Possible trace metal load from fertilizers

M. Sager

Zur möglichen Fracht an Spurenmetallen aus Düngemitteln

1. Introduction

In central Europe, application of fertilizers is essential to obtain sufficient food for its rather densely populated areas. As there is a tendency towards decoupling between cropping and animal-keeping facilities, nutrient N- and P-compounds have been increasingly added to the soil as inorganic salts, so called "mineral-fertilizers". For some time, there has been serious concern about the simultaneous input of unwanted trace elements, present in these mineral fertilizers, like Cd or Cr. These trace elements are much more likely available to biota than those amounts bound to the soil (reviewed e.g. by SALOMONS and FÖRSTNER, 1984; SAGER, 1992). At background level, parts of trace element contents can be found in silicates, sulfides, refractory oxides, as well as tightly bound to humic material, whereas it is expectable to encounter trace element contents of mineral fertilizers in a rather soluble form.

Due to this concerns, trace element contents of mineral fertilizers sold all over Austria have been controlled by state authorities, and threshold values for e.g. Cd and Cr have been set, to reject contaminated products from the market. Before the onset of intense control, the annual Cd input to the Lowlands of eastern Austria has been estimated to be 1.67 g/ha due to samples from spring 1983, for the fertilization rate usual at this time (43.5 kg P_2O_5/ha) (OBERLÄNDER and KÖCHL, 1984).

On the other hand, there is continuous deposition of dust and wet precipitation upon the entire agriculturally used area, which also may contain unwanted trace elements, emanating from combustion or corrosion processes. It may be worth while comparing these sources of input on a nation-wide scale.

Within the soil, trace elements can be either transformed to less soluble forms, they can move to living biota (e.g. agricultural plants), or they may be eluted into the watershed, thus contributing to diffuse pollution. Additional load of surface waters with nutrients and trace metals derives from soil erosion processes, which is largely influenced by the kind of crop grown. In Austria, about 20 % of arable land are estimated to suffer from erosion, preferably if maize, wine or turnips are grown (KUMPFMÜLLER, 1989).

Within this work, data from samples of the period 1986–1994 have been evaluated, the period before Austria

Zusammenfassung

Es wird die Fracht an Spurenelementen (As, Cd, Co, Cr, Ni, Pb) berechnet, die jährlich durch die Aufbringung von Mineraldüngern in landwirtschaftlich genutzte Böden gelangt. Hierfür wird der durchschnittliche Spurenelementgehalt jener Düngemittel, die im Zuge der staatlichen Düngemittelkontrolle im Osten Österreichs im Zeitraum 1986–94 beprobt wurden, sowie die Menge an Mineraldüngern, die in Österreich in der Saison 1992/93 verkauft wurden, herangezogen. Die Phosphorkomponente liefert viel höhere Spurenelementgehalte als die Stickstoffkomponenten. Die bekannte Korrelation zwischen nominellem Phosphorgehalt und gefundenem Cadmiumgehalt wird bestätigt. Im Vergleich mit dem Ausbringen von Klärschlamm bringt die mineralische Düngung signifikant niedrigere Frachten an Blei und Nickel in die Böden. Etwa 80 % der Gesamtfracht an aus mineralischen Düngemitteln eingebrachtem Chrom stammt aus Thomasphosphat und Thomaskali. Regionale Unterschiede infolge verschiedener Aufbringungsmengen und verschiedenen Feldfrüchten führen zu Unterschieden in der Spurenelementbeladung pro landwirtschaftlicher Nutzfläche bis zum Sechsfachen. Ferner wird der Eintrag aus Düngemitteln mit dem Eintrag aus der atmosphärischen Deposition auf die Ackerfläche verglichen mit Daten aus 1989/90. Im großen und ganzen übersteigt die durch Ferntransport über die Atmosphäre eingebrachte Fracht von Blei und Cadmium den Eintrag aus den Mineraldüngern, während es für Chrom umgekehrt ist.

