Contents Part B

IV. General Function of Inorganic Nutrients in Growth and Metabolism

IV.1 Genetic Basis of Inorganic Plant Nutrition G.C. GERLOFF and W.H. GABELMAN (With 2 Figures)

	1 Introduction	3
	2 Major Nutritional Variations	4
	2.1 Inefficiency in Nutrient Utilization	4
	2.2 Efficiency Under Nutrient Stress	5
	2.2.1 Economic Plants	5
	2.2.2 Wild Plants	9
	2.3 Toxicities	9
	2.3.1 Metals	9
	2.3.2 Phosphorus	1
	3 Mechanisms for Differences in Nutrient Requirements	1
	3.1 Inefficiency Under Normal Nutrient Supply	1
	3.2 Efficiency Under Nutrient Stress	3
	3.2.1 Acquisition from the Environment	3
	3.2.2 Movement Across Roots and Delivery to Xylem	6
	3.2.3 Distribution in Plant Shoots	7
	3.2.4 Utilization in Metabolism and Growth	8
	3.3 Nutrient Efficiency in Wild Plants	9
	4 Screening and Selection Techniques	0
	4.1 Nutrient Cultures	Ô
	4.2 Cell and Tissue Cultures	1
	4.3 Nutrient Variations in Seeds	2
	5 Discussion and Future Outlook 47	2
	References	6
IV 2	Minoral Nutrition and Crowth	
1 4	I MOORDY and R T. RESEARD (With 24 Figures)	
	J. MOORBY and R.T. DESFORD (With 24 Figures)	
	1 Introduction	1
	2 The Supply of Mineral Nutrients and Their Concentration in Plants 482	2
	3 The Effect of Mineral Nutrients on Photosynthesis, Respiration and the	
	Transport of Assimilates	0
	3.1 Photosynthesis	0
	3.2 Respiration	8
	3.3 Translocation	0
	4 The Relationships Between Mineral Nutrients and Plant Growth Substances 500	6
	4.1 Cytokinins	6
	4.2 Abscisic Acid	7
	5 The Effects of Mineral Nutrients on Growth	8
	5.1 Root Growth	9
	5.2 Leaf Growth	0
	5.3 Growth of Other Organs	3

6 Mathemati	ica	1 N	Mo	ode	els	of	M	lin	er	al	Nı	utr	ier	nt	Re	sp	on	se	s							513
References										•	٠		•							•		•	•	·	·	521

IV.3 Proteins, Enzymes and Inorganic Ions R.G. WYN JONES and A. POLLARD (With 5 Figures)

T . 1	10
	28
Water, Inorganic Ions and Protein Structure	29
2.1 Some Properties of Water	29
2.2 Protein Conformation and Its Stabilisation	32
2.3 Inorganic Ion Effects on Protein Conformation	36
Inorganic Ions and Enzyme Activity	40
3.1 General Electrostatic Effects	40
3.2 Lyotropic Effects 5	41
3.3 Specific Ion Effects	42
3.3.1 Dotassium	43
	75
	40
3.3.3 Magnesium	40
3.3.4 Calcium	47
3.3.5 Chlorine	47
3.3.6 Other Metals	47
The Biological Context	48
4.1 State of Cellular Water and Inorganic Ions	48
4.2 Inorganic Ion Composition of Eukaryotic Cytoplasm	49
4.3 Osmo-Remedial Mutants of Microorganisms	50
44 Integrated Cellular Functions of K ⁺	51
Problems and Reservations	54
eferences	55
A. SANDMANN and P. BÖGER (With 4 Figures)	
Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in	
Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	63
SANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	i63 i65
SANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	63 65
SANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts Chloropla	i63 i65 i65
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts Metallo-Proteins 2.1 Iron Proteins 2.1.1 Iron-Sulfur Proteins 2.1 2 Cytochromes	i63 i65 i65 i65
SANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	63 65 65 65 69
As a matrix of the formation of the	63 65 65 65 69 74
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.2 Superoxide Dismutase 5	63 65 65 65 65 65 67 75
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.1 True 1 Connegr. Plastographing 5	63 65 65 65 67 67 67 576
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5	663 665 665 665 674 675 676
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3 Type-2 Copper 5	63 65 65 665 674 675 676 676
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	663 665 665 665 674 676 676 676 679
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.3 Type-3 Copper 5 2.3.4 Multicopper Proteins 5	563 565 565 569 574 576 576 576 576 578 580
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.3 Type-3 Copper 5 2.3.4 Multicopper Proteins 5 2.4 Zn-Containing Proteins 5	663 665 665 665 674 676 676 676 679 680 680 681
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.4 Multicopper Proteins 5 2.4 Zn-Containing Proteins 5 2.4.1 Carbonic Anhydrase 5	63 65 65 665 675 675 676 676 676 678 680 681 681
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.4 Multicopper Proteins 5 2.4 Zn-Containing Proteins 5 2.4.1 Carbonic Anhydrase 5 2.4.2 Alcohol Dehydrogenase 5	563 565 565 576 576 576 576 578 580 581 581
SANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.4 Multicopper Proteins 5 2.4 Zn-Containing Proteins 5 2.4.1 Carbonic Anhydrase 5 2.4.2 Alcohol Dehydrogenase 5	63 65 65 665 674 675 676 677 678 680 681 681 681 681 681 681
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.4 Multicopper Proteins 5 2.4.1 Carbonic Anhydrase 5 2.4.2 Alcohol Dehydrogenase 5 2.4.1 Mitochondria 5	663 665 665 665 674 675 676 678 680 681 581 581 581 582 582
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.3 Type-3 Copper 5 2.4 In Carbonic Anhydrase 5 2.4.1 Carbonic Anhydrase 5 2.4.2 Alcohol Dehydrogenase 5 2.4.2 Alcohol Dehydrogenase 5 2.4.2 Alcohol Dehydrogenase 5 2.4.2 Alcohol Dehydrogenase 5 2.4.1 Mitochondria 5 3.1 Mitochondria 5 3.2 Chloroplasts 5	63 65 65 65 67 67 67 67 67 67 67 67 67 67 67 67 67
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	63 65 65 665 67 67 67 67 67 67 67 67 67 67 67 67 67
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts	63 65 65 66 57 67 57 6 57 6 57 6 57 6 57
ANDMANN and P. BÖGER (With 4 Figures) Essential Heavy Metals in Plant Metabolism: Deficiency and Toxicity in Chloroplasts 5 Metallo-Proteins 5 2.1 Iron Proteins 5 2.1.1 Iron-Sulfur Proteins 5 2.1.2 Cytochromes 5 2.1.3 Heme-Containing Enzymes 5 2.3 Copper Proteins 5 2.3.1 Type-1 Copper: Plastocyanin 5 2.3.2 Type-2 Copper 5 2.3.3 Type-3 Copper 5 2.4 Zn-Containing Proteins 5 2.4 Zn-Containing Proteins 5 2.4 Zhohol Dehydrogenase 5 2.4 Chloroplasts 5 3.1 Mitochondria 5 3.2 Chloroplasts 5 3.2.1 Iron 5 3.2.2 Copper 5 3.2.3 Manganese 5	63 65 65 65 65 65 65 65 65 65 65

