Contents

Introduction 1
R. Brumme and P.K. Khanna

Part A Description of Long-term Observation Sites

1 General Description of Study Sites
H. Meesenburg and R. Brumme

References 11

2 Climatic Condition at Three Beech Forest Sites in Central Germany
O. Panferov, H. Kreilein, H. Meesenburg, J. Eichhorn, and G. Gravenhorst

2.1 Climate of Germany 13
2.2 Experimental Sites 16
2.2.1 Climatic Variables 16
2.3 Climatic Conditions at Beech Sites 17
2.3.1 Solar Radiation 17
2.3.2 Air Temperature 18
2.3.3 Precipitation 20
2.3.4 Variations of Air Temperature and Precipitation During the Observation Period 22
2.3.5 Soil Temperature 24
2.4 Comparison with Other Climatic Regions 27
2.5 Conclusions 30
References 31

3 Soil Properties
H. Meesenburg, R. Brumme, C. Jacobsen, K.J. Meiwes, and J. Eichhorn

3.1 Introduction 33

3.2 Parent Material, Mineral Composition, Soil Texture 33
3.3 Soil Types, Soil pH, and Buffer Systems of Soils 36
3.4 Cation Exchange Capacity, and Exchangeable Cations 37
3.5 Nutrient Status of Soils and Organic Layer Types 40
3.6 Additional Study Plots at the Solling Site 41
3.7 Conclusions 46
References 46

4 Changes in C and N Contents of Soils Under Beech Forests over a Period of 35 Years
K.J. Meiwes, H. Meesenburg, J. Eichhorn, C. Jacobsen, and P.K. Khanna

4.1 Introduction 49
4.2 Content and Distribution of C and N in Soils from Three Beech Sites 50
4.3 Long-term Periodic Measurements of C and N Contents in the Soil at Solling Site 54
4.4 Human Impacts and Management Issues at Solling 57
4.5 Summary 61
References 62

5 Vegetation
W. Schmidt

5.1 Introduction 65
5.2 Vegetation Structure and Phyto-sociological Classification 66
5.2.1 Solling 66
5.2.2 Zierenberg 68
5.2.3 Göttinger Wald 71
5.3 Vegetation Ecology of the Beech Forest Ecosystems: Impact of Site Conditions 74
5.4 Vegetation Dynamics 77
5.4.1 Solling 77
5.4.2 Zierenberg 78
5.4.3 Göttinger Wald 78
5.5 Conclusion 81
References 82

6 Microbial Biomass
R. Brumme, M. Raubuch, J. Priess, C. P. Wang, and T.-H. Anderson

6.1 Introduction 87
6.2 Microbial Carbon and Nitrogen 88
6.3 Metabolic Quotient and C_{mic}-to-C_{org} Relationship 89
6.4 Conclusions and Indications of Human Impacts 91
References 92

7 Soil Fauna
M. Schaefer and J. Schauermann

7.1 Introduction 93
7.2 Fauna 94
7.3 Macro-Gradient from Base-Rich to Acid Beech Forests 94
7.4 Meso-Gradient from Basalt to Limestone at the Zierenberg Site 99
7.5 Conclusions 100
References 101

Part B Ecosystem Processes

8 Tree Growth, Biomass, and Elements in Tree Components of Three Beech Sites
P. Rademacher, P.K. Khanna, J. Eichhorn, and M. Guericke

8.1 Introduction 105
8.2 Sites and Methods of Data Collection 107
8.2.1 Stem Growth 107
8.2.2 Biomass Measurements of Different Tree Components on Two Sites 109
8.2.3 Biomass Modelling at Different Experimental Sites 110
8.2.4 Nutrient Concentration of Various Tree Components 111
8.3 Stand Growth 111
8.3.1 Solling Site 111
8.3.2 Göttinger Wald Site 113
8.3.3 Zierenberg Site 113
8.4 Comparison of Stand Growth at the Three Experimental Sites 114
8.5 Biomass of Harvested Trees and Annual Biomass Increments 116
8.6 Nutrients in Various Tree Components 121
8.7 Stand Harvesting and Nutrient Export 130
8.8 Summary 132
References 133

9 Fine Root Biomass, Turnover and Litter Production
D. Murach, A. Horn, W. Ke-Hong, and C. Rapp

9.1 Introduction 137
9.2 Methods 137
9.3 Fine Root Production and Turnover 142
9.4 Element Recycling with Litter of Fine Root 147
9.5 Summary 148
References 151

