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MICROELEMENTS IN POTATOES UNDER 'NORMAL' CONDITIONS, AND AS AFFECTED BY MICROELEMENTS IN MUNICIPAL WASTE COMPOST, SEWAGE SLUDGE, AND DREDGED MATERIALS FROM HARBOURS*

by

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1. INTRODUCTION

Most microelements mentioned in this paper belong to the heavy metals (specific gravity > 5); the terms microelements and heavy metals are used as synonyms here although this is not correct for arsenic, molybdenum, and borium.

The microelements B, Cu, Fe, Mn, Mo and Zn have long been of interest as essential plant nutrients. Main concern was to assess and establish the levels of plant-available micronutrients in soils needed for maximum growth.

In recent times more and more negative effects due to excessive levels of microelements in soils and crops have come into the picture, especially with respect to elements without a positive effect on crop growth: As, Cd, Cr, Hg, Ni, Pb.

Excessive levels of microelements may be harmful to the crop, but also to man and animals consuming the crop. Seemingly healthy crops may contain more of a microelement than is considered safe upon prolonged consumption. This is especially true for cadmium, regarded as one of the most hazardous heavy metals since it was found responsible for the Itai-Itai disease with many casualties in Japan.

To protect soils and crops against excessive levels of heavy metals, maximum permissible levels in sewage sludges for agricultural use have been established in the Netherlands and in many other countries. The Dutch levels are the lowest in the world. They are presented in table I, together with "guide" and "imperative" values for sewage sludges as well as for soils as proposed by the European Economic Community for its member states. Like in most countries, maximum permissible heavy-metal levels for soils have not yet been established in the Netherlands, and the same is true for municipal waste compost.

The concentrations in table I are expressed as total metals, although it is known that plant-availability of heavy metals is generally very low and dependent on soil factors as pH and contents of humus and clay. Moreover, concentrations in the plant depend on species, variety, part of the plant, age, etc. For these reasons it may be necessary to protect the food chain not only by setting limits to permissible concentrations

TABLE I. Maximum permissible concentrations (mg/kg DM) of heavy metals in sewage sludges for agricultural use in the Netherlands, together with "guide" and "imperative" values for sewage sludges and soils, proposed by the European Economic Community.

Element	the Netherlands	European Economic Community			
	sewage sludge	sewage sludge		soils	
		guide	imperative	guide	imperative
As	10	-	-	-	-
Cd	10	20	40	1	3
Cu	600	1000	1500	50	100
Cr	500	750	-	50	-
Hg	10	16	-	2	-
Ni	100	300	400	30	50
Pb	500	750	1000	50	100
Zn	2000	2500	3000	150	300

in soils and soil additives, but also to those in crops or parts of the crops used for consumption. For arsenic, cadmium, mercury and lead, elements considered to be the most hazardous, the following maximum permissible levels in potatoes have been proposed: As 0.1, Cd 0.1, Hg 0.02 and Pb 0.2 mg per kg fresh material. In this paper these values are assumed to correspond with the following values in mg/kg DM (dry matter): As 0.4, Cd 0.4, Hg 0.08 and Pb 0.8 (based on a DM content of potato tubers of 25%).

The heavy-metal concentrations in potatoes reported here are the results of investigations done at the Institute for Soil Fertility with municipal waste compost, sewage sludge, and reclaimed dredged material from Rotterdam harbours; these results are compared with concentrations found under "normal" conditions.

The analytical methods used have been described by Vierveijzer *et al.* (1979). The tubers were either washed only or peeled and washed before analysis. Peeling may have some effect on the heavy-metal concentrations of the tuber. Concentrations may be twice as high in the peelings compared with the inner parts of the tuber (Brunt, 1981).

