheat experiment in 1995

Wheat was characterized by intensive nutrient uptake at the shooting phase when the crop stand was visually estimated and plant samples were taken. At this stage of the phenophase Cr and Zn treatments were highly, As and Cu loads moderately phytotoxic. The data of visual assessment and shoot weight are presented in Table 2. With higher loads, the crop grew yellow and dry, the dry matter content increased, which reflected problems in life functions.

Table 3

Effect of treatments causing decrease in wheat yield at harvest (Acidic brown forest soil with clay illuviation, Gyöngyös, 31 July, 1995)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
			Grain, t/ha			
As		5.21	4.52	4.00		4.58
Cr	4.67	4.96	4.67	2.52	1.23	4.05
Cu		5.11	4.22	3.19		4.17
Zn		4.59	4.15	2.37		3.70
			Straw/grain rate			
As		1.09	1.22	1.15		1.15
Cr	1.17	1.12	1.05	1.10	0.53	1.09
Cu		1.06	0.96	1.54		1.19
Zn		1.10	1.09	1.87		1.35
			Husks/grain rate			
As		0.27	0.38	0.35		0.33
Cr	0.29	0.30	0.30	0.38	0.39	0.33
Cu		0.29	0.35	0.90		0.51
Zn		0.28	0.32	0.72		0.44
			Straw + husks, t/ha			
As		7.13	7.23	6.02		6.79
Cr	6.81	6.96	6.31	3.65	1.44	5.64
Cu		6.89	5.55	5.05		5.83
Zn		6.32	5.79	3.98		5.36
			Air-dried total biomass, t/ha			
As		12.3	11.8	10.0		11.4
Cr	11.5	11.9	11.0	6.2	2.6	9.7
Cu		12.0	9.8	8.2		10.0
Zn		10.9	9.9	6.4		9.1

The degressive effect of As could no longer be proven statistically at harvest, while there was a more than 2 t/ha loss of grain due to Cr, Cu and Zn treatments.

There was only a slight decrease in the weight of straw in Cu and Zn treatments, so the straw/grain and husk/grain rates increased. The total air-dried biomass reached 10-12 t/ha on the control plots, while it was only 6-8 t/ha on plots with high Cr, Cu and Zn loads (Table 3).

Table 4

Effect of treatments on the mineral composition of wheat (mg/kg)
(Acidic brown forest soil with clay illuviation, Gyöngyös, 1995)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
	Above ground part at the end of shooting (5 May)					
Al	135	-	208	74	378	139
Zn	31	34	38	39	9	37
Hg	0	5	19	86	25	37
Cu	8	9	8	11	3	9
As	0.0	0.4	2.0	2.8	1.2	1.7
Cd	0.1	1.0	1.7	2.2	0.9	1.6
Cr	0.5	4.6	2.7	13.1	8.8	6.8
Pb	0.5	1.7	2.6	3.0	2.7	2.4
	Straw at harvest (31 July)					
Al	130	-	168	159	173	153
Zn	16	16	22	40	8	24
Hg	2	10	23	111	14	36
Cu	6	7	6	19	7	10
As	0.0	0.1	1.1	5.2	0.9	1.6
Cd	0.2	1.6	2.7	7.7	2.2	3.0
Cr	0.4	0.7	2.6	6.9	0.7	2.6
Pb	0.8	1.0	1.4	4.3	1.1	1.9
	Grain at harvest (31 July)					
Al	22	-	46	22	21	30
Zn	38	42	46	54	7	45
Hg	0.0	0.0	0.0	0.0	0.0	0.0
Cu	4.7	4.3	4.4	5.5	1.1	4.7
As	0.0	0.0	0.0	0.0	0.0	0.0
Cd	0.1	0.6	0.9	1.0	0.1	0.6
Cr	0.4	0.6	0.4	0.7	0.3	0.5
Pb	0.6	0.4	0.7	1.1	0.8	0.7

No significant changes were observed in the Al, Zn and Cu content in shoot in spite of the increased load. As, Cd and Pb concentrations only increased slightly, reaching 2-3 mg/kg. The Cr content made up 13, while that of Hg 86 ppm. Hg concentrations reached 111 ppm in straw at harvest and increased during the growth period. However, grain was not contaminated with this dangerous pollutant, so the generative organ was protected genetically. At the same time Zn and Cd loads were reflected in grain composition, while Al, Cu, Cr and Pb did not affect the grain element content (Table 4).

