The Nature and Properties of Soils

TWELFTH EDITION

NYLE C. BRADY

EMERITUS PROFESSOR OF SOIL SCIENCE CORNELL UNIVERSITY

RAY R. WEIL

PROFESSOR OF SOIL SCIENCE
UNIVERSITY OF MARYLAND AT COLLEGE PARK



PRENTICE HALL
UPPER SADDLE RIVER, NEW JERSEY 07458

PREFACE хi

1.1	Functions of Soils in Our Ecosystem	2
1.2	Medium for Plant Growth	3
1.3	Regulator of Water Supplies	6
1.4	Recycler of Raw Materials	7
1.5	Habitat for Soil Organisms	7
1.6	Engineering Medium	8
1.7	Soil as a Natural Body	9
1.8	The Soil Profile and Its Layers (Horizons)	- 11
1.9	Topsoil and Subsoil	13
1.10	Soil: The Interface of Air, Minerals, Water, and Life	14
1.11	Mineral (Inorganic) Constituents of Soils	17
1.12	Soil Organic Matter	. 19
1.13	Soil Water: A Dynamic Solution	21
1.14	Soil Air: A Changing Mixture of Gases	22
1.15	Interaction of Four Components to Supply Plant Nutrients	23
1.16	Nutrient Uptake by Plant Roots	25
1.17	Soil Quality, Degradation, and Resilience	27
1.18	Conclusion	28
	Study Questions	28
	Reference	28
2 FORMATION	of Soils from Parent Materials 29	
2.1	Weathering of Rocks and Minerals	29

-	Weathering of the cite and trimerate	
2	Physical Weathering (Disintegration)	33
3	Chemical Weathering (Decomposition)	34
4	Factors Influencing Soil Formation	37
_	D	2.2

2.5 Parent Materials 38 2.6 Residual Parent Material 41

2.7	Colluvial Debris	42
2.8	Alluvial Stream Deposits	42
2.9	Marine Sediments	45
2.10	Parent Materials Transported by Glacial Ice and Meltwaters	46
	Parent Materials Transported by Wind	49
	Organic Deposits	51
	Climate	53
	Biota: Living Organisms	55
	Topography	59
	Time	61
	Soil Formation in Action	62
	The Soil Profile	65
	Conclusion	69
2.10	Study Questions	69
	References	69
3 SOIL CLASSII	fication 71	
	,	73
	Concept of Individual Soils	72
	Comprehensive Classification System: Soil Taxonomy	74
	Categories and Nomenclature of Soil Taxonomy	79
	Soil Orders	81
	Entisols (Recent: Little If Any Profile Development)	85
	Inceptisols (Few Diagnostic Features: Inception of B Horizon)	87
	Andisols	88
3.8	Gelisols (Permafrost and Frost Churning)	89
3.9	Histosols (Organic Soils without Permafrost)	92
3.10	Aridisols (Dry Soils)	94
3.11	Vertisols (Dark, Swelling and Cracking Clays)	96
3.12	Mollisols (Dark, Soft Soils of Grasslands)	99
3.13	Alfisols (Argillic or Natric Horizon, Medium to High Bases)	102
3.14	Ultisols (Argillic Horizon, Low Bases)	104
	Spodosols (Acid, Sandy, Forest Soils, Low Bases)	105
	Oxisols (Oxic Horizon, Highly Weathered)	107
	Lower-Level Categories in Soil Taxonomy	108
	Conclusion	114
	Study Questions	114
	References	116
4 Soil Archii	TECTURE AND PHYSICAL PROPERTIES 117	•
4 1	Soil Color	118
	Soil Texture (Size Distribution of Soil Particles)	118
	Soil Textural Classes	125
	Structure of Mineral Soils	130
	Soil Density	134
	Pore Space of Mineral Soils	. 144
	Formation and Stabilization of Soil Aggregates	149
	Tillage and Structural Management of Soils	154
	Soil Properties Relevant to Engineering Uses	161
4.10	Conclusion	168
	Study Questions	168
	References	169
5 SOIL WATER	: CHARACTERISTICS AND BEHAVIOR 171	
5 1	Structure and Related Properties of Water	172
	Capillary Fundamentals and Soil Water	174
	/	

