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TRACE
ELEMENTS
in
SOILS
and
PLANTS

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Trace Elements in Soils and Plants

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TABLE OF CONTENTS

Chapter 1	
The Biosphere	1
Chapter 2	
The Anthroposphere	3
I. Introduction	3
II. Air Pollution	3
III. Water Pollution	5
IV. Soil	9
A. Soil Contamination	9
B. Soil Reclamation	12
V. Plants	13
Chapter 3	
Soils and Soil Processes	15
I. Introduction	15
II. Weathering Processes	15
III. Pedogenic Processes	19
A. Dissolution	22
B. Transport	25
C. Sorption	27
D. Adsorption	29
Chapter 4	
Soil Constituents	33
I. Introduction	33
II. Minerals	33
A. Clay Minerals and Other Aluminosilicates	34
B. Oxides and Hydroxides	36
C. Carbonates	38
D. Phosphates	38
E. Sulfides, Sulfates, and Chlorides	38
III. Organisms in Soils	40
IV. Organic Matter	45
Chapter 5	
Trace Elements in Plants	51
I. Introduction	51
II. Absorption	51
A. Root Uptake	52
B. Foliar Uptake	52
III. Translocation	53
IV. Availability	54
V. Essentiality, Deficiency, and Excess	56
VI. Toxicity and Tolerance	60
VII. Interaction	66
Chapter 6	
Elements of Group I	69
I. Introduction	69

II.	Lithium	69
A.	Soils	69
B.	Plants	69
III.	Rubidium	73
A.	Soils	73
B.	Plants	73
IV.	Cesium	74
A.	Soils	74
B.	Plants	74
C.	¹³⁷ Cesium	74
V.	Copper	75
A.	Soils	75
1.	Reactions with Soil Components	78
2.	Contamination of Soils	80
B.	Plants	81
1.	Absorption and Transport	81
2.	Biochemical Functions	83
3.	Interactions with Other Elements	84
4.	Concentrations in Plants	85
VI.	Silver	86
A.	Soils	86
B.	Plants	89
VII.	Gold	89
A.	Soils	89
B.	Plants	90

Chapter 7

Elements of Group II	91
I. Introduction	91
II. Beryllium	91
A. Soils	91
B. Plants	93
III. Strontium	94
A. Soils	94
B. Plants	95
IV. Barium	96
A. Soils	96
B. Plants	98
V. Radium	98
VI. Zinc	99
A. Soils	99
1. Reactions with Soil Components	100
2. Contamination of Soils	103
B. Plants	104
1. Absorption and Transport	104
2. Biochemical Functions	106
3. Interactions with Other Elements	107
4. Concentrations in Plants	108
VII. Cadmium	109
A. Soils	109
B. Plants	113

..... 69
..... 69
..... 69
..... 73
..... 73
..... 73
..... 74
..... 74
..... 74
..... 74
..... 74
..... 75
..... 75
..... 78
..... 80
..... 81
..... 81
..... 83
..... 84
..... 85
..... 86
..... 86
..... 89
..... 89
..... 89
..... 90

..... 91
..... 91
..... 91
..... 91
..... 93
..... 94
..... 94
..... 95
..... 96
..... 96
..... 98
..... 98
..... 99
..... 99
..... 100
..... 103
..... 104
..... 104
..... 106
..... 107
..... 108
..... 109
..... 109
..... 113

	1.	Absorption and Transport	113
	2.	Biochemical Roles	115
	3.	Interactions with Other Elements	115
	4.	Concentrations in Plants	116
VIII.	Mercury		116
	A.	Soils	116
	B.	Plants	122
	1.	Biochemical Roles	122
	2.	Concentrations in Plants	123

Chapter 8

Elements of Group III		127
I.	Introduction	127
II.	Boron	127
	A. Soils	127
	B. Plants	129
	1. Absorption and Transport	129
	2. Biochemical Functions	132
	3. Interactions with Other Elements	132
	4. Concentrations in Plants	133
III.	Aluminum	134
	A. Soils	134
	B. Plants	135
IV.	Gallium	136
	A. Soils	136
	B. Plants	137
V.	Indium	137
	A. Soils	137
	B. Plants	138
VI.	Thallium	138
	A. Soils	138
	B. Plants	139
VII.	Scandium	139
	A. Soils	139
	B. Plants	140
VIII.	Yttrium	141
	A. Soils	141
	B. Plants	141
IX.	Lanthanides	141
	A. Soils	141
	B. Plants	144
X.	Actinides	145
	A. Soils	145
	B. Plants	149