10 Phytomass, Litter and Net Primary Production of Herbaceous Layer
I.-M. Schulze, A. Bolte, W. Schmidt, and J. Eichhorn

10.1 Introduction 155
10.2 Definitions and Methods 156
10.2.1 Biomass and NPP Estimates by Harvesting Methods 156
10.2.2 Aboveground Phytomass Estimates by Dimension Analysis 157
10.3 Phytomass Estimates 161
10.3.1 Total Biomass Estimated from Harvest Studies 161
10.3.2 Aboveground Phytomass Estimated by Plant Dimension Analysis 165
10.3.3 Comparison of Methods of Biomass Assessment 165
10.4 Phenological Patterns of Annual Development of Herbaceous Biomass 167
10.5 Annual Production of Biomass and Litterfall of the Herbaceous Layer 169
10.6 N-storage, Dynamic and Internal N-Cycling 171
10.7 Annual Changes in N-Contents 172
10.8 C/N-Ratios 174
10.9 Ground Vegetation as a Part of Internal N-Cycling in Beech Stands 175
10.10 Conclusion 176
References 177

11 Biomass and Element Content of Foliage and Aboveground Litterfall on the Three Long-Term Experimental Beech Sites: Dynamics and Significance
P.K. Khanna, H. Fortmann, H. Meesenburg, J. Eichhorn, and K.J. Meiwes

11.1 Introduction 183
11.2 Site Description and Collection and Measurements of Aboveground Litterfall Components and Green Foliage 185
11.3 Components and Annual Patterns of Aboveground Litterfall 187
11.4 Amount of Nutrients in Litterfall 189
11.5 Nutrient Concentrations in the Total Litterfall and Leaf Litter Components of the Different Sites 192
11.6 Foliar Chemistry 193
11.7 Nutrients and Heavy Metals in Green Foliage and Litterfall in Relation to Atmospheric Inputs 198
11.8 Autumn Withdrawal of Nutrients at the Time of Leaf Senescence 200
11.9 Conclusions 203
References 204

12 The Role of Soil Fauna for Decomposition of Plant Residues
M. Schaefer, S. Migge-Kleian, and S. Scheu

12.1 Introduction 207
12.2 Influence of Soil Fauna on Decomposition of Canopy Leaf Litter 210
12.3 Influence of Soil Fauna on Decomposition of Herb Litter 211
12.4 Decomposition of Roots and Woody Material 213
12.5 Faunal Control of Litter Decay 213
12.5.1 Micro-fauna, Meso-fauna, and Macro-fauna 214
12.5.2 Carbon and Nitrogen Mineralisation 216
12.5.3 Acid Rain and Liming 218
12.6 The Decomposer Web 219
12.6.1 Important Interactions Between Decomposer Groups ... 220
12.6.2 Bottom-up and Top-down Effects 221
12.7 Earthworms as Ecosystem Engineers 223
12.7.1 Food Ingestion, Gut Passage, Production of Casts and Mucus 224
12.7.2 Bioturbation 224
12.7.3 Earthworm Burrows and Middens 225
12.7.4 Earthworms in the Rhizosphere 226
12.8 Conclusions 226
References 227

13 Nitrogen and Carbon Transformations
R. Brumme, J. Priess, C.P. Wang, M. Raubuch, G. Steinmetz, and H. Meyer

13.1 Introduction 231
13.2 Experimental Details 232
13.3 Nitrogen Mineralisation in Soil Cores 233
13.3.1 Depthwise Distributions of Net N-Mineralisation 237
13.3.2 Temperature Sensitivity of Net N-Mineralisation 238
13.4 Carbon Mineralisation 239
13.4.1 Depthwise Distributions of Net C-Mineralisation 240
13.4.2 Temperature Sensitivity of Net C-Mineralisation 241
13.5 Relationship Between N-Mineralisation and C-Mineralisation 241
13.6 Nitrification 243
13.6.1 Autotrophic Versus Heterotrophic Nitrification 246
13.6.2 Effects of Temperature and Water Stress on Nitrification 247
13.7 Conclusions and Indications of Human Impacts 248
References 249

14 Fate, Transport, and Retention of Applied ^{15}N Labelled Nitrogen in Forest Soils
R. Brumme, C.P. Wang, J. Priess, M. Raubuch, and G. Steinmetz

14.1 Introduction 253
14.2 Experimental Details 254
14.3 Transport and Leaching Losses of Added ^{15}N Labelled Nitrogen 255
14.4 Retention of Applied Ammonium and ^{15}N Balance of Forest Soils 258
14.5 Retention of Added Nitrate and ^{15}N Balances of Forest Soils 260
14.6 Temperature Effects on Transformation of Ammonium Applied to the Surface Organic Layer and to Mineral Soil Layers of the Solling Site 261
14.7 Conclusions 262
References 262