The average element composition of shoot, straw and grain originating from the control plots is shown in Table 5. The average concentration of elements is

Table 5

Mineral composition of winter wheat on control plots
(Acidic brown forest soil with clay illuviation, Gyöngyös, 1995)

Element	Shoot	Straw	Grain	Shoot	Straw	Grain
		%			%	
K	4.56	2.36	0.55	100	52	12
P	0.60	0.23	0.46	100	38	77
Ca	0.48	0.58	0.05	100	121	10
S	0.37	0.25	0.17	100	68	46
Mg	0.16	0.14	0.13	100	88	81
		%			%	
Fe	223	312	74	100	140	33
Na	152	112	12	100	74	8
Al	105	130	22	100	124	21
Mn	49	62	45	100	127	92
Zn	31	16	38	100	52	123
Ba	24	63	4.3	100	262	17
Sr	15	21	1.6	100	140	11
Cu	8	6	4.7	100	75	59
B	1.9	5.6	1.1	100	295	58
Se	0.9	0.1	0.4	100	11	44
Pb	0.5	0.8	0.6	100	160	120
Cr	0.5	0.4	0.4	100	80	80
Hg	0.5	2.0	0.0	100	400	0
Ni	0.2	0.5	0.7	100	250	350
Mo	0.1	0.4	0.2	100	400	200
Cd	0.1	0.2	0.1	100	200	100
Co	0.1	0.1	0.01	100	100	1
As	0.0	0.0	0.0	100	-	-

Remark: The source of Hg contamination is unknown also expressed in the percentage of young shoot to indicate the elements that had accumulated in grain or in by-product straw. If straw is ploughed in, pollutants in straw will remain in the soil-plant system. Grains were rich in P, Zn, Se, Ni and partly in Cr, so these elements will be present in flour and bread. Unfortunately, Cd in grain increased from 0.1 to 1.0 ppm, thus proving to be no longer good for human consumption.

The Hungarian standard allows 0.1 ppm As and Cd, 0.5 ppm Pb, 5 ppm Cu and 30 ppm Zn in ground cereals and flour. All Cd treatments resulted in values exceeding the limit concentration. Grain originating from Pb and Zn treatments was also mostly unfit for consumption. It was observed that even on control soil wheat had developed with relatively high Cd, Cr, Pb and Zn concentrations, sometimes around the limit values. Further studies are necessitated with other crop varieties in order to get a clearer picture about plant background contamination.

Table 6

Effect of treatments causing decrease in maize yield
(Acidic brown forest soil with clay illuviation, Gyöngyös, 1996)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
Stand evaluation at 6-leaf stage (7 June)						
As		4.8	4.1	3.7		4.2
Cd		4.3	4.1	3.3		3.9
Cr	4.8	4.3	4.0	3.2	0.6	3.8
Cu		4.6	4.5	4.4		4.5
Zn		4.2	4.2	3.8		4.1
Stand evaluation at flowering (17 July)						
As		4.7	4.0	3.7		4.1
Cd		4.2	3.5	3.2		3.6
Cr	4.7	4.5	3.9	3.6	0.7	4.0
Cu		4.8	4.7	4.2		4.6
Zn		4.6	4.1	3.8		4.2
Plant height at flowering (17 July)						
As		204	186	182		191
Cd		191	176	172		180
Cr	198	204	190	186	18	193
Cu		209	199	180		196
Zn		205	190	189		194

Visual evaluation:
1 = very weak, 2 = weak, 3 = satisfactory, 4 = good, 5 = excellent stock.

Maize experiment in 1996

In the first year As, Cr, Cu and Zn proved to be phytotoxic – so 4 of the 8 elements decreased the yield of wheat. In the second year Cd also showed some toxic effect on young maize stand together with As, Cr, Cu and Zn (Table 6).

Straw at harvest was decreased only by As, Cd and Cr, while grain yield did not show any significant depression.

The total above ground biomass reached 16 t/ha on the control soil and had a slight, but statistically significant loss on As, Cd and Cr treated plots. The dry matter content made up 12% in young shoot, 30% in leaves at flowering

Table 7

Effect of treatments causing decrease in maize yield
(Acidic brown forest soil with clay illuviation, Gyöngyös, 1996)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
	Air-dried shoot at 6-leaf stage, g/20 plants					
As		203	197	151		184
Cd		211	182	156		183
Cr	187	192	171	137	31	167
Cu		210	195	171		192
Zn		197	209	163		190
	Air-dried straw, t/ha					
As		7.21	5.73	5.04		6.00
Cd	8.00	7.25	4.98	5.72	1.90	5.98
Cr		7.70	7.36	5.76		6.94
	Grain, t/ha (14% dry matter)					
As		7.18	6.34	7.20		6.90
Cd	7.00	6.29	6.02	6.50	1.19	6.27
Cr		7.61	7.77	7.08		7.49
	Total weight, t/ha					
As		15.4	13.0	13.3		13.9
Cd	16.1	14.4	11.9	13.2	2.5	13.2
Cr		16.5	16.1	13.9		15.5