Chapter 9

Elements of Group IV		151
I.	Introduction	151
II.	Silicon	151
	A. Soils	151
	B. Plants	151

III.	Germanium	153
	A. Soils	153
	B. Plants	153
IV.	Tin	154
	A. Soils	154
	B. Plants	154
V.	Lead	154
	A. Soils	154
	1. Reactions with Soil Components	155
	2. Contamination of Soils	155
	B. Plants	158
	1. Absorption and Transport	158
	2. Biochemical Roles	161
	3. Interactions with Other Elements	162
	4. Concentrations in Plants	163
VI.	Titanium	164
	A. Soils	164
	B. Plants	165
VII.	Zirconium	166
	A. Soils	166
	B. Plants	168
VIII.	Hafnium	169

Chapter 10

Chapter 16		
Elements of Group V		171
I.	Introduction	171
II.	Arsenic	171
	A. Soils	171
	B. Plants	175
III.	Antimony	177
	A. Soils	177
	B. Plants	177
IV.	Bismuth	178
V.	Vanadium	178
	A. Soils	178
	B. Plants	179
VI.	Niobium	182
VII.	Tantalum	183

Chapter 11

Chapter VI		
Elements of Group VI		185
I.	Introduction.....	185
II.	Selenium.....	185
	A. Soils.....	185
	B. Plants.....	189
III.	Tellurium	191
IV.	Polonium	193
V.	Chromium	193
	A. Soils.....	193
	B. Plants.....	195
VI.	Molybdenum.....	199
	A. Soils.....	199

... 153
... 153
... 153
... 154
... 154
... 154
... 154
... 155
... 155
... 158
... 158
... 161
... 162
... 163
... 164
... 164
... 165
... 166
... 166
... 168
... 169

... 171
... 171
... 171
... 171
... 175
... 177
... 177
... 177
... 178
... 178
... 178
... 179
... 182
... 183

... 185
... 185
... 185
... 185
... 189
... 191
... 193
... 193
... 193
... 195
... 199
... 199

B.	Plants.....	203
1.	Absorption and Biochemical Functions	203
2.	Interactions with Other Elements	203
3.	Concentrations in Plants	204
VII.	Tungsten.....	206
Chapter 12		
Elements of Group VII		209
I.	Introduction.....	209
II.	Fluorine.....	209
A.	Soils.....	209
B.	Plants.....	213
1.	Absorption and Transport	213
2.	Biochemical Roles	214
3.	Concentrations in Plants	215
III.	Bromine	217
A.	Soils.....	217
B.	Plants.....	217
IV.	Iodine.....	219
A.	Soils.....	219
B.	Plants.....	220
V.	Manganese.....	222
A.	Soils.....	222
B.	Plants.....	226
1.	Absorption and Transport	226
2.	Biochemical Functions	227
3.	Interactions with Other Elements	229
4.	Concentrations in Plants	229
VI.	Rhenium	229
Chapter 13		
Elements of Group VIII		233
I.	Introduction.....	233
II.	Iron	233
A.	Soils.....	233
B.	Plants.....	236
1.	Absorption and Transport	236
2.	Biochemical Functions	236
3.	Interactions with Other Elements	237
4.	Concentrations in Plants	238
III.	Cobalt.....	238
A.	Soils.....	238
B.	Plants.....	241
1.	Absorption and Transport	241
2.	Biochemical Functions	242
3.	Interactions with Other Elements	245
4.	Concentrations in Plants	245
IV.	Nickel.....	246
A.	Soils.....	246
B.	Plants.....	249
1.	Absorption and Biochemical Functions	249