2. EXPERIMENTS WITH MUNICIPAL WASTE COMPOST (MWC)

2.1. Effect of heavy-metal accumulation in soils, resulting from MWC application over a long period, on heavy-metal concentrations in crops

This effect is studied in a micro-plot experiment with three sandy soils varying in humus content, and three marine loam soils varying in clay content, referred to as clay soils in this paper. MWC has been applied to these soils at rates of 0, 10, 20, 30 and 40 tonnes/ha every two years in the period 1948-71 and every year in the period 1972-79. MWC applications were then stopped. Five soil-pH levels were subsequently substituted for the five mineral nitrogen application levels that had been present up to that time.

MWC used in this experiment was supplied by the VAM Waste Disposal Company, which produces more than 90% of the total MWC production in the Netherlands. Mean heavy-metal concentrations in the compost, determined as from 1971, were as follows: As 6, B 25, Cd 8, Co 13, Cr 230, Cu 745, Fe 65940, Hg 4, Mn 620, Mo 36, Ni 130, Pb 1280 and Zn 2420 mg/kg DM.

Soil heavy-metal concentrations have been determined in 1971, 1975 and 1979. Values for 1975 for the lowest (= zero) and highest MWC application rate (15 x 40 t/ha), and for the sandy soils compared with the clay soils are presented in table II. Concentrations generally increased rather strongly, except when they were already high without added MWC, e.g. manganese in the clay soils.

Potatoes were grown in 1973 and analyzed for a number of heavy metals. Results, again for the sandy soils compared with the clay soils and the lowest compared with the highest MWC application rate (13 x 40 t/ha), are presented in table III. The values are means for the five mineral N application rates then existing. The table shows that the heavy-metal concentrations in the tubers were only slightly affected by MWC, even at the highest rate. Only for copper and zinc was there a statistically significant increase due to MWC. Cadmium decreased rather than increased.

TABLE II. Average concentrations of microelements (mg/kg DM) in three sandy soils and three clay soils, without MWC and with MWC (= following 15 applications of 40 t MWC/ha in the period 1948-75).

Element	Without MWC		With MWC	
	sandy soils	clay soils	sandy soils	clay soils
As	2.2	16.4	4.2	17.5
B	1.2	3.0	1.9	3.0
Cd	0.24	0.88	0.76	1.51
Co	1.18	10.06	3.49	12.13
Cr	18	85	31	101
Cu	22	32	76	106
Fe	2400	30000	6200	33400
Hg	0.10	0.14	0.42	0.52
Mn	89	882	137	838
Mo	0.34	0.60	1.18	1.67
Ni	2.1	34.7	8.7	43.6
Pb	26.5	56.6	144	180
Zn	38	126	206	348

TABLE III. Average concentrations of microelements (mg/kg DM) in potato tubers from three sandy soils and three clay soils without MWC and with MWC (= following 13 applications of 40 t MWC/ha in the period 1948-73).

Element	Without MWC		With MWC	
	sandy soils	clay soils	sandy soils	clay soils
Cd	0.12	0.06	0.07	0.05
Cr	0.4	0.2	0.3	0.3
Cu	4.4	4.0	5.3	5.0
Fe	14	35	16	27
Mn	3	2	2	3
Ni	0.1	0.3	0.1	0.2
Pb	0.7	0.9	0.7	1.1
Zn	11	9	16	10

Concentrations of lead were rather high compared with the maximum permissible level (0.8), but that may be due to analytical problems that still existed with lead at that time.

2.2. MWC as a soil amendment, including its use as a plant substrate

In 1972 a light sandy soil and a heavy fluvial clay soil were mixed with MWC in the following soil/MWC (v/v) ratios: 100/0, 90/10, 80/20, 50/50 and 0/100. These mixtures were placed in 140-l vessels equipped to catch drainage water. Microelement concentrations in the soils and the MWC are presented in table IV, together with those in sewage sludges used in experiments which will be referred to later in this paper.

TABLE IV. Microelement concentrations (mg/kg DM) in a sandy soil and a clay soil, and in MWC and sewage sludges used in experiments described in this paper.