Schlagworte: Düngemittel, Spurenelementfracht, atmosphärische Deposition, Cd, Cr.

Summary

The annual load of various trace elements (As, Cd, Co, Cr, Ni, Pb) deriving from the application of mineral fertilizers to arable soils, has been calculated. As a data base, averaged trace element contents of fertilizers, sampled due to state control of fertilizers within the period 1986–94, as well as the amount of mineral fertilizers sold in Austria in the cropping season 1992/93, are compiled. The phosphate component supplies significantly higher trace element loads than the nitrogen components. The well-known correlation between nominal phosphorus contents and cadmium contents found, is reconfirmed. In comparison with the application of sewage sludge, the input of lead and nickel from mineral fertilizers into arable soils is significantly lower. Approximately 80 % of total chromium from mineral fertilizers emanates from basic slag and basic slag potash. Regional differences in application rates and crops lead to differences in trace element loads per farmed area up to 6-fold. Further on, inputs from fertilizers have been compared with input by atmospheric deposition, based on data from 1989/90. On the whole, as a source of lead and cadmium, long-range transport via the atmosphere supersedes the input from mineral fertilizers, whereas in case of chromium, it is reverse.

Key words: fertilizers, trace element load, atmospheric deposition, Cd, Cr.

joined the European Union, and compared with atmospheric deposition data from 1990. Due to current investigations and controls, the Cd, Cr and Ni contents in mineral fertilizers has not significantly changed since the 1. 1. 1995, when Austria joined the EU. Discrimination of the estimated total load of trace elements per surface according to their source is necessary to find risks as well as strategies against. Flux from fertilizers is influenced by the local farming practice, as well as from fertilizer production. Flux from total deposition, however, cannot be influenced by the farmer, because it derives from atmospheric pollution. Second, input via fertilizers occurs discontinuously to the soil, whereas input via deposition is continuously, either to the soil or plant surface.

2. Material and methods

Some samples were sent by companies, which wanted to sell their product, prior to its admission (or rejection) to the Austrian market, for an official investigation. The other samples were taken as control samples from the authorities themselves. All analytical data presented here were obtained at the Federal Research Centre for Agriculture, Vienna (till 1994: Landwirtschaftlich-Chemische Bundesanstalt) by common atomic absorption methods (flame AAS; graphite furnace for low levels, hydride-AAS for arsenic).

3. Trace element contents of mineral fertilizers

About 1500 data-sets were compiled. Grouping was done according to types of fertilizers, taken from the Austrian Statistics of Fertilizers.

Within each data set, Gaussian distribution seemed probable, and the average values could be calculated (see table 1). In control samples, data for element contents, which have not been restricted by law, were not done in any case, thus the number of single data varies. In case of cadmium, however, a subdivision of NPK-fertilizers due to their nominal P-contents was possible (table 2).

Data for Cu, Zn, and Mo were not taken into account. These trace elements are essential for plant growth, and thus sometimes artificially added. For reasons of control, samples of declared Cu/Zn/Mo-contents were preferably analyzed, giving a bias to the data set.

Recent average data from mineral fertilizers sampled in Austria after joining the common market at 1. 1. 1996, are added in brackets. They are on the whole within the same range. Due to open borders since this time, the amounts of fertilizers sold in Austria do not necessarily reflect the input to the arable soils within the country.

4. Trace metal load by fertilizers

A compilation of data about the amounts of various mineral fertilizers, sold within the growth period 1992/93, has been available. The sold amount times concentration gives the absolute load of trace elements introduced into Austrian soils. The detailed data can be easily calculated for each political district. Some districts, however, cover quite different types of landscape and landuse.

The calculated annual trace element load of Austrian soils due to the input by inorganic fertilizers, with respect to different types is shown in Table 3.