	2.	Interaction with Other Elements	251
	3.	Concentrations in Plants	252
V.		Platinum-Group Metals	252
	A.	Ruthenium.....	255
	B.	Rhodium	255
	C.	Palladium.....	255
	D.	Osmium	255
	E.	Iridium	256
	F.	Platinum.....	256
		Appendix	257
		References.....	261
		Index	293

IV. SOIL

A. Soil Contamination

Soil is a very specific component of the biosphere because it is not only a geochemical sink for contaminants, but also acts as a natural buffer controlling the transport of chemical elements and substances to the atmosphere, hydrosphere, and biota. Trace elements originating from various sources may finally reach the surface soil, and their further fate depends on soil chemical and physical properties. Although the chemistry of soil contaminants recently has been the subject of many studies, our knowledge of the behavior of polluting trace elements is far from complete. The persistence of contaminants in soil is much longer than in other components of the biosphere, and contamination of soil, especially by heavy metals, appears to be virtually permanent. Metals accumulated in soils are depleted slowly by leaching, plant uptake, erosion, or deflation. The first half-life of heavy metals, as calculated by Iimura et al.³³⁶ for soils in lysimetric conditions, varies greatly — for Zn, 70 to 510 years; for Cd, 13 to 1100 years; for Cu, 310 to 1500 years; and for Pb, 740 to 5900 years.

The input-output balance of metals in soils discussed in Chapter 3, Section III. B. shows that trace metals concentrations in surface soil are likely to increase, on a global scale, with growing industrial and agricultural activities. There are several indications that the composition of surface soil may be influenced by both local contamination and long-range transport of pollutants. Purves⁶³⁴ concluded that the extent of soil contamination in the urban environment is now so great that it is possible to identify most soils as urban or rural on the basis of their content of a few trace metals that are known to be general urban contaminants. The annual increment of heavy metals caused by dust fallout in Tokyo is estimated for Cd to be 0.05 ppm and for Pb and Mn to be about 0.5 ppm.³⁹⁵

The regional contamination of soils, as reported most commonly, occurs mainly in industrial regions and within centers of large settlements where factories, motor vehicles, and municipal wastes are the most important sources of trace metals. However, due to the long distance aerial transport of trace pollutants, especially those which form volatile compounds (e.g., As, Se, Sb, and Hg), it has become difficult to estimate the natural background values for some trace elements in soils.

In addition to aerial sources of trace pollutants, fertilizers, pesticides, and all sewage-derived materials have added to the trace element pool in soils. The mobilization of heavy metals from smelter and mine spoil by transport with seepage waters or by windblown dust may also be an important source of soil contamination in some industrial regions. The variability of trace element concentrations in materials used in agriculture is presented in Table 5. Goodroad,²⁷³ Piotrowska and Wiacek,⁶²⁰ and Stenström and Vahter^{755a} reported that long-term use of inorganic phosphate fertilizers adds substantially to the natural levels of Cd and F in soils, while other elements such as As, Cr, Pb, and V do not increase significantly. Effects of sewage sludge applications on soil composition are especially of great environmental concern and have been the subject of many studies and much legislation. Advisory standards and guidelines for safe addition of trace elements in sewage sludge to land is still in the stage of experiment and negotiation; however, several authors have given threshold values for the maximum addition of trace elements in one dose and over a period of time (Table 6). In spite of some diversity of opinion, there is general agreement, especially regarding the maximum concentrations of heavy metals in soils. Maximum allowable limits set up for paddy soils in Japan are somewhat different.³⁹⁵ Cu content was established at 125 ppm (0.1 N HCl soluble) and As was established at 15 ppm (1 N HCl soluble) as critical for rice growth. The hazardous concentration in soils of Cd is limited by allowable Cd in rice, which should not exceed 1 ppm. It should be emphasized, however, that all the allowable limits need to be related not only to the given plant-soil system, but also to ratios between single elements as well as to their total burden in soil.

