CONTENTS

	Page
DEDICATION	xv
GENERAL FOREWORD AND FOREWORD	xvi
PREFACE	xvii
CONTRIBUTORS	xviii
CONVERSION FACTORS FOR U.S. AND METRIC UNITS	XX

1 Origin and Distribution of Nitrogen in Soil

F. J. STEVENSON

I. Introduction	1
II. The N Cycle	3
A. Geochemistry of N	4
B. Evolutionary Aspects	6
III. Mechanisms by Which N is Added to Soil in Nature	11
A. Nitrogen in Atmospheric Precipitation	11
B. Biological N ₂ Fixation	12
IV. Nitrogen Losses from Soil	21
A. Volatilization of NH ₃	21
B. Bacterial Denitrification	22
C. Leaching	23
D. Chemical Reactions of NO_2^{-}	24
V. Factors Affecting the N Content of Soils	24
A. Nitrogen Accumulations during Soil Development	
(the Time Factor)	25
B. Effect of Climate	27
C. Vegetation	30
D. Parent Material	31
E. Topography	31
F. Effect of Cropping	32
VI. Summary	38
LITERATURE CITED	39

2 Inorganic Forms of Nitrogen in Soil

J. L. YOUNG AND R. W. ALDAG

I. Introduction	43
II. Mineral-Fixed NH [*] -N	44
A. General Terminology	44
B. Origin	44
C. Methods of Estimation	46
D. Amounts of Distribution in Soil Profiles	48
E. Effect on C/N Ratios	54
F. Stability, Transformation, Fluctuation, and Movement	55
III. Exchangeable and Water-soluble Forms	- 56
A. Methods of Determination	57
B. Amounts and Distribution	58
IV. Soil Nitrogen Gases	60
A. Methods of Determination	61
B. Amounts and Distribution	61
LITERATURE CITED	62

3 Organic Forms of Soil Nitrogen

F. J. STEVENSON

I. Introduction
II. Fractionation of Soil N
A. Distribution of Organic Forms of N in Mineral Soils
B. Distribution of the Forms of N in Histosols and Aquatic
Sediments
C. Humic and Fulvic Acids
D. Distribution and Stabilization of Newly Immobilized N 83
E. Natural Variations in N Isotope Abundance
III. Amino Acids
A. Extraction and Quantitative Determination
B. Identification of Amino Acids
C. Distribution Patterns in Soil
D. Factors Affecting the Distribution of Amino Acids
E. Amino Acids in Humic and Fulvic Acids
F. Stereochemistry of Amino Acids
G. Free Amino Acids
H. State of Amino Acids in Soil
IV. Amino Sugars 101
A. Extraction and Quantitative Determination
B. Isolation of Amino Sugars 103
V. Other N Compounds 105
A. Nucleic Acids and Derivatives
B. Chlorophyll and Chlorophyll Degradation Products 107
C. Phospholipids 109
D. Amines, Vitamins, and Other Compounds 109
E. Pesticide and Pesticide Degradation Products 111
VI. Stability of Soil Organic N 112
VII. Summary 114
LITERATURE CITED 114

4 Retention and Fixation of Ammonium and Ammonia in Soils

HANS NOMMIK AND KAAREL VAHTRAS

1. Introduction	123
II. Exchangeable Binding of NH ₄ ⁺ in Soils and Clay Minerals	123
A. Cation Adsorption and Exchange	124
B. Cation Exchange Reactions.	126
III. Nonexchangeable Binding (Fixation) of NH ₄ ⁺ in Soils and	
Clay Minerals	127
A. Mechanism of NH ₄ ⁺ Fixation	127
B. Methods Used for Studying NH₄ ⁺ Fixation	130
C. Factors Affecting Rate and Magnitude of NH ₄ ⁺ Fixation	132
D. Release of Fixed NH ₄ ⁺ from Soils and Minerals by Different	
Extraction and Distillation Procedures	139
E. Availability of Fixed NH4 ⁺ to Soil Microorganisms	143
F. Availability of Fixed NH ₄ ⁺ to Higher Plants	148
IV. Retention of NH ₃ and Fixation of NH ₃ in Soil Organic Matter	152
A. General Remarks	152
B. Physical Sorption of NH,	154
C. Chemisorption of NH ₃	156
D. Fixation of NH, in Soil Organic Matter	156
LITERATURE CITED	166