Dry matter content:	In shoot at 6-leaf stage	12%
	In leaves at flowering	30%
	In grain at harvest	75%

Table 8

Effect of treatments on mineral composition of maize (mg/kg)
(Acidic brown forest soil with clay illuviation, Gyöngyös, 1996)

Element	Treatment in autumn 1994 (kg/ha)				$LSD_{5\%}$	Average
	0	30	90	270		
			Shoot at 4-6 leaf stage			
Al	390	-	566	488	400	481
As	0	0	0	0	-	0
Cd	0.53	9.88	16.4	21.83	1.32	12.16
Cr	0.84	0.83	1.04	1.32	0.62	1.01
Cu	7.92	9.39	9.89	11.00	1.30	9.55
Hg	0	0	0	0	-	0
Pb	1.04	0.36	1.18	2.71	1.63	1.32
Zn	36.6	48.7	73.9	80.1	20.1	59.8
			Leaves at flowering			
Al	85.5	-	63.7	131.7	80.5	93.6
As	0	0	0	0	-	0
Cd	0.27	5.45	8.82	12.17	0.57	6.68
Cr	0.26	0.17	0.24	0.26	0.20	0.23
Cu	11.70	13.13	14.87	13.30	2.43	13.25
Hg	0	0	0	0	-	0
Pb	0.61	0	0.14	0.93	0.90	0.42
Zn	38.0	52.0	87.7	87.6	29.9	66.3
			Shoot at harvest			
Al	219	-	200	357	111	259
As	0.41	0.61	0.27	1.51	0.64	0.7
Cd	0.39	5.72	8.95	11.62	0.58	6.67
Cr	0.53	0.48	0.53	0.61	0.22	0.54
Cu	7.25	4.87	7.48	7.85	2.64	6.86
Hg	0	0	0.2	0.61	0.36	0.2
Pb	1.12	2.08	2.65	1.97	1.04	1.96
Zn	25.2	36.6	56.9	63.9	28.1	45.7
			Grain at harvest			
Al	1.00	-	4.71	1.80	2.65	2.50
As	0	0	0	0	-	0
Cd	0	0 .56	0.89	0.89	0.15	0.59
Cr	0.09	0.21	0.22	0.07	0.12	0.17
Cu	3.31	3.70	4.48	4.84	1.53	4.08
Hg	0	0	0	0	-	0
Pb	0.05	0.19	0.28	0.22	0.37	0.30
Zn	43.0	46.4	49.3	55.1	14.5	48.5

and 75% in grain at harvest. The air-dry cob yield was 1.4 t/ha on the average (Table 7).

While a considerable accumulation of Hg, Cr, Cd, As and Pb was detected in young shoot of wheat in 1995, young maize plants showed only Cd and Zn accumulation at 6-leaf stage.

In the straw and grain Cd and Zn concentrations increased significantly, too. Hg and As were under the detectable 0.1 ppm level in grain and straw also only had traces. Hg and As seem to turn quickly into unavailable forms in this soil and cannot be used by plants. Cd content was rather high both in young shoot and in leaves at flowering, thus this dangerous contaminant still remained mobile in the soil-plant system in the second year of the experiment (Table 8).

Summary

Summarizing the main conclusions from this two-year field trial, the following can be stated:

– While As, Cr, Cu and Zn loads significantly depressed the grain yield of wheat in the first year, these loads did not cause any grain loss in maize in the second year.

Apparently, the most soluble and toxic fractions became immobile in this acidic brown forest soil with clay illuviation or were washed into deeper layers.

– Among the 8 elements examined only Cd and Zn concentrations rose above the permissible level in wheat grain. However, plants growing on the control soil also showed relatively enhanced Cr, Zn, Pb, Ni, Fe, B, Mn, Cu and Al level as compared to wheat of other regions.

This is partly due to the soil characteristics and the polluted environment of the area. Grain is generally well protected genetically against most pollutants and if straw is ploughed in regularly, the polluting elements remain in soil.

– In the second year there was no depression in the grain, but in straw yield of maize. Hg and As concentrations stayed below the detectable level in grain (0.1 ppm), while these concentrations were around 1-2 ppm on the average in straw.

Further studies are needed with other crop varieties in order to clear the situation about plant background contamination and uptake.

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