5.4 5.5 5.6 5.7 5.8 5.9 5.10	Soil Water Energy Concepts Soil Moisture Content and Soil Water Potential The Flow of Liquid Water in Soil Infiltration and Percolation Water Vapor Movement in Soils Qualitative Description of Soil Wetness Factors Affecting Amount of Plant-Available Soil Water Mechanisms by Which Plants Are Supplied with Water Conclusion Study Questions References	176 183 190 195 198 200 204 208 210 211 212
6 SOIL AND TH	E HYDROLOGIC CYCLE 213	
6.2 6.3 6.4 6.5 6.6 6.7 6.8 6.9 6.10	The Global Hydrologic Cycle Fate of Precipitation and Irrigation Water The Soil—Plant—Atmosphere Continuum Efficiency of Water Use Control of Evapotranspiration (ET) Control of Surface Evaporation (E) Liquid Losses of Water from the Soil Percolation and Groundwaters Enhancing Soil Drainage Septic Tank Drain Fields Irrigation Principles and Practices Conclusion Study Questions References	214 216 220 227 230 231 233 236 241 247 254 262 263
7 Soil Aeratio	ON AND TEMPERATURE 265	
7.1 7.2 7.3 7.4 7.5 7.6 7.7 7.8 7.9 7.10 7.11	The Nature of Soil Aeration Soil Aeration in the Field Means of Characterizing Soil Aeration Oxidation-Reduction (Redox) Potential Factors Affecting Soil Aeration Ecological Effects of Soil Aeration Aeration in Relation to Soil and Plant Management Wetlands and Their Poorly Aerated Soils Processes Affected by Soil Temperature Absorption and Loss of Solar Energy Thermal Properties of Soils Soil Temperature Control Conclusion Study Questions References	265 268 270 273 276 279 280 286 293 294 300 304 305
8 SOIL COLLOI	DS: THEIR NATURE AND PRACTICAL SIGNIFICANCE 307	
8.2 8.3 8.4 8.5 8.6 8.7	General Properties of Soil Colloids Types of Soil Colloids Adsorbed Cations Fundamentals of Layer Silicate Clay Structure Mineralogical Organization of Silicate Clays Genesis of Soil Colloids Geographic Distribution of Clays Sources of Charges on Soil Colloids	308 308 311 313 315 319 322 323

8.9	Constant Charges on Silicate Clays	323
8.10	pH-Dependent Charges	325
	Cation Exchange	328
	Cation Exchange Capacity	329
	Exchangeable Cations in Field Soils	335
	Cation Exchange and the Availability of Nutrients	335
8.15	Anion Exchange	336
8.16	Sorption of Pesticides and Groundwater Contamination	338
8.17	Physical Properties of Colloids	339
8.18	Environmental Uses of Swelling-Type Clays	339
	Conclusion	341
	Study Questions	342
	References	342
9 SOIL REACTI	ON: ACIDITY AND ALKALINITY 343	
9.1	Sources of Hydrogen and Hydroxide Ions	344
	Classification of Soil Acidity	349
9.3	Colloidal Control of Soil Reaction	350
9.4	Buffering of Soils	351
	Buffering Capacity of Soils	353
9.6	Variability in Soil pH	354
9.7	Soil Reaction: Correlations	359
9.8	Determination of Soil pH	363
9.9	Methods of Intensifying Soil Acidity	364
	Decreasing Soil Acidity: Liming Materials	365
	Reactions of Lime in the Soil	367
9.12	Lime Requirements: Quantities Needed	367
9.13	Practical Considerations	370
9.14	Ameliorating Acidity in Subsoils	374
9.15	Conclusion	375
,	Study Questions	376
	References	376
10 ALKALINE	AND SALT-Affected Soils and Their Management 37,8	
10.1	Sources of Alkalinity	378
	Nonsaline Alkaline Soils of Dry Areas	380
	Development of Salt-Affected Soils	382
10.4	Measuring Salinity and Alkalinity	385
	Classes of Salt-Affected Soils	387
10.6	Growth of Plants on Saline and Sodic Soils	391
10.7	Selective Tolerance of Higher Plants to Saline and Sodic Soils	391
10.8	Management of Saline and Sodic Soils	393
10.9	Reclamation of Saline Soils	395
10.10	Reclamation of Saline-Sodic and Sodic Soils	, 397
10.11	Management of Reclaimed Soils	401
	Conclusion	401
	Study Questions	402
	References	402
II ORGANISM	IS AND ECOLOGY OF THE SOIL 404	
- 11.1	The Diversity of Organisms in the Soil	404
	Organisms in Action	407
	Organism Abundance, Biomass, and Metabolic Activity	410
	Earthworms	412