5 Biochemistry of Ammonification

J. N. LADD AND R. B. JACKSON

I. Introduction	173
II. Proteins, Peptides, Amides, Amidines, and Amino Acids	174
A. Proteinases and Peptidases	175
B. Proteinases and Peptidases in Soil	178
C. Amidohydrolases and Amidinohydrolases	186
D. Amino Acid Dehydrogenases and Oxidases	187
III. Aminopolysaccharides and Amino Sugars	189
A. Origin and Hydrolysis	190
B. Stability of Aminopolysaccharides in Soil.	191
C. Hydrolysis of Aminopolysaccharides in Soil	192
D. Ammonia Production From Amino Sugars	193
IV. Nucleic Acids, Nucleotides, Nucleosides, Purines, and	
Pyrimidines	194
A. Nucleic Acids	195
B. Nucleotides and Nucleosides	197
C. Nucleases, Nucleotidases, and Nucleosidases in Soil	198
D. Deamination of Nucleotides and Nucleosides	198
E. Catabolism of Purines	199
F. Degradation of Pyrimidines	204
G. Degradation of Purines and Pyrimidines in Soil.	207
V. Urea	208
A. Ureases.	209
B. Soil Ureases	210
VI. Other Compounds	221
LITERATURE CITED	222

6 Mineralization and Immobilization of Soil Nitrogen

S. L. JANSSON AND J. PERSSON

Ι.	Background	229
	A. The Processes of Mineralization and Immobilization	229
	B. Relations to the Universal N Cycle	230
	C. Partition of the Universal N Cycle Into Three Subcycles	231
	D. Competition Among the N Subcycles	232
	E. Mineralization-Immobilization Turnover (MIT)	233
П.	Features and Functions of MIT.	233
	A. Inadequacies of Net Effect Determinations	233
	B. Possibilities of Measuring Gross Effects: Usefulness of	
	Tracer Techniques	233
	C. Confusion Caused by MIT	234
	D. Priming Effect and Related Phenomena	235
	E. Fertilizer N and MIT	236
	F. Evaluation of N Fertilizers	238
	G. MIT and Nitrification	239
	H. Consequences of N ₂ Fixation and Denitrification on MIT	239
	I. MIT Interactions with Plants	240
	J. Effects of Physical and Chemical Soil Factors	240
	K. Energy-Nutrient Relationships	240
	L. The C/N Ratio: C and N Interdependence	241
	M. The Phase Concept of Soil Organic Matter	242
	N. Humus Formation and Decay: A Dynamic Phenomenon	242

P. "A" and Related Values
O Attended The And The Control of
Q. Attempts at Extended Phase Separations
III. Problems and Prospects
A. A New Line in Soil Organic Matter Research
B. Inorganic Phase Problems. 247
C. Simulation Modeling 247
D. Future Role of Tracer Techniques 248
LITERATURE CITED 248

7 Nitrification in Soil

EDWIN L. SCHMIDT

I. Introduction	253
II. The Process of Nitrification in Soils	254
A. Factors Regulating Nitrification in Soils	254
B. Substrates and Products	257
C. Interactions with Other N Cycle Events	258
D. Approaches to Soil Nitrification	259
III. Microbiological Basis of Nitrification	260
A. Nitrification by Heterotrophs	260
B. Methane Oxidizing Bacteria	262
C. Autotrophic Nitrifiers	263
IV. Ammonium Oxidizing Bacteria in Soil	264
A. Biochemistry of NH ⁺ Oxidation	264
B. Carbon Metabolism	267
C. Soil Genera	268
V. Nitrite Oxidizing Bacteria of Soil	269
A. Biochemistry of NO ₂ ⁻ Oxidation	269
B. Carbon Metabolism	269
VI. Study of Nitrifying Populations of Soils	270
A. Isolation.	271
B. Most Probable Number (MPN) Enumeration	271
C. Fluorescent Antibody (FA) Techniques	272
D. Short Term Nitrification Activity	272
VII. Regulation of Nitrifying Populations in Soils	273
A Naturally Occurring Inhibitors	274
B. Inhibition by Pesticides Added to Soil.	275
C Specific Inhibitors of Nitrification	276
VIII Growth of Nitrifving Bacteria in Soil	278
A Growth Rates	278
B Yields	280
C Activity	281
IX. Concluding Comments	282
ACKNOWI EDGMENT	283
LITERATURE CITED	283

