Original scientific paper

Effect of soil contamination on alfalfa yield and quality in a long term field experiment

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Abstract

A long-term field experiment on microelement contamination was set up in spring of 1991 on a calcareous chernozem soil. Salts of 13 microelements ($AlCl_3$, $NaAsO_2$, $BaCl_2$, $CdSO_4$, K_2CrO_4, $CuSO_4$, $HgCl_2$, $(NH_4)_6Mo_7O_{24}$, $NiSO_4$, $Pb(NO_3)_2$, Na_2SeO_3, $SrSO_4$, $ZnSO_4$) were applied in four levels: 0, 90, 270 and 810 kg/ha. In this paper the results of the 13th year of the experiment are discussed. The test plant in this year was alfalfa. The main results are the following: The contamination is still detectable in the plant available (Lakanen - Erviö extraction) element fraction of soil. In the test plant the Se concentration due to the highest load increased many magnitude of order compared to the control plots. The As, Cd, Hg, Mo and Se treatments resulted in a yield that was not suitable for any utilisation. The after effect of As, Se, and highest Cr loads induced a moderate depression in the air-dry yield. The highest toxicity was observed in the highest Cd-treatment where almost the total yield perished.

Key words: contamination, soil, plant uptake, yield

Introduction

Our environment and especially soils are more and more exposed to the contamination of heavy metals and other potentially toxic elements. Sources of heavy metal contamination are: settlements, industry, traffic, agriculture, wastewater (Kadar, 1993; Meszaros et al., 1993; Izsaki & Debreceni, 1987; Tamas and Filep, 1995). The high trace element concentration may have a harmful effect on soil microorganisms, the quality of yield and groundwater (Csato, 1994).

Most metals present in soils are fixed. Only trace of them can be found in the soil solution but this fraction is determinative from ecological view. This fraction affects plant uptake and hence the contamination of complete food chain and groundwater (Kadar, 2005).

The results of laboratory experiments on plant element uptake may be misleading. The only way to investigate of the basics of soil contamination is a long-term field experiment. An extensive experiment has already been set up for the examination of heavy metal uptake by plants in Hungary (Kadar,1995). In this paper the results of the 13th year of this experiment are discussed.

We are looking for answers of the following questions: a) how did the mobilisable (ammonium-acetate + EDTA extractable) fraction change after heavy metal loads? b) which element concentration increase significantly in the plant after 13 years of the soil contamination? c) is there any effect on the alfalfa yield after 13 years of the soil contamination?

Material and methods

A long-term field microelement experiment was set up in spring of 1991 on a calcareous chernozem soil at the Experiment station of the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences in Nagyhörcsök. The ploughed layer of the growing site contained around 5% $CaCO_3$ and 3% humus and was very well supplied with Ca and Mn, satisfactory supplied with Mg and Cu, moderately well with N and K and poorly with P and Zn. The soil texture is loam with 40% clay + silt fraction. Half of its clay minerals are illite, one third is clorite and partly smectite. The pH (KCl) of the ploughed layer was 7.3. The groundwater depth was 15 m and the water balance was negative, tending to drought (Kadar, 2000). In the examined year (2004) the total precipitation was 607 mm which is above the 50 years average value, 590 mm.

Salts of the 13 microelements tested were applied at four levels in spring 1991, prior to maize sowing. The 13 x 4 = 54 treatments were set up in two replications giving a total of 104 plots in a split-plot design. The area of a plot was 21 m^2.

The loads were 0, 90, 270 and 810 kg/ha for each element in the form of $AlCl_3$, $NaAsO_2$, $BaCl_2$, $CdSO_4$, K_2CrO_4, $CuSO_4$, $HgCl_2$, $(NH_4)_6Mo_7O_{24}$, $NiSO_4$, $Pb(NO_3)_2$, Na_2SeO_3, $SrSO_4$, $ZnSO_4$. The extreme high doses are used for modelling the soil contamination levels.

Microelements were applied once on the spring of 1991. Next to the micronutrients N-P-K fertilizers were applied in the 100-100-100 kg/ha N, P_2O_5 and K_2O dose in every year.

The representative plant samples were made from at least 20 plants collected from the net plot area. Determination of plant element concentrations was carried out with ICP-AES method after cc. HNO_3 + H_2O_2 digestion. 20-20 soil core samples of each plot were united to get a representative sample. The mobilisable or plant available element fraction of soil (0.5 M ammonium-acetate + 0.02 M EDTA extractable; Lakanen and Ervio, 1971) was determined with ICP-AES method.

Results and discussion

The plant available or mobilisable soil element fractions of As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Se, Sr and Zn showed significant increment even after 13 years of contamination (Table 1). The highest increment can be found in case of As since the concentration of this element was low in the control soil. Only the Al concentration did not show any significant increase. Thus the contamination after 13 years of the beginning of the experiment is still detectable in the plant available element fraction of soil though the concentration values decreased significantly compared to the values measured in the first year of the experiment (Kadar et al., 2000).

In 2004 there was 4 harvest of alfalfa during the growing period. The concentrations were similar in each harvest. After 13 years of the soil contamination Al and Cd, and did not show any significant accumulation in the plant. While Se concentration in the plots with the highest load increased many magnitude of order compared to the control plots. The Cr gave also a 8-fold increment (Table 1). According to these values the As, Cd, Hg, Mo and Se treatments resulted in a yield that was not suitable for any utilisation.