V. Special Functions of Some Elements

V.1 Calcium Transport and Function D. MARMÉ (With 2 Figures)

1	Introduction)
2	Cellular Ca ²⁺ Transport)
3	β Calmodulin β	l
4	Subcellular Ca ²⁺ Transport	4
	4.1 Mitochondrial Ca^{2+} Transport	4
	4.2 Microsomal Ca ²⁺ Transport	5
4	$5 \text{ Cellular Ca}^{2+} \text{ Function} \qquad 609$)
	5.1 Growth)
	5.1.1 Auxin-Dependent Growth)
	5.1.2 Pollen Tip Growth 61	Í
	5.2 Mimosa Leaf Movement	2
	5.3 Mougeotia Chloroplast Movement	2
	5.4 Chlamydomonas Flagellar Movement	ŝ
	5.5 Microtubules and Mitosis	1
	5.6 Membrane Fusion 614	5
	5.7 Development 614	ŝ
	5.7 Development 5.7 Contraction of the second secon	ś
f	Conclusion 619	ź
ī	Peferences 610	ŝ
1		'

V.2 Boron in Plant Metabolism W.M. DUGGER (With 4 Figures)

1 The Absorption and Distribution of Boron in Plants	628
1.1 Absorption of Boron by Plants	628
1.2 Distribution of Boron in Plants	628
1.3 Boron as an Essential Element in Higher and Lower Plants	630
2 The Effect of Boron on Vegetative Growth	630
2.1 Cell Division and Enlargement	631
2.2 Cell Differentiation and Maturation	632
2.3 Cellular Membrane Activity	633
3 The Influence of Boron on Phenolic Compounds and Lignin Biosynthesis	634
4 The Influence of Boron on Pollen Germination and Pollen Tube Growth	635
5 The Effect of Boron on Plant Metabolism and Enzymatic Reactions	636
5.1 Respiration	636
5.2 Photosynthesis	636
5 3 Cell Wall Biosynthesis	637
54 Protein Metabolism	638
5.5 Phosphorus Metabolism	638
5.6 Auxin Content and Metabolism	639
5.7 Regulation of Enzymatic Reactions in Plants	640
6 Translocation and Metabolism of Sugars	641
7 Nucleic Acid Metabolism, RNA and DNA Synthesis	643
8 Prospectus	646
References	646
	010
V 3 Sodium Varsus Potassium Substitution and Compartmentation	
T I ELOWERS and A L'IJCHL (With 6 Figures)	
1.J. I LOWERS AND A. LAUCHLI (WITH O FIGURES)	

1	Introduction																								651
2	Plant Requirer	ne	nt	s f	or	Sc	odi	iur	n a	ind	d F	Pot	tas	siı	ım										652
	2.1 Potassium																								652
	2.2 Sodium		•				•	•			•	-		·		•	•	•	•	•	•			•	653