8 Biological Denitrification

M. K. FIRESTONE

I.	Introduction	289
П.	Biochemical and Microbiological Basis	290
	A. Definition and Pathway	290

B. Organisms Involved	292
C. Cellular Control	294
D. Characteristics of Specific Reductases	299
E. Energy Conservation During Denitrification	305
III. Denitrification in Soil	306
A. Carbon Supply	306
B. Oxygen Control	310
C. Nítrate Supply	314
D. Effect of Temperature	315
E. Effect of pH	316
IV. Concluding Comments	318
LITERATURE CITED	318

9 Gaseous Losses of Nitrogen Other Than Through Denitrification

DARRELL W. NELSON

1. Introduction	327
II. Ammonia Loss From Soils	327
A. Ammonia Volatilization Following Ammonium Fertilization	
of Soils	328
 B. Ammonia Losses from Soils Following Anhydrous Ammonia 	
Application	339
III. Gaseous Nitrogen Loss From Soils Through Nitrite Reactions	341
A. Nitrite-Nitrous Acid Equilibria in Soils	343
B. Factors Affecting Nitrite Instability in Soils	343
C. Gaseous Products of Nitrite Reactions in Soils	344
D. Mechanisms for Gaseous Loss of Nitrite N from Soils	346
E. Importance of Nitrite Reactions in Nitrogen Losses	
from Soils	354
IV. Gaseous Nitrogen Loss from Soils Through Reactions of	
Nitrate and Hydroxylamine	356
V. Management Techniques to Minimize Gaseous Nitrogen Losses	357
LITERATURE CITED	358

10 Biological Nitrogen Fixation

U. D. HAVELKA, M. G. BOYLE, AND R. W. F. HARDY

I.	General Introduction	365
	A. Extent of N ₂ Fixation	366
	B. Nitrogenase Enzyme	360
	C. Nitrogenase Reaction	366
	D. Nitrogenase Regulation	36
П.	Microbiology of N ₂ Fixation	36
	A. Introduction	36
	B. Free-Living Diazotrophs	37(
	C. Symbiotic N ₂ Fixation	375
III.	Physiology and Agronomy of N ₂ Fixation—Legume/Rhizobium	
	Symbiosis	383
	A. Introduction	383
	B. Nodulation Process	384
	C. Energy Relationships in N ₂ Fixation	387
	D. Methodology of N ₂ Fixation Measurement	398
	E. Rhizobium Classification	406

F. Legume/Rhizobium Interactions	408
G. Seed Inoculant Technology	409
H. Inoculant Application	411
IV. Future Applications	413
LITERATURE CITED	413

11 Nitrogen Transport Processes in Soil

D. R. NIELSEN, J. W. BIGGAR, AND P. J. WIERENGA

I. Introduction	423
II. Deterministic Analyses	424
A. Soil Water Movement	425
B. Soil Solute Movement	426
III. Stochastic Analyses	433
LITERATURE CITED	445

12 Nitrogen Transformations in Submerged Soils

W. H. PATRICK, JR.

I. Introduction	449
II. Properties of Submerged Soils that Affect Nitrogen Behavior	449
III. Nitrogen Transformations in Submerged Soils	452
A. Mineralization and Immobilization	452
B. Nitrification-Denitrification	454
C. Nitrogen Fixation	457
D. Ammonium Volatilization	460
IV. Management of Submerged Soil to Minimize Nitrogen Loss	461
LITERATURE CITED	462

13 Advances in Methodology for Research on Nitrogen Transformations in Soils

J. M. BREMNER AND R. D. HAUCK

I.	Introduction	467
П.	Determination of Different Forms of Nitrogen	468
	A. Total Nitrogen	468
	B. Inorganic Forms of Nitrogen	471
	C. Organic Forms of Nitrogen	473
	D. Gaseous Forms of Nitrogen	474
Ш.	Tracer Techniques	479
	A. Stable N Techniques	479
	B. Nitrogen-13 Techniques	483
	C. Use of Variations in Natural Nitrogen-15 Abundance	484
IV.	Methods for Assay of the Activity of Enzymes Causing Nitrogen	
	Transformations in Soils	486
	A. Nitrogenase Activity	487
	B. Urease Activity	487
	C. Other Enzymes	488
V .	Methods for Research on Biological Nitrogen Fixation	488
VI.	Methods for Research on Denitrification.	491
LITE	RATURE CITED	493