	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
sandy soil	2	0.3	19	2	2287	0.1	67	8	17	14
clay soil	12	1.1	69	77	36356	0.1	1024	42	56	151
MWC	4	2	157	618	57550	2.9	622	79	1208	2262
*Sewage sludges**										
Almelo	15	102	996	1410	48200	2.1	1275	232	294	1852
Alkmaar	11	10	86	483	10900	7.8	310	29	455	1818
Apeldoorn	8	4.4	515	542	11635	3.7	124	56	1580	1269
Assen	6	2.5	148	497	29675	5.9	327	22	282	984
Eindhoven	12	168	1800	3422	54176	3.1	1190	336	1874	5249
Heerlen	10	4.4	83	197	11653	8.4	248	24	195	931
Leeuwarden	46	2.9	193	933	26536	27.5	1084	46	538	2391
Leiden	20	135	1693	1084	25841	4.9	625	934	637	5533

* Sewage sludges are presented in alphabetical order according to the names of the towns of origin

In 1976 potatoes were grown on the soil/MWC mixtures. The microelement concentrations in potato tubers, peeled and washed before analysis, are presented in table V for the soil/MWC mixtures 100/0, 90/10 and 0/100. MWC decreased tuber Cd, Fe and Mn, and increased Mo, Pb and Zn. However, even in tubers grown on the 100% MWC substrate, microelement concentrations were not excessive. Results for Cu were erroneous due to copper contamination from a mill, as was found out later.

TABLE V. Microelement concentrations (mg/kg DM) in potato tubers from a sandy soil and a clay soil, mixed with MWC in the following soil/MWC-ratios: 100/0, 90/10 and 0/100% by volume.

Element	Sandy soil		Clay soil		
	MWC, % by volume		MWC, % by volume		
	0	10	0	10	100
As	0.020	0.016	0.013	0.014	0.008
B	5.4	5.7	6.2	6.6	5.5
Cd	0.275	0.170	0.253	0.160	0.100
Cr	0.070	0.035	0.040	0.030	0.160
Cu	(erroneous results)				
Fe	21.3	17.9	20.1	16.4	15.5
Hg	0.002	0.003	0.003	0.003	0.002
Mn	9.5	5.6	5.8	4.9	4.4
Mo	0.29	0.35	0.08	0.19	0.77
Ni	1.1	1.2	2.5	1.0	0.5
Pb	0.1	0.3	0.2	0.4	0.6
Zn	22.1	31.1	14.0	19.7	21.6

3. EXPERIMENTS WITH SEWAGE SLUDGE

3.1. Sewage sludge from the town of Leeuwarden as a soil amendment or plant substrate

In 1972 an experiment was started with sewage sludge from the town of Leeuwarden as a soil amendment, including its use as a plant substrate. The sludge, after having been dewatered on drying beds, was mixed with the same sandy and clay soils as described before in the following soil/sludge-ratios: 100/0, 95/5, 90/10. 80/20, 60/40, 30/70 and 0/100% by volume. The mixtures were placed in 140-l vessels equipped to collect drainage water. The concentrations of microelements in the sludge are reported in table IV. The concentrations of arsenic, copper, mercury, lead and zinc were above the maximum permissible levels in sludge for agricultural use.

Potatoes were grown in the soil/sludge mixtures in 1976. Microelement concentrations in the tubers, peeled and washed before analysis, are presented in table VI for the soil/sludge-ratios 100/0, 90/10 and 0/100% by volume. Concentrations of arsenic, copper, mercury, molybdenum and zinc have increased by admixing with sludge, but not to extreme levels. Concentrations of the most critical elements As, Cd, Hg and Pb remained well below the maximum permissible levels mentioned in the introduction.