3 Techniques for the Localisation of Sodium and Potassiu	n.			656
3.1 X-Ray Microanalysis				656
3.1.1 Use of Frozen Specimens				656
3.1.2 Precipitation Methods				658
3.1.3 Freeze Substitution				659
3.2 Non-Aqueous Cell Fractionation				660
3.3 Autoradiography				661
3.4 Other Methods				661
3.4.1 Tracer Flux Analysis				662
2 A 2 Match - Via Estidament				667
3.4.2 Metabolic Evidence				004
4 Localisation of Potassium and Sodium in Plants, and	 Their	Roles	in	002 the
4 Localisation of Potassium and Sodium in Plants, and Cell	Their	Roles	in	the
4 Localisation of Potassium and Sodium in Plants, and Cell	Their	Roles	in	the 663
4 Localisation of Potassium and Sodium in Plants, and Cell	Their	Roles	in	the 663 663 664
4 Localisation of Potassium and Sodium in Plants, and Cell	Their	Roles	in	the 663 663 664 664
 4 Localisation of Potassium and Sodium in Plants, and Cell 4.1 Localisation Within the Plant 4.2 Localisation Within the Cell 4.3 Roles of Sodium and Potassium 5 The Substitution of Na for the Roles of K in Plant Cells 	Their	Roles	in	the 663 663 664 664 669 671
 4 Localisation of Potassium and Sodium in Plants, and Cell 4.1 Localisation Within the Plant 4.2 Localisation Within the Cell 4.3 Roles of Sodium and Potassium 5 The Substitution of Na for the Roles of K in Plant Cells References 	Their	Roles	in	the

V.4 Silica Metabolism D. WERNER and R. ROTH (With 3 Figures)

1 Introduction \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots	582
2 Silica Metabolism in Cormophytes	582
2.1 Silicon as an Essential Trace Element	582
2.2 Silica Accumulation	585
3 Silica Metabolism in Diatoms	587
3.1 Uptake of Silicic Acid	587
3.2 Silica Content in Diatoms and Silica Structures	588
3.3 Regulation of General Metabolism by Silica	589
3.4 Biochemistry of Silica Compounds	591
4 Conclusion and Outlook	592
References	592

V.5 Involvement of Unusual Elements in Plant Growth and Nutrition

E.G. BOLLARD (With 4 Figures)

1 Introduction			. 693
2 Aluminium			. 690
2.1 Content			. 69
2.2 Essentiality			. 69
2.3 Toxicity			. 69
2.3.1 Expression of Toxicity			. 69
2.3.2 Plant Growth in Acid Soils			. 70
2.3.3 Resistance to Acid Soil Conditions			. 70
2.3.4 Toxicity at Higher pH's			. 70
2.4 Mechanisms of Toxicity			. 70
2.4.1 Interaction with Phosphate			. 70
2.4.2 Interaction with Calcium and Other Nutrient Ions .			. 70
2.4.3 Effect on Cell Growth			. 70
2.4.4 Differences Between Susceptible and Tolerant Plants			. 70
2.4.5 Toxicity to Plant Cells			. 70-
2.5 Physiology and Biochemistry			. 70
3 Iodine			. 70
3.1 Content \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots			. 70
3.2 Essentiality			. 70
3.3 Toxicity			. 70
3.4 Physiology and Biochemistry			. 70

4	Selenium																	707
	4.1 Content																	707
	4.2 Essentiali	ty																708
	4.3 Toxicity																	709
	4.4 Physiolog	y																710
	4.5 Biochemis	strv .																710
	4.6 Metabolic	Differ	rences	Betv	veen	Accu	ımu	late	or	and	N	on-	Ac	cu	mu	late	ər	
	Species .																	712
5	Chromium .												÷					714
	5.1 Content																	714
	5.2 Essentiali	ty.																714
	5.3 Toxicity												÷			÷		715
	5.4 Physiolog	y																715
6	Cobalt	· · · ·																717
	6.1 Content																	717
	6.2 Essentiali	ty																717
	6.3 Toxicity	·																719
	6.4 Physiolog	v											÷					719
7	Nickel	·											÷					720
	7.1 Content																	720
	7.2 Essentiali	tv.																721
	7.3 Toxicity	·																722
	7.4 Physiolog	v and B	iocher	nistry	· .					÷						Ż		723
8	Vanadium .	·																723
-	8.1 Content											÷						723
	8.2 Essentiali	tv.																724
	8.3 Toxicity																	724
	8.4 Physiolog	v and B	iocher	nistrv													÷	725
9	Concluding R	emarks																726
-	9.1 Essentialit	tv.															÷	726
	9.2 Toxicity											÷						728
R	eferences .																	729
-												•	•	•		•		
VI. Sy R	y nthesis and (.L. Bieleski an	Dutlool d A. La	K AUCHLI	(Wit	h 1 F	igure	e) .							•				745
Autho	or Index							•		•			•			•		757
Subje	ct Index																	829