In several soils the threshold levels already have been exceeded either in gardens and

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Table 5
AGRICULTURAL SOURCES OF TRACE ELEMENT CONTAMINATION IN SOILS (PPM DW)

Element	Sewage sludges ^a	Phosphate fertilizers ^b	Limestones ^c	Nitrogen fertilizers ^{d,1}	Manure ^e	Pesticides ^f (%)
As	2—26	2—1,200	0.1—24.0	2.2—120	3—25	22—60
B	15—1,000	5—115	10	—	0.3—0.6	—
Ba	150—4,000	200	120—250	—	270	—
Be	4—13	—	1	—	—	—
Br	20—165	3—5	—	185—716 ^f	16—41	20—85
Cd	2—1,500	0.1—170	0.04—0.1	0.05—8.5	0.3—0.8	—
Ce	20	20	12	—	—	—
Co	2—260	1—12 ^g	0.4—3.0	5.4—12	0.3—24 ^g	—
Cr	20—40,600	66—245	10—15	3.2—19	5.2—55	—
Cu	50—3,300	1—300	2—125	<1—15	2—60	12—50
F	2—740	8,500—38,000 ^h	300	—	7	18—45
Ge	1—10	—	0.2	—	19	—
Hg	0.1—55	0.01—1.2 ^d	0.05	0.3—2.9	0.09—0.2	0.8—42
In	—	—	—	—	1.4	—
Mn	60—3,900	40—2,000	40—1,200	—	30—550	—
Mo	1—40	0.1—60	0.1—15	1—7	0.05—3	—
Ni	16—5,300	7—38 ^d	10—20	7—34	7.8—30	—
Pb	50—3,000	7—225 ⁱ	20—1,250	2—27	6.6—15	60
Rb	4—95	5	3	—	0.06	—
Sc	0.5—7	7—36	1	—	5	—
Se	2—9	0.5—25 ^j	0.08—0.1	—	2.4	—
Sn	40—700	3—19 ^d	0.5—4.0	1.4—16.0	3.8	—
Sr	40—360	25—500	610	—	80	—
Te	—	20—23	—	—	0.2	—
U	—	30—300 ^k	—	—	—	—
V	20—400	2—1,600 ^d	20	—	—	45
Zn	700—49,000	50—1,450	10—450	1—42	15—250	1.3—25
Zr	5—90	50	20	—	5.5	—

^a Refs. 70, 249, 593.

^b Refs. 94, 381, 399.

^c Refs. 20, 25, 249, 532.

^d Ref. 701.

^e Ref. 510.

^f Ref. 875.

^g Ref. 744.

^h Refs. 55, 620.

ⁱ Ref. 755a.

^j Ref. 809.

^k Ref. 306.

¹ Mainly ammonium sulfate.

orchards or in other locations by contamination from industrial emissions or heavy and repeated applications of sewage sludges. A high heavy metal content of sludges is the most important hindrance to their use in agriculture. Although Purves⁶³⁴ reported that in practice the concern with using sludges commonly is only their phytotoxicity due to excesses of Zn, Cu, and Ni, their content of Cd in particular, as well as of Pb and Hg, should be of concern as serious health risks. As Andersson and Nilsson²⁵ have observed, long-term use of sewage sludge increased the soil levels of Zn, Cu, Ni, Cr, Pb, Cd, and Hg. Of these elements, however, only Zn, Cu, Ni, and Cd were increased in cereal grains, and Zn, Cu, Cr, and Pb were increased in cereal straw. Chaney¹²⁷ and Sikora et al.⁷²⁶ recommended higher doses of sewage sludges because of the relatively low availability of heavy metals to plants. Beckett

Table 6
TOTAL CONCENTRATIONS OF TRACE
ELEMENTS CONSIDERED AS
PHYTOTOXICALLY EXCESSIVE LEVELS IN
SURFACE SOILS (PPM DW)

Element	Concentrations as given by various authors					
	a	b	c	d	e	f
Ag	—	—	2	—	—	—
As	—	50	25	30	20	15
B	30	100	—	100	25	—
Be	—	10	—	10	10	—
Br	—	—	—	20	10	—
Cd	—	5	8	5	3	—
Co	30	50	25	50	50	50
Cr	—	100	75	100	100	—
Cu	60	100	100	100	100	125
F	—	500	—	1000	200	—
Hg	—	5	0.3	5	2	—
Mn	3000	—	1500	—	—	—
Mo	4	10	2	10	5	—
Ni	—	100	100	100	100	100
Pb	—	100	200	100	100	400
Sb	—	—	—	10	5	—
Se	—	10	5	10	10	—
Sn	—	—	—	50	50	—
Tl	—	—	—	—	1	—
V	—	—	60	100	50	—
Zn	70	300	400	300	300	250