3.2. Sewage sludges from the towns of Apeldoorn, Assen, Eindhoven, Heerlen and Leiden compared with that from Leeuwarden as plant substrates

The sludges were collected from drying beds, after several months of dewatering and ripening, except the sludges from Apeldoorn and Leiden, which were collected from landfills. Microelement concentrations in the sludges are presented in table IV. Concentrations in the sludges from Assen and Heerlen were in agreement with the recommendations for agricultural use (table I). Cd, Cr, Cu, Ni, Pb and Zn concentrations in the sludges from Eindhoven and Leiden and the Pb concentration in the

TABLE VI. Microelement concentrations (mg/kg DM) in potato tubers from a sandy soil and a clay soil, mixed with air-dried sewage sludge from Leeuwarden in the following soil/sludge-ratios: 100/0, 90/10 and 0/100% by volume.

Element	Sandy soil		Clay soil		
	sludge, % by volume		sludge, % by volume		
	0	10	0	10	100
As	0.024	0.049	0.008	0.017	0.056
B	5.9	3.7	5.2	4.1	4.7
Cd	0.340	0.220	0.200	0.188	0.135
Cr	0.105	0.005	0.030	0.030	0.005
Cu	5.6	7.5	5.4	6.0	8.6
Fe	20.2	16.9	16.3	16.8	18.9
Hg	0.003	0.006	0.001	0.004	0.005
Mn	10.1	6.7	5.4	5.2	7.3
Mo	0.25	0.47	0.11	0.39	1.59
Ni	0.3	0.9	1.9	0.7	0.5
Pb	0.2	0.2	0.0	0.1	0.1
Zn	19.4	30.4	13.4	22.6	30.6

sludge from Apeldoorn were too high. The concentrations of some elements were extremely high: Cd, Zn (Eindhoven, Leiden), Cu (Eindhoven), Ni (Leiden). In 1972, the sludges were placed in 140-l vessels as described before.

Microelement concentrations in potato tubers grown on the sludges in 1976 are presented in table VII. In tubers grown on the sludges of Eindhoven, Leiden and Heerlen, of the most critical elements As, Cd, Hg and Pb, only Cd concentrations were above the permissible level. Ni concentration was extremely high in tubers grown on the sludge from Leiden, which produced an extremely low yield. Manganese was rather low in tubers grown on the sludges from Apeldoorn and Leiden, leaf symptoms indicating Mn deficiency.

TABLE VII. Microelement concentrations (mg/kg DM) in potato tubers grown on sewage sludges from various towns, used as plant substrates.

Element	Sewage sludge from:					
	Leeuwarden	Apeldoorn	Leiden	Eindhoven	Assen	Heerlen
As	0.055	0.008	0.006	0.003	0.010	0.015
B	4.7	5.1	6.3	4.7	4.0	3.8
Cd	0.135	0.370	0.870	0.965	0.200	0.550
Cr	0.005	0.015	0.030	0.013	0.290	0.005
Cu	8.6	7.7	5.6	7.7	7.2	7.3
Fe	18.9	13.1	15.3	13.3	19.3	17.7
Hg	0.005	0.002	0.003	0.013	0.010	0.002
Mn	7.3	4.5	8.0	3.8	7.3	7.1
Ni	0.5	3.5	17.1	6.0	1.2	2.5
Pb	0.1	0.5	0.3	0.1	0.0	0.0
Zn	30.6	40.8	30.5	34.7	30.6	29.8

3.3. Liquid sewage sludge as an organic fertilizer

Since 1972 liquid sewage sludge from the towns of Almelo and Alkmaar has been applied to a sandy soil in 140-l vessels at annual rates of 0, 7½, 15 and 22½ tonnes DM/ha. The microelement concentrations of the sludges are reported in table IV. The sandy soil in this experiment was the same as that mentioned in the table. The sludge from Alkmaar complies with the requirements for agricultural use mentioned in the Dutch Guideline, the sludge from Almelo is marked by high concentrations of cadmium, chromium, copper and nickel.