The same figures in relative amounts are expressed in Table 4. K-salts without any P or N-component are excluded from statistics. The contribution of N-only products is quite low; if it is taken into account, they make half of the overall weight. The fields, for which no data have been available, are of minor economic importance and can be omitted in absolute terms. Cr, Ni and Cd loads mainly derive from the P-component as such. The high Co-load from diammonium phosphate may be accidentially. Basic slag potash, which is frequently very high in Cr and Ni, is fortunately rarely used. In case of NPK-multinutrient-fertilizers, the number of nominal nutrient contents mixtures is too large to be given in detail, and the number of analyzed samples per nominal composition is too small to yield accurate results; therefore the average of all respective samples was taken into consideration.

The trace element contents of commercial NPK-multinutrient fertilizers is shown in Table 5 together with their contents of other solid substrates of ecological significance, as well as the values for the mean crust. (Note that the soils were dissolved with aqua regia, whereas all other data refer to total decomposition; aqua regia does not deliver complete regain of e.g. Cr, Pb and Ni). The fertilizers are rather high in Cd and Cr, medium in As, and quite low in Co, Pb and Ni. Substitution of the inorganic fertilizers by sewage sludges, however, would significantly worsen the situation, except for Cadmium. As an example, the mean trace element contents of sewage sludges, which have been analyzed in our institute within the period 1987-92, is given for comparison.

Table 2: Average Cd versus average P-contents of mineral NPK-fertilizers
Tabelle 2: Gegenüberstellung durchschnittlicher Cadmiumgehalte und durchschnittlicher Phosphatgehalte mineralischer NPK-Dünger

Type	% P_2O_5	tons annually sold	Cd (mg/kg)
NPK 15/5/20	5	4 554	1.7
NPK 15/8/20	8	619	1.5
NPK 20/8/8	8	45 084	1.5
NPK 15/10/10	10	37 503	1.7
NPK 20/10/10	10	3 306	3.5
NPK 12/12/17	12	14 785	4.2
NPK 6/12/24	12	24 466	3.3
NPK 13/13/21	13	43 147	3.8
NPK 15/15/15	15	63 904	3.9
NPK 9/15/15	15	6 199	3.0
Basic slag	10-16	28 065	5.2
Super phosphate	16-19	7 624	4.9
Hyper phosphate	26-32	16 202	7.0
Triple phosphate	42-45	4 900	14.4
			r = 0.958
			(N = 14)

Table 1: Average trace element contents of mineral fertilizers (mg/kg)
Tabelle 1: Durchschnittliche Spurenelementkonzentrationen in Mineraldüngern

Type of fertilizer	tons annually sold	Co	As	Pb	Cd	Cr	Ni
Ammonium nitrate lime	3 814	0.2	0.15	0.9	0.17	1.0	0.95
Ammonium sulfate	7 113	0.2	0.15	0.9	0.17	1.0	0.95
Urea	8 439	0.2	0.15	0.9	0.17	1.0	0.95
Calcium nitrate	108	0.2	0.15	0.9	0.17	1.0	0.95
Nitrogen-Magnesia	1 720	0.2	0.15	0.9	0.17	1.0	0.95
Basic slag	28 065	X	X	4	5.2	2490	19
Super phosphate	7 624	< 0.25	X	14	4.9	35	20
Hyper phosphate	16 202	0.8	X	10.6	7.0	76	13
Triple phosphate	4 900	X	9.8	2.6	14.4	79	58
PK 0/18/18	13 045	X	X	4	4.9	83	14
PK 0/10/30	3 461	X	X	X	X	X	X
PK 0/15/30	41 078	0.3	2.5	3	4.2	42	14
Hyperkali	21	X	X	X	5.0	X	X
NP 20/20/0	2	2	11.5	4	7.8	184	26
Basic slag potash	1 556	X	6.8	2	1.6	738	7
P 16/48/0	16 285	2.9	X	3	6.8	4	4
NPK (all types)	51 853	2.6	7.0	2.8	3.1	48	11
[NPK from 1995/96]				*[5.1]*	*[2.6]*	*[42]*	*[9.5]*

