

Contents

Chapter 1 Multi-element analysis of plant and soil samples	1
<i>S. Ayrault</i>	

1 Introduction	1
2 Formulating the question.....	2
3 The steps of the analysis and associated errors.....	4
3.1 Sampling.....	6
3.2 Cleaning.....	6
3.3 Drying, homogenisation and storage	7
4 Trace element determination	9
4.1 Direct measurements	9
4.2 Destructive methods	13
5 Choosing the analytical method	20
5.1 Optimal detection limits	22
5.2 Detection limits in environmental samples.....	22
5.3 Comparative evaluation	24
6 Quality control.....	24
7 Concluding comments	28

Chapter 2 Exploratory multivariate data analysis of soil and plant multi-element data	33
<i>K. Heydorn</i>	

1 Introduction	33
2 Statistics and chemometrics.....	35
3 Strategy.....	41
3.1 Autoscaling.....	41
3.2 Outliers	41
3.3 Clusters.....	43
3.4 Replicates	44
3.5 Trends.....	45
3.6 Dimensionality	45

3.7 Selection of variables.....	47
3.8 Back to square one.....	47
3.9 Classification	47
4 Definition of a project	48
4.1 One factor at a time	48
4.2 Several factors at a time.....	50
5 Description of a project	51
5.1 Overview	51
5.2 Individual sample types	53
6 Conclusion.....	67

Chapter 3 Processes and factors regulating the behaviour and uptake of trace elements in the rhizosphere **69**

M. Arienzo

1 Introduction	69
2 The rhizosphere	70
3 Geochemical forms of trace elements in the rhizosphere	71
4 Processes affecting the behaviour of trace elements in the rhizosphere	72
4.1 Cation exchange capacity	72
4.2 Adsorption	73
4.3 Trace element association with oxides and hydroxides.....	74
4.4 Trace element association with organic substances.....	75
4.5 Mobilisation of trace elements.....	77
5 Factors affecting the uptake of trace elements in the rhizosphere	78
5.1 Abiotic factors	81
5.2 Biotic factors	84
6 Conclusions	90

Chapter 4 Metal and arsenic bioavailability and uptake by hyperaccumulator plants **97**

E. Lombi & A.L. Nolan

1 Introduction	97
2 Phytoavailability of trace metals in soils	98
2.1 Aqueous-phase metal speciation.....	98
3 Phytoavailability of arsenic in soils.....	109
3.1 Forms of arsenic in soils	109
4 Metal and arsenic uptake by hyperaccumulator plants	111
4.1 Rhizosphere processes.....	111
4.2 Metal uptake by hyperaccumulators.....	114
4.3 Arsenic uptake by hyperaccumulators.....	116
5 Conclusions	117

Chapter 5 Copper

129

N.W. Lepp

1 Introduction	129
2 Bioavailability of soil copper	130
3 Plant copper uptake	133
4 Copper transport within the plant	134
5 Copper toxicity in plants	135
6 Copper tolerance.....	137
7 Copper indicators and accumulators.....	138
8 Soil copper contamination from fungicides.....	138
9 Remediation of Cu-contaminated soils.....	139
10 Conclusions	141

Chapter 6 Arsenic in plants, soils and foodstuffs

149

M. Anke

1 Introduction	149
2 Arsenic in the earth's crust	150
2.1 Arsenic in rocks.....	151
2.2 Arsenic in soils and its bioavailability.....	151
2.3 Arsenic in water.....	153
3 Arsenic in plants.....	154
3.1 Influence of the geological origin of soil.....	154
3.2 Influence of plant age	155
3.3 Influence of species and plant organs.....	156
3.4 Arsenic in green foodstuffs and in beverages.....	156
3.5 Essentiality of arsenic for plants.....	160
3.6 Toxicity of arsenic for plants.....	160
3.7 Metabolic transformation	162
4 Conclusions	163

Chapter 7 Cadmium

171

T. Punshon, A.L. Neal & B.P. Jackson

1 Introduction	171
1.1 Status of Cd as a potentially toxic element (PTE).....	172
2 Cd and the soil	174
2.1 Anthropogenic sources of Cd to soil	174
2.2 Sorption of Cd to pure mineral phases.....	175
2.3 Measuring Cd bioavailability	178
2.4 Cd species in the soil and soil solution.....	179
3 Cd and bacteria.....	180