In 1976, after the fifth sewage sludge application, potatoes were grown. Microelement concentrations in the tubers are presented in table VIII for the zero and highest sludge treatment. Especially cadmium and nickel concentrations were increased by the sludge from Almelo, and so was zinc, although the Zn concentration of the Almelo sludge was similar to that of the Alkmaar sludge. This may be explained by the higher nitrogen and lower lime content of the sludge from Almelo, resulting in a decrease in soil pH. The sludge from Alkmaar decreased tuber manganese and increased molybdenum to some extent.

TABLE VIII. Microelement concentrations (mg/kg DM) in potato tubers grown on a sandy soil without sewage sludge, or with 5 annual applications of liquid sewage sludge from the towns of Almelo and Alkmaar amounting to 22.5 t DM/ha per year.

Element	Sewage sludge, t DM per ha per year		
	0	22.5	22.5
		Almelo	*Alkmaar*
As	0.028	0.009	0.027
B	6.0	4.8	5.7
Cd	0.265	1.325	0.303
Cr	0.050	0.042	0.030
Cu	6.0	7.8	4.6
Fe	29.2	23.5	15.4
Hg	0.003	0.001	0.001
Mn	11.0	12.0	4.7
Mo	0.39	0.41	0.54
Ni	0.4	6.4	0.3
Pb	0.2	0.2	0.3
Zn	19.7	50.4	19.5

3.4. Sewage sludge as an organic fertilizer in large-scale field experiments

Since 1977, sewage sludges from mainly domestic water after dewatering on drying beds have been applied at rates of 0, 10 and 20 t DM/ha per 2 years to six arable soils on experimental farms in different parts of the country: "A.G. Mulderhoeve"in Emmercompascuum (AGM 316), "Van Bemmelenhoeve" in the Wieringermeerpolder (BEM 265), "Feddemaheerd" in Kloosterburen (FH 86), "De Kandelaar" in Biddinghuizen (KL 289), "Rusthoeve" in Colijnsplaat (RH 400) and "Wijnandsrade" in Wijnandsrade (WR 158). This research is done in co-operation between the Research Station for Arable Farming and Field Production of Vegetables in Lelystad and the Institute for Soil Fertility in Haren, and is sponsored by the Foundation for

Applied Research of Waste Water in Rijswijk. The soils are loams of marine origin, except a reclaimed peat soil (AGM 316) and a loess soil (WR 158). To AGM 316, sludge was applied every year to the present, except 1979, and only to this field was it applied in liquid form. Heavy-metal concentrations in the sewage sludges applied were all well below the upper limits set in the Guideline.

So far, potatoes have been grown on each of the experimental fields as indicated in table IX. This table presents tuber concentrations of the heavy metals that generally best reflect the effects of sludge application. Up to now, at most experimental sites sludge gave only a small increase in copper concentration of the tubers, and increased cadmium concentration in experiments RH 400 (1979) and WR 158 (1978).

TABLE IX. Concentrations of Cd, Cu, Mn, Ni and Zn in mg/kg dry matter in potato tubers from experimental fields at various locations, treated with sewage sludge at rates of 0, 10 and 20 t DM/ha every two years since 1977 (AGM 316 every year, except 1979).

Trial	Year	Sewage sludge, t/ha	Element				
			Cd	Cu	Mn	Ni	Zn
AGM 316	1978	0	0.13	2.9	7	0.0	15
		10	0.11	3.8	8	0.0	17
		20	0.08	4.1	8	0.0	17
AGM 316	1980	0	0.03	3.5	7	0.1	12
		10	0.05	3.5	7	0.1	15
		20	0.04	3.6	7	0.0	12
FH 86	1979	0	0.12	1.5	3	0.0	7
		10	0.11	2.3	5	0.1	10
		20	0.10	1.8	4	0.1	7
BEM 265	1979	0	0.00	4.6	4	0.4	13
		10	0.01	5.3	5	0.4	13
		20	0.00	4.9	5	0.4	15
KL 289	1977	0	0.37	4.6	6	0.3	14
		10	0.34	5.0	5	0.3	13
		20	0.33	5.5	5	0.3	14
KL 289	1981	0	0.09	5.3	5	0.1	15
		10	0.06	6.0	6	0.1	17
		20	0.00	5.8	6	0.1	18
RH 400	1979	0	0.03	3.7	4	0.5	13
		10	0.02	5.2	4	0.4	11
		20	0.10	5.3	4	0.5	12
WR 158	1978	0	0.19	4.4	5	0.0	18
		10	0.44	5.7	5	0.1	22
		20	0.43	4.8	5	0.1	22
mean values		0	0.12	3.8	5	0.2	13
		10	0.14	4.6	6	0.2	14
		20	0.13	4.5	5	0.2	14