X ... no data available

Table 3: Trace element load from inorganic fertilizers in absolute terms
Tabelle 3: Spurenelementkonzentrationen in anorganischen Düngemitteln in Absolutmengen

Type	Nutrient contents	tons sold	Co(kg)	As(kg)	Pb(kg)	Cd(kg)	Cr(kg)	Ni(kg)
Ammonium nitrate lime	N/26-28 %	293 814	58,76	44,07	264,43	49,95	293,81	279,12
Ammonium sulfate	N/20-21 %	7 113	1,42	X	6,40	1,21	7,11	6,76
Urea	N/46 %	8 439	1,69	X	7,60	1,44	8,44	8,02
Calcium nitrate	N/15.5 %	108	0,02	X	0,10	0,02	0,11	0,10
Nitrogen magnesia	N-Magn. 22 %	1 720	0,34	X	1,55	0,29	1,72	1,64
Basic slag	P/10-16 %	28 065	X	44,71	364,85	X	69882,35	224,52
Super phosphate	P/16-19 %	7 624	X	X	106,73	37,36	266,84	152,48
Hyper phosphate	P/26-32 %	16 202	12,96	X	171,74	113,41	1231,34	210,63
Triple phosphate	P/42-45 %	4 900	X	48,02	12,74	70,56	387,08	284,19
Multinutrient fertilizer	PK 0/18/18	13 045	X	X	52,18	63,92	1082,70	182,62
	PK 0/10/30	3 461	X	10,38	X	X	X	X
	PK 0/15/30	41 078	12,32	102,69	123,23	172,53	1725,26	575,08
	PK 0/16/22	21	X	X	X	0,10	X	X
	NP 20/20/0	2	0,004	0,02	0,007	0,014	0,33	0,05
Basic slag potash	0/10/20	1 556	X	10,58	3,11	2,49	1148,55	10,89
Diammonium phosphate	16/48/0	16 285	683,98	14,66	48,86	110,74	65,14	65,14
Multinutrient fertilizer	NPK all types	251 850	654,82	1762,97	705,19	780,75	12088,96	2770,39

Total load: 695 391 tons = 1426 kg Co + 2041 kg As + 1869 kg Pb + 1349 kg Cd + 88230 kg Cr+ 4772 kg Ni
X ... no data available, or below detection limit

Table 4: Relative contribution of different types of fertilizers to trace metal load
Tabelle 4: Relativer Beitrag verschiedener Düngemitteltypen zur Spurenelementfracht

Type	Nutrient contents	tons sold	% Co	% As	% Pb	% Cd	% Cr	% Ni
Ammonium nitrate lime	N/26-28 %	293 814	4,12	2,16	14,15	3,70	0,33	5,85
Ammonium sulfate	N/20-21 %	7 113	0,10	-	0,40	0,08	0,01	0,13
Urea	N/ 46 %	8 439	0,12	-	0,47	0,10	0,01	0,16
Calcium nitrate	N/ 15.5 %	108	0,00	-	0,01	0,00	0,00	0,00
Nitrogen magnesia	N/ 22 %	1 720	0,02	-	0,10	0,02	0,00	0,03
Basic slag	P/10-16 %	28 065	-	2,34	19,52	0,00	79,20	4,71
Super phosphate	P/16-19 %	7 624	-	-	5,71	2,77	0,30	3,20
Hyper phosphate	P/26-32 %	16 202	0,91	-	9,19	8,41	1,40	4,41
Triple phosphate	P/42-45 %	4 900	-	2,35	0,68	5,23	0,44	5,59
Multinutrient fertilizer	PK 0/18/18	13 045	-	-	2,79	4,74	1,23	3,83
	PK 0/10/30	3 461	-	0,52	-	-	-	-
	PK 0/15/30	41 078	0,86	5,03	6,59	12,79	1,96	12,05
	PK 0/16/22	21	-	-	-	0,01	-	-
	NP 20/20/0	2	0,00	0,00	0,00	0,00	0,00	0,00
Basic slag potash	0/10/20	1 556	-	0,54	0,19	0,17	1,30	0,21
Diammonium phosphate	16/48/0	16 285	47,95	0,75	2,61	8,21	0,07	1,37
Multinutrient fertilizer	NPK all types	251 850	45,91	86,37	37,74	57,86	13,70	58,06