11.5	Termites	415
11.6	Soil Microanimals	418
11.7	Roots of Higher Plants	422
	Soil Algae	424
	Soil Fungi	425
11.10	Soil Actinomycetes	432
	Soil Bacteria	433
11.12	Conditions Affecting the Growth of Soil Microorganisms	434
	Beneficial Effects of Soil Organisms	435
	Soil Organisms and Damage to Higher Plants	436
	Ecological Relationships Among Soil Organisms	439
	Genetically Engineered Microorganisms	442
	Conclusion	444
	Study Questions	444
	References	444
12 SOIL ORGA	ANIC MATTER 446	-
	The Global Carbon Cycle	446
	The Process of Decomposition in Soils	449
12.3	Factors Controlling Rates of Decomposition and Mineralization	453
12.4	Humus: Genesis and Nature	460
12.5	Composts and Composting	463
12.6	Direct Influences of Organic Matter on Plant Growth	466
12.7	Influence of Organic Matter on Soil Properties and the Environment	468
	Management of Amount and Quality of Soil Organic Matter	468
	Carbon Balance in the Soil–Plant–Atmosphere System	472
12.10	Factors and Practices Influencing Soil Organic Matter Levels	474
	Soils and the Greenhouse Effect	482
	Organic Soils (Histosols)	485
12.13	Conclusion	487
	Study Questions	488
	References	489
13 Nitrogen	AND SULFUR ECONOMY OF SOILS 491	
	Influence of Nitrogen on Plant Growth and Development	492
	Origin and Distribution of Nitrogen	494
	The Nitrogen Cycle	495
	Immobilization and Mineralization	495
	Ammonium Fixation by Clay Minerals	497
	Ammonia Volatilization	498
	Nitrification	499
	The Nitrate Leaching Problem	502
	Gaseous Losses by Denitrification	506
	Biological Nitrogen Fixation	512
	Symbiotic Fixation with Legumes	514
	Symbiotic Fixation with Nonlegumes	518
	Nonsymbiotic Nitrogen Fixation	519
	Addition of Nitrogen to Soil in Precipitation	520
	Reactions of Nitrogen Fertilizers	521
	Practical Management of Soil Nitrogen in Agriculture	522
	Importance of Sulfur	524
	Natural Sources of Sulfur	525
	The Sulfur Cycle	529
	Behavior of Sulfur Compounds in Soils	530
	Sulfur Oxidation and Reduction	532

- 13.22	Sulfur Retention and Exchange	535
13.23	Sulfur and Soil Fertility Maintenance	536
13.24	Conclusion	536
	Study Questions	537
	References	538
14 Can Duan		
	PHORUS AND POTASSIUM 540	
	Role of Phosphorus in Plant Nutrition and Soil Fertility	541
	Effects of Phosphorus on Environmental Quality	543
	The Phosphorus Cycle	549
	Organic Phosphorus in Soils	552
	Inorganic Phosphorus in Soils	554
	Solubility of Inorganic Phosphorus in Acid Soils	558
	Inorganic Phosphorus Availability at High pH Values	561 562
	Phosphorus-Fixation Capacity of Soils Practical Capital of Phosphorus Availability	566
	Practical Control of Phosphorus Availability Potassium: Nature and Ecological Roles	569
	Potassium in Plant and Animal Nutrition	570
	The Potassium Cycle	57I
	The Potassium Problem in Soil Fertility	57.4
	Forms and Availability of Potassium in Soils	57 .4 576
	Factors Affecting Potassium Fixation in Soils	579
	Practical Aspects of Potassium Management	580
	Conclusion	582
(7.17	Study Questions	582 582
	References	583
15 Micronut	RIENT ELEMENTS 585	
15.1	Deficiency versus Toxicity	586
	Role of the Micronutrients	587
	Source of Micronutrients	590
	General Conditions Conducive to Micronutrient Deficiency	591
	Factors Influencing the Availability of the Micronutrient Cations	593
	Organic Compounds as Chelates	598
	Factors Influencing the Availability of the Micronutrient Anions	602
	Need for Nutrient Balance	605
	Soil Management and Micronutrient Needs	606
15.10	Conclusion	609
	Study Questions	610
	References	610
16 PRACTICAL	Nutrient Management 612	
		613
	Goals of Nutrient Management	612 616
	Environmental Quality Nutrient Resources	621
		622
	Soil–Plant–Atmosphere Nutrient Cycles Paggeling Nutrients through Animal Manuros	625
	Recycling Nutrients through Animal Manures Storage Treatment, and Management of Animal Manures	630
	Storage, Treatment, and Management of Animal Manures Industrial and Municipal By-Products	632
	Sewage Effluent and Sludge	633
	Practical Utilization of Organic Nutrient Sources	636
	Integrated Recycling of Wastes	638
	Inorganic Commercial Fertilizers	638
	The Concept of the Limiting Factor	645
10.12	THE CONCEPT OF THE CHIRITIES LECTOR	U-T J