4. SOILS FROM RECENTLY RECLAIMED LANDFILLS CONTAINING CONTAMINATED RIVER SEDIMENTS FROM ROTTERDAM HARBOUR BASINS AS COMPARED WITH SOILS RECLAIMED FROM UNCONTAMINATED RIVER SEDIMENTS CENTURIES AGO

River sediments have become more and more contaminated with heavy metals in recent times (Salomons and De Groot, 1978). This is especially true for sediments from the rivers Rhine and Meuse, and Rotterdam harbour basins act as a sink for these sediments. Largely uncontaminated marine sediments are transported inland with the tidal flux. For this reason heavy-metal contamination of dredged materials decreases from eastern to western harbour basins in the Rotterdam area. Dredged materials from the western basins are transported back to sea, those from the eastern basins are pumped to landfills, which after a number of years of ripening may be reclaimed. Studies have been performed as to growth and heavy-metal uptake by various food crops grown in soils from these landfills (Van Driel *et al.*, 1975; Smilde and Van Driel, 1979).

Among the most contaminated landfills is the Kralingerpolder, finished in 1972. Every landfill contains sites with lower and higher clay (and OM) contents, corresponding with lower and higher heavy-metal contents, as a consequence of differential settling of coarse and fine particles in the dredged material. Heavy-metal concentrations in soil samples from sites with a low and a high clay content are presented in table X. Data for similar arable soils, reclaimed centuries ago from uncontaminated fluvial sediments, are given as a reference. Also in these soils heavy-metal concentrations increase with increasing clay content.

Table XI presents heavy-metal concentrations of potato tubers grown in these soils. Although concentrations are generally higher for the contaminated landfill soils, they remain within acceptable limits, notably of the critical elements arsenic, cadmium, mercury and lead.

Leaves were also sampled for heavy-metal analysis in this experiment. As shown in table XII, leaf concentrations are higher than tuber concentrations, and differences between contaminated and uncontaminated soils, notably for cadmium, copper and zinc, are more pronounced.

TABLE X. Microelement concentrations (mg/kg DM) in uncontaminated and contaminated river sediments (fluvial clay soil and reclaimed dredged material from Rotterdam harbours, respectively), each with a low and a high clay content.

Sediment	Uncontaminated		Contaminated	
clay content	low	high	low	high
As	8	15	35	69
Cd	0.2	0.3	8.9	16.3
Cr	53	83	248	411
Cu	12	14	113	206
Fe	18700	29400	26500	37900
Hg	0.04	0.07	4.5	9.2
Mn	659	511	631	790
Ni	25	32	39	66
Pb	19	29	180	331
Zn	58	83	697	1240

TABLE XI. Microelement concentrations (mg/kg DM) in potato tubers grown on uncontaminated and contaminated fluvial sediments.

Sediment	Uncontaminated		Contaminated	
clay content	low	high	low	high
As	0.02	0.04	0.07	0.08
Cd	0.08	0.08	0.21	0.21
Cr	0.25	0.17	0.09	0.30
Cu	5.1	4.6	8.3	5.1
Fe	32	41	50	48
Hg	0.005	0.005	0.013	0.012
Mn	2.4	2.0	3.1	3.1
Ni	0.13	0.07	0.13	0.24
Pb	0.11	0.11	0.41	0.33
Zn	10	10	16	18

TABLE XII. Microelement concentrations (mg/kg DM) in leaves of potato grown on uncontaminated and contaminated fluvial sediments.