5. Regional differences

The global figures for the entire arable Austrian territory was split into 8 regions, which differ in geology, climate, precipitation, and thus the kind of crops grown. For reasons of comparison, this split was done similar to the "report about biomonitoring of heavy metal deposition by mosses in Austria" (ZECHMEISTER, 1991), as far as possible. With respect to overall mass, the percentage of N-only fertilizers is higher in the Bohemian crystalline, the Northern Pre-

Table 5: Comparison of selected trace element contents of mineral fertilizers with other solids of ecological significance
Tabelle 5: Vergleich der Konzentrationen ausgewählter Spurenelemente von Mineraldüngern mit anderen ökologisch relevanten Feststoffen

	Co	As	Pb	Cd	Cr	Ni
Ammonium nitrate lime	0,2	0,15	0,9	0,17	1,0	0,95
NPK- fertilizer	2,6	7,0	2,8	3,1	48	11
Mean crust	20	1,5	14	0,11	100	80
Sandstone	0,3	1	10	0,05	35	9
Limestone	0,1	1	5,7	0,03	11	7
Soils of Upper Austria	[10]	[8,2]	[23]	[0,26]	[34]	[21]
Sewage sludge	[5,5]	[11]	[60]	[1,4]	[50]	[28]

[ ] ... decomposition with aqua regia

alpine, and the Southeast, than in the other parts of the country. The hyper-phosphate is preferred in the limestone/sandstone region, and it is at a relative minimum in the Northeast. To the contrary, the triple-phosphate is above all used in the Northeast. Minima of diammonium phosphate and basic slag potash in the Western Crystalline are probably due to structures of the market, rather than to agricultural necessities (see table 6).

Similar to the relative amounts of fertilizer types, the load of trace metals per area of arable land can be calculated for each region. Different application rates and different types of fertilizers lead to regional differences of trace metal load. In Table 7, this calculated input is shown together with the

Table 6: Tons of fertilizers sold in different geographical regions
Tabelle 6: Tonnen verkaufter Düngemittel, aufgeschlüsselt nach geographischen Regionen

Region Type	Limestone/ Sandstone	Northern Pre-alpine	Eastern Alpine Crystalline	Southeastern Lowlands	Southern Alpine	Western Alpine Crystalline	Bohemian Crystalline	Northeast Lowlands
N/26-28 %	10213	76520	14049	38319	3603	1029	33291	95116
N/20-21 %	936	2641	654	443	53	265	1843	376
Urea N/46 %	180	2402	275	1402	13,2	4,4	475	3692
$Ca(NO_3)_2$ N/15.5 %	6,3	103	1,1	34	0	1,1	2,2	11480
N-Magnesia N/22 %	178	1046	5,5	2,3	0	84	323	99
P/10-16 %	3826	9511	3550	4363	497	486	5007	1008
P/16-19 %	1001	2915	442	491	42,5	155	1213	1439
P/26-32 %	1378	5176	1740	1767	110	49	5223	773
P/42-45 %	45,3	253	26,3	125	1,0	0	4,7	4468
PK 0/18/18	14,2	325	210	415	23,5	0	184	11778
PK 0/10/30	25,6	134	27,7	422	2,2	32,6	388	2441
PK 0/15/30	318	8151	390	1824	58	12,4	1415	28911
DAP 16/48/0	265	4140	1709	1550	625	0	1077	6919
Hyperkali 0/16/22	0	5,1	1,9	12,9	0	0	0,6	0,2
Kaliphoskal 0/6/6	0	3,0	102	0	0	0	0	0
NP 20/20/0	0	0,02	0,1	1,4	0	0	0,3	0
Basic slag potash 0/10/20	13,6	68,5	247	351	0,5	0	139	779
NPK 12/12/17	493	923	985	1649	81	358	3946	6457
NPK 9/15/15	275	472	280	248	25,9	0	1728	3057
NPK 6/12/24	361	4674	541	5101	38,4	0	1805	11513
NPK 15/5/20	236	315	125	1300	0	68	419	2878
NPK 10/10/30	0	0,5	0	0	0	0	0	0
NPK 12/10/15	1,5	13	3,3	0	0	0	0	0
NPK 12/10/18	62	189	35,4	107	2,9	5,6	231	532
NPK 13/13/21	2597	9362	1904	8971	506	364	3897	15708
NPK 15/5/18	393	1239	299	1738	103	105	553	3078
NPK 15/8/20	17,8	3455	16,9	133	0	0	71	85
NPK 15/15/15	4295	17440	8046	13265	3147	629	8238	9733
NPK 20/8/8	2085	18613	350	3383	160	121	3220	18250
NPK 20/10/10	109	2198	38,4	312	0	7,2	118	821
NPK 15/10/10	994	13780	2111	901	337	187	2965	8521