Note: Sources are the following: a, 419; b, 206; c, 479; d, 376a; e, 398; and f, 395.

et al.⁵⁹ concluded that in addition to the commonly monitored levels of Cu, Ni, Zn, Cd, Cr, and Pb during the disposal of sewage sludge on farm land, it may be necessary to monitor levels of Ag, Ba, Co, Sn, As, and Hg and also possibly Mo, Bi, Mn, and Sb, until their likely accumulations in surface soil can be shown to be harmless.

Soil contaminated with heavy metals can produce apparently normal crops that may be unsafe for human or animal consumption. Klope³⁹⁸ calculated that if the content of Hg, Cd, and Pb in the soil is not higher than the threshold values (Table 6), it can be expected that the contents of these metals in human diets will not exceed weekly tolerable intakes established by FAO/WHO.³⁹⁸ Therefore, safe use of sewage sludge must be assessed on the basis of a safe addition of trace metals into soils.

Permissible levels of trace elements, particularly heavy metals, used on farmland can be calculated based on several factors. It is most important, however, to evaluate acceptable application rates in relation to:

1. Initial trace element content of soil
2. Total amount added of one element and of all heavy metals
3. Cumulative total load of heavy metals
4. Heavy metal dose limitation
5. Equivalency of trace element toxicity to plants
6. Threshold values of trace element concentrations in soils
7. Relative ratios between interacting elements

ON IN

Pesticides
(%)

22—60

—

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20—85

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12—50

18—45

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0.8—42

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8. Soil characteristics, e.g., pH, free carbonates, organic matter, clay content, and moisture
9. Input-output balance
10. Plant sensitivity

Lewin and Beckett⁴⁶⁹ widely reviewed monitoring of heavy metal accumulation in agricultural soils treated with sewage sludge and pointed out that it will be unreasonable to assume, without checks, whether heavy metals in soil will become immobilized with time or not.

Different soil types, plant species, and growing conditions contribute to the divergent influences of soil contamination on trace element status in plants. Some authors use a term "soil resistance to heavy metal contamination", which is related to the critical levels of metallic pollutants that exhibit toxic effects on plants and environments. This term is largely related to the cation exchange capacity (CEC) of soils (see Chapter 3, Section III.D.). Usually the resistance of a nonacid heavy soil with a higher content of organic matter exceeds several times the resistance of a light sandy acid soil. Loamy neutral soils may accumulate a higher amount of trace elements with much less environmental risk. However, a general chemical imbalance of such soils usually results in decreased biological activity, decreased or increased pH, and, as a further consequence, in degradation of organic and mineral sorption complexes.

Contamination of agricultural soils has already become relatively common and is likely to continue. Noticeable, also, is the fact that most often soils become contaminated by several metallic pollutants that are accompanied quite frequently by acid rains (mainly SO₂ and HF). Such an association of pollutants in soil greatly complicates their impact on the environment.

B. Soil Reclamation

The improvement of soils damaged and contaminated by pollutants has recently become a great practical problem. Reclamation of the particular soil requires, in so far as possible, a full understanding of soil properties and of the deteriorating factors. Soil contamination with heavy metals is usually quite permanent, as has been reported by Davies,¹⁶⁶ Johnson et al.,³⁶⁵ Purves,⁶³⁴ and Kitagishi and Yamane.³⁹⁵ Therefore, it is necessary to emphasize that a soil heavily contaminated, especially by trace metals, is likely to be the sink of these contaminants, resulting in degradation of biological and chemical properties of the soil.

Several specific techniques for amelioration of various industrial wastes and for their revegetation have been described by Gemmell.²⁶⁰ For soils contaminated by trace elements, the practices advised to prevent plant pollution are based on two main reactions — the leaching of easily soluble elements and the immobilization of microcations in soils. Heavily contaminated soil may need some special treatment, as was done by Kobayashi et al.⁴⁰⁵ who removed an excess of soil Cd by repeated treatment with EDTA solution and lime (the Cd content of the surface soil decreased from 27.9 to 14.4 ppm). Mixing polluted topsoils with unpolluted soil material, as well as covering over the polluted soils, or replacement of the polluted topsoils, as reported by Kitagishi and Yamane³⁹⁵ have been used for arable soils in Japan.