3.1 Responses of natural soil bacterial communities to Cd	180
3.2 Bacterial resistance to Cd	181
3.3 Fate of Cd in the presence of bacteria in soils and sediments.....	182
4 Cd and mycorrhizal symbiosis	183
4.1 Tolerance of mycorrhiza to Cd.....	185
5 Plant uptake of Cd	185
5.1 Tolerance of plants to Cd.....	186
6 Trophic transfer of Cd	189
7 Remediation of Cd contaminated soils.....	191
7.1 Phytoremediation and Short Rotation Forestry (SRF).....	191
7.2 Chemical sorbents.....	192
8 Conclusion.....	193

Chapter 8 Phytoremediation of lead **209**

S.V. Sahi & N.C. Sharma

1 Introduction	210
2 Lead transport and accumulation in <i>Sesbania</i>	211
2.1 <i>Sesbania</i> grown in nutrient solution	211
2.2 <i>Sesbania</i> grown in soil.....	212
2.3 Cellular localisation of Pb in <i>Sesbania</i>	213
3 Transport pathway and mechanism	214
3.1 Physiology of Pb acquisition and accumulation	214
3.2 Lead transport pathways.....	215
3.3 Metal tolerance and resistance mechanisms	216
4 Improving plants for efficient phytoremediation.....	217

Chapter 9 Scandium **223**

I. Shtangeeva

1 Introduction	223
1.1 Scandium in the earth crust	224
1.2 Geochemistry of scandium	224
1.3 Application of scandium.....	224
2 Analytical problems of scandium determination	225
3 Scandium in soil	227
4 Scandium and micro-organisms	229
5 Scandium in plants	232
5.1 Scandium in mosses and lichens.....	232
5.2 Scandium in higher plants	233
6 Relationships of scandium and other elements in plants and soil.....	236
7 Toxicity of scandium.....	238

7.1 Toxicity of scandium for wheat plants	240
8 Conclusions	242

Chapter 10 Fractionation and bioavailability of rare earth elements in soils 249

X.-Q. Shan, S. Zhang & B. Wen

1 Introduction	249
2 Adsorption and desorption of REEs by and from soils.....	250
2.1 Adsorption of REEs in soils	250
2.2 Desorption of REEs from soils	252
2.3 Effect of low-molecular-weight-organic-acids on adsorption by and desorption of REEs from soils	252
2.4 Adsorption and desorption kinetics of REEs from soils	256
3 Bioavailability of REEs in soils to plants	261
3.1 Free metal ion activity model	262
3.2 Correlation methods	263
4 Subcellular location, sequestration and transport of REEs.....	272
4.1 Subcellular location of REEs.....	273
4.2 Separation and characterisation of REE-binding proteins and peptides.....	273
4.3 A natural perennial fern that hyperaccumulates REEs	274
5 Conclusions	277

Chapter 11 Biogeochemistry of gold: accepted theories and new opportunities 287

C.W.N. Anderson

1 Introduction	288
1.1 Gold the most noble of metals	288
1.2 Mining gold	289
2 Geochemistry of gold	289
2.1 Solution geochemistry of gold.....	289
2.2 Geochemical mobility of gold	290
3 Plants as indicators of mineralisation: geobotany and biogeochemistry ...	293
3.1 Gold in plants: biogeochemistry	294
4 Gold in microbes and animals	296
5 Phytoextraction.....	297
5.1 Induced hyperaccumulation.....	298
5.2 Phytoextraction of gold	301
6 Geochemical explanation for induced solubility and uptake.....	304
6.1 Thiocyanate-induced solubility	305

6.2	Thiosulfate-induced solubility	310
7	Studies on the form and location of gold stored inside a plant.....	313
7.1	Distribution of gold in leaves, stems and roots.....	313
7.2	Storage of the metal complex	314
8	Review and conclusions: the application of gold phytoextraction	315

Chapter 12 Thorium 323

I. Shtangeeva

1	Introduction	323
1.1	Application of thorium	324
1.2	Mineralogy of thorium.....	324
1.3	Geochemistry of thorium.....	325
2	Thorium in soils.....	325
3	Thorium and micro-organisms	327
4	Thorium in lower plants	330
5	Thorium in higher plants	330
6	Toxicity of thorium.....	335
7	Accumulation of thorium in plants and possible application of the effect for remediation of contaminated soils and wastes	337
8	Conclusions	343