Table 7: Regional differences of trace metal input/Data for total atmospheric deposition taken from ZECHMEISTER, 1991
Tabelle 7: Regionale Unterschiede im Spurenelementeintrag/Daten über die atmosphärische Deposition aus ZECHMEISTER, 1991

Load, g/ha	Limestone/ Sandstone	Northern Pre-alpine	Eastern Crystalline	Southeastern Lowlands	Southern Alps	Western Crystalline	Bohemian Crystalline	Northeastern Lowlands
Fertilizable area (ha)	217 099	542 965	235 941	314 200	52 855	79 132	356 228	628 147
Co-load by fertilizers	0,166	0,392	0,209	0,336	0,268	0,064	0,231	0,380
by atmosph. dep.	0,37	0,28	0,28	0,29	0,25	0,22	0,27	0,25
As-load by fertilizers	0,330	0,737	0,414	0,640	0,411	0,132	0,513	0,876
by atmosph. dep.	0,10	0,11	0,07	0,06	0,04	0,05	0,31	0,10
Pb-load by fertilizers	0,553	0,949	0,550	0,710	0,482	0,184	0,685	0,753
by atmosph. dep.	9,18	8,65	9,53	9,80	6,02	7,94	8,19	8,85
Cd-load by fertilizers	0,237	0,524	0,312	0,427	0,399	0,072	0,318	0,640
by atmosph. dep.	2,39	2,45	2,47	4,21	1,50	3,07	3,02	2,22
Cr-load by fertilizers	47,10	51,19	41,86	42,09	27,49	16,43	40,04	13,14
by atmosph. dep.	3,69	4,45	3,70	22,86	3,81	3,56	3,52	3,81
Ni-load by fertilizers	2,73	6,18	3,13	4,95	4,10	1,12	3,59	6,01
by atmosph. dep.	1,71	1,69	1,80	4,01	1,03	1,68	1,65	3,24

input by atmospheric deposition, estimated by a biomonitoring programme of moss (ZECHMEISTER, 1991).

6. Deposition of trace metals from the atmosphere

Within the period 1980-1982, wet deposition of Pb, Cd and Ni in Germany has been estimated to be within the range 9–40 $\mu g/m^2$.day for Pb, 0.3–1.0 $\mu g/m^2$.day for Cd, and 2.4–4.2 $\mu g/m^2$.day for Ni (NÜRNBERG et al., 1984). More elevated levels have been found in urban areas and in mining districts. In Norway, flux of Co, Ni and Cr from atmospheric deposition to the surface was found within the same range like in Austria, whereas Cd-flux was lower, but Pb and As-flux was higher found than in Austria. Long-range transport led to a significant rise of wet deposited Pb and Cd on the south-western coast, with respect to the interior areas (BERG et al., 1994).