Reclamation of soils contaminated by heavy metals is usually based on the application of lime and phosphates and the addition of organic matter. The addition of lime, resulting in increased soil pH, however, does not always bring the expected results in the immobilization of some trace metals. The metals that are most likely to occur in soil as organic chelates in larger particulates may become soluble quite easily after heavy liming, as has been reported mainly for Cu, Zn, and Cr.^{152,260,618} In most cases, however, lime and phosphate are quite effective in lowering heavy metal concentrations in plants, especially those growing on acid sandy soils. This response is an effect of both chemical and physical reactions in soil materials and cation interactions physiologically characteristic of a plant.

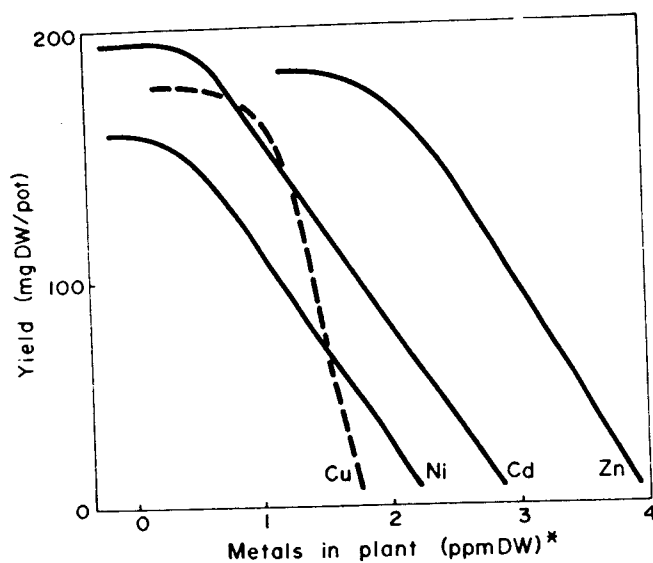


FIGURE 2. Response of young barley plants to heavy metal concentrations in their tissues. Asterisk indicates concentration of metals is given in powers of ten.³⁹

A review of the literature does not reveal any generally adequate method for rapid reclamation of soils heavily contaminated by trace metals. The effects of each treatment will depend upon soil properties, mainly on CEC and on plant response. Therefore, the reclamation or improvement of arable land polluted with trace elements needs to be designed for a specific plant-soil system.

V. PLANTS

The significant role of plants in both cycling of trace elements and contaminating the food chain has been well illustrated for various ecosystems and published in numerous papers. Plants can accumulate trace elements, especially heavy metals, in or on their tissues due to their great ability to adapt to variable chemical properties of the environment, thus plants are intermediate reservoirs through which trace elements from soils, and partly from waters and air, move to man and animals. As Tiffin⁷⁸⁹ has concluded, plants may be passive receptors of trace elements (fallout interception or root adsorption), but they also exert control over uptake or rejection of some elements by appropriate physiological reactions.

One of the basic environmental problems relates to the quantities of accumulated metals in plant parts used as food. Special attention also should be given to the forms of metals distributed within plant tissues, for the metal forms in plants seem to have a decisive role in metal transfer to other organisms.

Several authors have observed that the yield of various crops can be decreased due to metallic pollution (Figure 2). The generalized effects of metal concentrations in nutrient solution on yield and metal content of plants are shown in Figure 3. Most important, however, are the biological and health effects on man and animals caused by metallic pollution in plants. This subject has been reviewed in detail by many textbooks on environmental health.

Each case of plant pollution is unique and should be studied for a specific environment. There is an increasing awareness that results of studies based on simulation-type systems cannot be related to those in a natural system. This fact is supported by de Vries and Tiller,⁸³¹ who reported a much lower absorption of heavy metals by lettuce and onions grown in a market garden soil than by those grown under greenhouse and miniplot conditions.

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