16.13	Fertilizer Application Methods	647
	Timing of Fertilizer Application	651
	Diagnostic Tools and Methods	653
	Plant Symptoms and Field Observations	653
	Plant Analysis and Tissue Testing	653
	Soil Analysis	656
	Site-Specific Nutrient Management	659
	Broader Aspects of Fertilizer Practice	661
	Conclusion	664
	Study Questions	664
	References	666
17 Soil Erosi	on and Its Control 668	
17.1	Significance of Soil Erosion and Land Degradation	669
	On-Site and Off-Site Effects of Accelerated Soil Erosion	673
	Mechanics of Water Erosion	678
	Models to Predict the Extent of Water-Induced Erosion	681
	Factors Affecting Interrill and Rill Erosion	682
	Conservation Tillage	691
	Vegetative Barriers	696
	Control of Gully Erosion and Mass Wasting	696
	Control of Accelerated Erosion on Range and Forest Land	699
	Erosion and Sediment Control on Construction Sites	702
	Wind Erosion: Importance and Factors Affecting It	707
	Predicting and Controlling Wind Erosion	710
	Land Capability Classification as a Guide to Conservation	713
	Progress in Soil Conservation	717
	Conclusion	719
	Study Questions	720
	References	721
18 Soils and	CHEMICAL POLLUTION 723	
18.1	Toxic Organic Chemicals	724
	Kinds of Pesticides	725
	Behavior of Organic Chemicals in Soil	727
	Effects of Pesticides on Soil Organisms	732
	Regional Vulnerability to Pesticide Leaching	,735
	Remediation of Soils Contaminated with Organic Chemicals	736
	Contamination with Toxic Inorganic Substances	740
	Potential Hazards of Chemicals in Sewage Sludge	742
	Reactions of Inorganic Contaminants in Soils	744
	Prevention and Elimination of Inorganic Chemical Contamination	746
	Landfills	748
	Soils as Organic Waste Disposal Sites	753
	Radionuclides in Soil	753
18.14	Radon Gas from Soils	755
	Conclusion	755
	Study Questions	756
	References	756
19 GEOGRAPH	IC SOILS INFORMATION 759	
191	Soil Spatial Variability in the Field	759
	Techniques and Tools for Mapping Soils	764
	Modern Technology for Soil Investigations	768

19.4	Remote Sensing Tools for Soils Investigations	769
	Air Photos	77
	Satellite Imagery	775
	Soil Surveys	778
	The County Soil Survey Report and Its Utilization	780
	Geographic Information Systems	783
	Conclusion	784
10.10	Study Questions	785
	References	787
	References	707
20 GLOBAL SC	DIL QUALITY AS AFFECTED BY HUMAN ACTIVITIES 788	
20.1	The Concept of Soil Quality/Soil Health	788
20.2	Sustaining Biological Productivity	792
	The Population Explosion	792
	Intensified Agriculture—The Green Revolution	793
	Effects of Intensified Agriculture on Soil Quality or Health	795
	Unplanned Production Intensification	798
	Prospects for the Future	801
	Modified Intensive Agricultural Systems	803
	Improving Low-Yielding Agricultural Systems	809
	Improving Soil Quality in sub-Saharan Africa	806
	Improving Soil Quality in Asia and Latin America	812
	Conclusion	813
	Study Questions	813
	References	813
Approximate A	II C. Cau Tarayany Cipanga Managan Inggan 015	
APPENDIX A	U.S. SOIL TAXONOMY SUBORDER MAP AND LEGEND 815	
Appendix B	Canadian and FAO Soil Classification Systems 819	
Approprie	CLUBUT CONTROLON ENGRADO AND DEDIGDIG TAGES OF THE ELECTRICA	022
APPENDIX C	SI Unit Conversion Factors and Periodic Table of the Elements	823
GLOSSARY	327	
- LO33/11(1	;	
	•	
INDEX 863		

xii Contents