At some sites of 1200–1700 mm precipitation in Western Switzerland, the concentration of trace elements in wet deposition samples was compared with their respective contents in spring water at the same sites. Mn, Zn, Cu, and Pb were found to be accumulated within the soil, whereas Ni, Rb, B, V, and Ba were rapidly eluted. Cr and Co showed differences between sites (ATTEIA et al., 1993).

In Austria, total atmospheric deposition has been estimated via analyses of moss samples (ZECHMEISTER, 1991), which were sampled at presumably non-contaminated sites. Pb, Cd, Zn and S-load was significantly correlated with amount of wet deposition, whereas this was not the case for As, Ni and Fe. The calculated input from mineral fertilizers versus the input obtained from total deposition data, for each agricultural Austrian region is shown in Table 7. On the whole contamination of soils from fertilizers was low with respect to annual input from the atmosphere. Remarkably, deposition data from Germany, obtained within 1980-82, yield about ten times higher input per area than the more recent data from Austria 1990. Substitution of leaded gasoline by other fuels, as well as purification of industrial emissions have improved the situation.

The rather high Cd contents of phosphates contained in fertilizers, cause a Cd-load to the area far above Co, but which is still lower than via the atmosphere. Decline of utilization of phosphate fertilizers and strict control of commercial products led to a significant decrease of cadmium contamination, compared with earlier estimations (OBERLÄNDER and KÖCHL, 1984). Basic slag and basic slag potash cause serious contaminations with Cr, which lift the level of input far above the input from the atmosphere. Without the contribution of basic slag, the levels would be approximately equal. The input of As into the soil from fertilizers may be higher than via the atmosphere. For Co, input from the air as well as input from fertilizers is generally low. Regarding Co as essential for plant growth, the input of Co would not be unwanted.

Taking into consideration that background levels of Ni are approximately twice of Co, Ni is encountered enriched with respect to Co in rain, dust and fertilizers.

References

AICHBERGER, K., G. HOFER and U. GRUBER (1994): Heavy metals in soil – an aspect of the Upper Austrian soil monitoring program. Mitt. Österr. Bodenkundl. Ges., 50, 5–14.

ATTEIA, O., J. C. VEDY and A. PARREAUX (1993): Trace element dynamics in soils and aquifers of western Switzerland. In: J. P. VERNET (ed.): Environmental Contamination. Elsevier, 79–101.

BERG, T., O. ROYSET and E. STEINNES (1994): Trace elements in atmospheric precipitation at Norwegian background stations (1989-1990) measured by ICP-MS. Atmosph. Environ., 28, 3519–3536.

KUMPFMÜLLER, M. (1989): Umweltbericht Boden. ÖBIG, Wien 1989.

NÜRNBERG, H. W., P. VALENTA, V. D. NGUYEN, M. GÖDDE and E. URANO DE CARVALHO (1984): Studies on the deposition of acid and of ecotoxic heavy metal with precipitates from the atmosphere. Fres. Z. Anal. Chem., 317, 314-323.

OBERLÄNDER, H. E. und A. KÖCHL (1984): Cadmium in Phosphatdüngemitteln – die Situation in Niederösterreich. Der Förderungsdienst, 32, 13–17.

SAGER, M. (1992): Chemical speciation and environmental mobility of heavy metals in sediments and soils. In: M. STOEPPLER (ed.): Hazardous Metals in the Environment. Elsevier, Amsterdam, 134–175.

SALOMONS, W. and U. FÖRSTNER (1984): Metals in the Hydrocycle. Springer, Berlin, Heidelberg, New York, Tokyo.

ZECHMEISTER, H. (1991): Biomonitoring der Schwermetalldepositionen mittels Moosen in Österreich. UBA-Monographie, 42.

Corresponding Author

Doz. Dr. Manfred Sager, Bundesamt und Forschungszentrum für Landwirtschaft, Institut für Agrarökologie, Spargelfeldstraße 191, A-1226 Wien, Austria.

Eingelangt am 1. August 1997
Angenommen am 16. Dezember 1997