Sediment	Uncontaminated		Contaminated	
	low	high	low	high
As	0.13	0.51	0.75	0.56
Cd	0.72	0.75	2.32	3.91
Cr	0.81	0.70	1.42	1.02
Cu	8.6	7.4	18.2	22.4
Fe	308	517	357	301
Hg	0.136	0.140	0.113	0.132
Mn	84	27	17	33
Ni	1.01	0.87	0.92	1.49
Pb	7.85	7.99	7.12	6.88
Zn	129	90	216	254

5. RESULTS OF A SURVEY OF CONCENTRATIONS OF ARSENIC, CADMIUM, MERCURY AND LEAD IN POTATOES FROM "NORMAL" SOILS

As the necessity of preventing accumulation of heavy metals in food crops became evident, the question arose which concentrations should be regarded as "normal". To answer this question, representative samples of the most important food crops were taken from all parts of the country and analysed for As, Cd, Hg and Pb. Soil samples were taken along with crop samples from the same sites. The investigation is conducted by the Institute for Soil Fertility (Van Goor) in cooperation with other institutes.

Data on potato tubers are presented in table XIII (courtesy Van Goor). Concentrations of the above mentioned elements were found to be below the maxima proposed for potatoes: 0.4, 0.4, 0.08, and 0.8 mg/kg DM for As, Cd, Hg and Pb, respectively.

TABLE XIII. Arsenic, cadmium, mercury and lead concentrations (mg/kg DM) in 96 samples of potato tubers grown on representative Dutch soils.

	As	Cd	Hg	Pb
mean	0.052	0.112	0.012	0.12
maximum	0.172	0.360	0.068	0.36
minimum	0.008	0.012	0.0004	0.04
95% limit	0.120	0.236	0.040	0.24

6. NORMAL, (TOO) LOW AND (TOO) HIGH CONCENTRATIONS OF MICROELEMENTS IN POTATOES

Based on data from the experiments mentioned before and data from the literature (Anon., 1982; Baerug and Martinsen, 1977; Diez and Rosopulo, 1976; Kick and Poletschny, 1972; Varo *et al.*, 1980; Lindsay, 1978; Loman, 1979; Schmid *et al.*, 1975; Webber, 1979) tentative values for normal, (too) low and (too) high concentrations of microelements in potatoes are presented in table XIV. (Too) low may point to the risk of micronutrient deficiency in plants, but may be desirable in the case of highly toxic elements as As, Cd, Hg and Pb. (Too) high may be dangerous for the health of the consumer (As, Cd, Hg, Pb) or for the crop (Cu, Ni, Zn).

TABLE XIV. "Normal" (= mean), (too) "low" and (too) "high" concentrations of microelements in mg/kg DM in potato tubers.

Element	(Too) low	Normal	(Too) high
As	0.01	0.05	0.40
B	4	6	8
Cd	0.01	0.10	0.40
Co	0.02	0.04	0.06
Cr	0.1	0.3	1.0
Cu	2	5	10
Fe	10	25	50
Hg	0.001	0.020	0.080
Mn	4	8	16
Mo	0.1	0.3	3.0
Ni	0.1	0.5	5.0
Pb	0.04	0.16	0.80
Zn	10	20	50

7. CONCLUSION

The potato crop seems to be fairly insensitive to excess heavy metals in the soil. Only under rather extreme experimental conditions, (e.g. with heavily contaminated sludges as plant substrates) not likely to occur in farm practice,was damage to the crop apparent; a potential hazard to human health resulting from too high a cadmium concentration in the tubers, existed only under these extreme conditions. Potatoes may therefore be a potential crop for production on contaminated soils where other crops fail because of their excessive heavy-metal uptake.

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