14 Soil Nitrogen Budgets

J. O. LEGG AND J. J. MEISINGER

I. Introduction	503
II. The N Cycle in Relation to N Budgets	505
A. Nitrogen Cycle Diagrams	505
B. Soil N Equilibrium Concept	505
III. Nitrogen Sources in Soil-Plant Systems	507
A. Indigenous Soil Organic N	507
B. Additions Through Crop and Animal Wastes	507
C. Additions by Precipitation and Irrigation Water	508
D. Adsorption of Atmospheric Gases	509
E. Biological N ₂ Fixation	510
F. Commercial Fertilizers	512
G. Miscellaneous Items	512
IV. Nitrogen Losses from Soil-Plant Systems	512
A. Removal by Crops and Livestock	513
B. Erosion and Runoff	513
C. Leaching Losses	516
D. Denitrification and Other Gaseous Losses	518
E. Ammonium Fixation	520
V. Recent Studies of N Budgets in Soil-Plant Systems	521
A. Use of Labeled N in N Budgets	521
B. N Balance Methodology	522
C. Problems in N Balance Studies	523
D. N Balance Studies	525
E. Summary	546
VI. Applications of N Balances to Soil and Crop Problems	547
A. General Aspects	547
B. Nitrogen Budgets Applied to Environmental Problems	547
C. Summary	555
VII. Summary and Conclusions	555
LITERATURE CITED	557

15 Crop Nitrogen Requirements, Utilization, and Fertilization

R. A. OLSON AND L. T. KURTZ

I.	Introduction	567
II.	Plant Use of N	568
	A. Functions of N in Plant Growth	568
	B. Uptake, Translocation, and Storage of N	570
	C. Biochemical Pathways of N in the Plant	575
	D. Genetic Effects on Biochemical Pathways	578
III.	Nitrogen in Crop Production	579
	A. Nitrogen Levels in Crops Associated with Deficiency,	
	Sufficiency, and Excess	579
	B. Amounts of N in Crops and Distribution within the Crop	581
	C. Influence of Fertilizer N on Crop Quality	585
	D. Impact of Applied Fertilizer N on Crop Utilization of	
	Other Nutrients	590
	E. Efficient Use of N Fertilizer	592
IV.	Influence of Climate and Cropping Systems on N Use	596
	A. Climate and N Fertilization	596
	B. Nitrogen Carriers and Cropping Systems	598

CON	TE	NTS	
-----	----	-----	--

V. Nitrogen Fertilization in the Future	598
LITERATURE CITED	599

16 Nitrogen Management for Maximum Efficiency and Minimum Pollution

DENNIS R. KEENEY

I. Introduction
II. N Requirements for Food and Fiber
III. Adverse Health and Environmental Impacts of N
A. Nitrogen and Human Health 606
B. Animal Health 608
C. Environmental Impacts 608
D. Perspectives
IV. Trends in Anthropogenic N Fixation
A. Worldwide
B. United States 612
V. Sources of N Pollution 613
A. Point Sources
B. Nonpoint Sources
VI. Some Examples of Agricultural N Pollution
A. U.S. Corn Belt
B. Irrigated Agriculture 617
C. Livestock Operations
D. Grasslands
E. Tropical Agriculture 624
VII. Factors Affecting Crop Yields and Use of N
VIII. Control of N Pollution From Croplands
A. Agricultural Best Management Practices
B. Improved Management of Nutrient Systems
C. Limitations on Rates of Fertilizer Applications
D. Fundamental Changes in Agriculture
IX. Summary
LITERATURE CITED

17 Assessment of Soil Nitrogen Availability

GEORGE STANFORD

I. Introduction	651
II. Estimating Residual Mineral Nitrogen in Soils	653
III. Incubation Methods for Measuring Mineralization of Soil	
Organic Nitrogen	658
A. Short-term Incubation Methods.	659
B. Potentially Mineralizable Soil Nitrogen	662
IV. Chemical Indexes of Soil Organic Nitrogen Availability	664
A. Intensive Extraction Methods	665
B. Extraction Methods of Intermediate Intensity	666
C. Relatively Mild Extraction Methods	669
V. Interpreting Chemical and Biological Assays of Soil Nitrogen	
Availability	673
A. Under Controlled Conditions	675
B. Under Field Conditions	676
LITERATURE CITED	683