Among the elements only As, Cd, Cr and Se had significant effect on the air-dry yield after 13 years of soil contamination. Table 3a and b. show that on the uncontaminated soil the sum of the 4 harvest gave 12 t/ha air-dry yield. 60% of the yield was gained from the first harvest. The autumn harvest gave less than 1 t/ha yield. The after effect of As, Se, and highest Cr loads induced a moderate depression in the air-dry yield. The total air-dry yield decreased significantly only in the As and Cd treatments. In case of Se only the last harvest gave significantly smaller yield compared to the control. The highest toxicity was observed in the highest Cd-treatment where almost the total yield was perished.

Table 1. Effects of treatments on the mobilizable element fraction of the ploughed layer in 2004, and alfalfa composition 13 years after the beginning of the experiment (calcareous chernozem soil, Nagyhörcsök)

	Load levels (kg/ha)				LSD	Mean		Load levels (kg/ha)				LSD	Mean
	0	90	270	810	5%			0	90	270	810	5%	
Soil (0-30 cm) mobilizable fraction mg/kg)							**Air-dried alfalfa hay status 2004 (mg/kg)**						
Al	86	87	83	87	12	86	**Sr**	101	165	210	372	64	212
Sr	28	43	61	94	15	57	**Al**	98	125	147	120	140	123
Ba	18	27	41	72	9	40	**Zn**	13	22	25	33	3	23
Pb	4	21	58	72	12	39	**Ba**	10	14	21	35	3	20
Ni	4	12	27	40	5	21	**Cu**	5.4	8.9	10.5	10.6	0.8	8.9
Cu	4	15	43	93	11	39	**Mo**	0.5	85	197	323	20	151
Zn	2	14	28	65	8	27	**Ni**	0.5	1.0	1.9	3.4	0.4	1.7
Mo	0.1	6	8	16	5	8	**Cd**	0.1	1.8	3.4	4.5	0.3	2.4
Cd	0.1	9	26	67	8	26	**As**	0.1	0.3	1.1	2.8	0.3	1.1
Cr	0.1	0.5	0.8	1.7	0.4	0.8	**Cr**	0.1	0.4	1.1	2.6	0.4	1.1
Se	0.1	0.7	1.2	2.1	0.5	1.0	**Se**	<kh	180	291	510	47	245
As	0.1	3	8	29	3	10	**Pb**	<kh	0.25	0.50	0.70	0.10	0.40
Hg	0.02	0.2	1.3	4.5	1.0	2	**Hg**	<kh	0.10	0.22	0.31	0.04	0.16

Table 2. Effects of selected treatments (As, Cd, Cr and Se) on the total alfalfa air-dry yield in 2004, 13 years after the beginning of the experiment, t/ha (calcareous chernozem soil, Nagyhörcsök, Hungary)

H†	Load levels (kg/ha)				LSD	Mean	H	Load levels (kg/ha)				LSD	Mean
	0	90	270	810	5%			0	90	270	810	5%	
Alfalfa hay air-dry yield (t/ha): **As treatment**							Alfalfa hay air-dry yield (t/ha): **Cd treatment**						
1st	7.2	7.2	6.8	4.8	2.5	6.5	1st	7.2	7.6	4.9	0.1	2.5	5.0
2nd	1.8	1.3	1.8	0.7	0.8	1.4	2nd	1.8	1.5	1.2	0.1	0.8	1.2
3rd	1.7	1.6	1.8	1.3	0.4	1.6	3rd	1.7	1.6	1.5	0.8	0.4	1.4
4th	1.0	1.0	1.0	1.0	0.4	1.0	4th	1.0	1.0	0.9	0.5	0.4	0.8
x	**2.9**	**2.8**	**2.8**	**2.0**	0.5	2.6	x	**2.9**	**2.9**	**2.1**	**0.4**	0.4	2.1
Σ	11.7	11.1	11.4	7.8	1.4	10.5	Σ	11.7	11.7	8.5	1.5	1.4	8.4
Alfalfa hay air-dry yield (t/ha): **Cr treatment**							Alfalfa hay air-dry yield (t/ha): **Se treatment**						
1st	7.2	8.0	7.6	7.9	2.5	7.7	1st	7.2	7.9	8.2	6.8	2.5	7.5
2nd	1.8	1.2	1.3	1.0	0.8	1.3	2nd	1.8	2.0	3.0	2.4	0.8	2.3
3rd	1.7	1.4	1.3	1.0	0.4	1.4	3rd	1.7	1.9	1.7	1.4	0.4	1.7
4th	1.0	0.9	0.8	0.5	0.4	0.8	4th	1.0	0.9	0.4	0.3	0.4	0.6
x	**2.9**	**2.9**	**2.8**	**2.6**	0.5	2.8	x	**2.9**	**3.2**	**3.3**	**2.7**	0.5	3.0
Σ	11.7	11.5	11.0	10.4	1.4	11.2	Σ	11.7	12.7	13.3	10.9	1.4	12.1

†H = harvest (cutting)

Conclusions

The contamination is still detectable in the plant available (Lakanen - Erviö extraction) element fraction of soil after 13 years of the beginning of the experiment. In the test plant the Se concentration due to the highest load increased many magnitude of order compared to the control plots. The As, Cd, Hg, Mo and Se treatments resulted in a yield that was not suitable for any utilisation. The after effect of As, Se, and highest Cr loads induced a moderate depression in the air-dry yield. The highest toxicity was observed in the highest Cd-treatment where almost the total yield perished.

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