18 The Effects of Pesticides on Nitrogen Transformations in Soils

C. A. I. GORING AND D. A. LASKOWSKI

1.	Introduction
II.	Soil Variability.
III.	Behavior of Pesticides
IV.	Effects of Pesticides on N Transformations
	A. Mineralization/Immobilization
	B. Nitrification
	C. Denitrification
	D. Symbiotic N ₂ Fixation
	E. Nonsymbiotic N ₂ Fixation
V .	Agronomic Implications
VI.	Environmental and Regulatory Implications
LITE	RATURE CITED

19 Modeling of the Soil Nitrogen Cycle

KENNETH K. TANJI

I. Introduction	721
II. Computers and Simulation Models	721
A. Computers and Programming	722
B. Development and Application of Systems Simulation Models.	724
III. Representative Nitrogen Models	725
A. Survey of Dynamic N Simulation Models	726
B. Evaluation of Selected Simulation Models	731
IV. Technical and Philosophical Critique	767
A. General Critique	767
B. Specific Critique	768
LITERATURE CITED	770

20 Economic Implications of Controls on Nitrogen Fertilizer Use

EARL R. SWANSON

I. Introduction	773
II. Alternative Methods of Control	774
III. Economic Framework	775
IV. Per-Hectare Restrictions on N Fertilizer Use	778
A. National Analyses	778
B. Regional Analyses	779
C. State Analyses	780
V. Restrictions on NO ₃ ⁻ -N Concentration in Leachate or Effluent	780
VI. Treatment of Water to Reduce NO ₃ ⁻ -N Content	781
VII. Restrictions on the N Balance at the Farm Level	. 781
VIII. An Excise Tax on N Fertilizer	. 782
IX. An Effluent Charge	783
X. A Market for Rights to Use N Fertilizer	. 784
XI. Information Programs	. 786
XII. Summary and Conclusions	. 787
ACKNOWLEDGMENT	788
LITERATURE CITED	. 788

21 Recycling of Nitrogen Through Land Application of Agricultural, Food Processing, and Municipal Wastes

J. H. SMITH AND J. R. PETERSON

I. Introduction	91
II. Agricultural Wastes 7	91
A. Crop Residues	91
B. Animal Manures 7	97
III. Food Processing Wastes 8	06
A. The Nature and Composition of Food Processing Wastes 8	06
B. Irrigating Agricultural Land 8	11
C. Nitrogen Loading and Utilization on Land	12
D. Nitrification and Denitrification	14
E. Pollution Potential 8	14
IV. Municipal Wastes 8	15
A. Sewage Effluent 8	15
B. Sewage Sludge 8	18
V. Summary	25
LITERATURE CITED 8	26

22 Energetics of Nitrogen Transformations

R. F. HARRIS

I. Introduction	833
II. Bioenergetic Frinciples of Environmental Nurogen Transformations	835
A Nonequilibrium Thermodynamics and Reaction Kinetics	835
B. Ecological Considerations.	842
III. Calculations and Interpretation of Group Transfer Energetics	845
A. General Equations	845
B. Energetics of Proton Transfer	847
IV. Pathway Energetics of Nitrogen Transformations	869
A. Assimilatory Pathways	869
B. Dissimilatory Pathways	871
C. Hydrogen Cyanide Metabolism	875
V. Efficiency of Reductive Dinitrogen Fixation	875
VI. Appendix	879
A. Selected Values of Thermodynamic Properties for Nitrogen	879
LITERATURE CITED	888

23 Nitrogen Transfers and Mass Balances

R. D. HAUCK AND K. K. TANJI

** *	
II. 1	N Transformations and Transfers
1	A. General Considerations
ļ	B. N Income, Outgo, and Transfer
III. I	N Mass Balances and Models
1	A. N Mass Balance Models
3	B. Small-Scale Models and N Balances.
(C. Regional Models and N Balances
ļ	D. Global Models and N Balances
IV. 1	Perspective
LITER	ATURE CITED