15 Atmospheric Deposition and Canopy Interactions
H. Meesenburg, J. Eichhorn, and K.J. Meiwes

15.1 Introduction 265
15.2 Precipitation Chemistry 269
15.3 Element Fluxes 273
15.4 Canopy Rain Interactions 279
15.5 Discussion 284
15.6 Conclusions 286
References 299

16 Changes in Soil Solution Chemistry, Seepage Losses, and Input–Output Budgets at Three Beech Forests in Response to Atmospheric Depositions
R. Brumme, H. Meesenburg, M. Bredemeier, C. Jacobsen, E. Schönfelder, K.J. Meiwes, and J. Eichhorn

16.1 Introduction 303
16.2 Soil Solution Collection and Statistical Analysis 304
16.3 Modelling of Water Fluxes 305
16.4 Calculation of Input–Output Balances of Various Elements and Acid Production 306
16.5 Solution Composition From Soils of Different Buffer Systems 308
16.6 Temporal Trends in Soil Solution Chemistry 311
16.7 Hydrologic Regime 316
16.8 Element Seepage Losses 319
16.9 Element Budgets 319

16.9.1 Solling Site 321
16.9.2 Göttinger Wald Site 325
16.9.3 Zierenberg Site 326
16.10 Acid Loading: Atmospheric Depositions and System–Internal H Production 327
16.11 Final Discussion 329
16.11.1 Response of Acid–Base Soil Properties to Decreasing Atmospheric Deposition 329
16.11.2 Response of N and C Budgets of Soils to Decreasing Atmospheric Depositions 330
16.12 Conclusions 332
References 332

17 Soil Respiration
R. Brumme, W. Borken, and J. Prenzel

17.1 Introduction 337
17.2 Soil Chamber Design Affects Soil Respiration Measurements 338
17.3 Temporal Variation of Soil Respiration 340
17.4 Spatial Variation of Soil Respiration 342
17.5 Soil Respiration in Temperate Beech Forests 343
17.6 Autotrophic Respiration 344
17.7 Effects of Additional N-inputs and Liming on Soil Respiration 347
17.8 Summary and Implications for Management Options 348
References 349

18 N_2O Emission from Temperate Beech Forest Soils
R. Brumme and W. Borken

18.1 Introduction 353
18.2 Method 353
18.3 Temporal Variation of N_2O Emission 354
18.4 Spatial Variation of N_2O Emissions 356
18.5 Landscape Control on N_2O Emissions 356
18.6 Relationship Between Temperature and N_2O Emission 360
18.7 Implications of Forest Management for N_2O Emissions 361
18.8 Conclusions 364
References 365

19 Methane Uptake by Temperate Forest Soils
W. Borken and R. Brumme

19.1 Introduction 369
19.2 Moisture and Temperature Effects 370

19.3 Site Factors Determine Methane Uptake 373
19.4 Effects of Liming and Forest Harvesting 377
19.5 Effects of Nitrogen Input 379
19.6 Conclusions and Indications of Human Impacts 382
References 383

Part C Forest Management and Regional Scale Issues Concerning C and N

20 Microbial Biomass in Broad-Leaved Forest Soils
T.-H. Anderson

20.1 Introduction 389
20.2 Regional Distribution of Microbial Carbon of Broad-Leaved Forest Soils in Lower Saxony 389
20.2.1 The Significance of the C_{mic}-to-C_{org} Relationship and the Specific Respiration Rate, qCO_2 392
20.3 Microbial Communities as Affected by Soil pH 397
20.3.1 pH Dependent Changes of the C_{mic}- to- C_{org} Relationship, qCO_2 and the Fungal–Bacterial Ratio of Broad-Leaved Forest Stands 397
20.4 Conclusion and Management Implications 400
References 401

21 Soil Organic Carbon and Nitrogen in Forest Soils of Germany
R. Brumme, M. Egenolf, C. Aydin, J. Block, K.J. Meiwes, and K.v. Wilpert

21.1 Introduction 405
21.2 Carbon and Nitrogen Stocks in Temperate Forest Soils 407
21.3 Environmental Controls on C- and N-Sequestration 409
21.4 Soil Control on C- and N-Sequestration 413
21.5 Environmental and Anthropogenic Control on C- and N-sequestration in Surface Organic Horizons 417
21.6 Conclusions 420
References 421

22 Management Options for European Beech Forests in Relation to Changes in C- and N-Status as Described by the Three Study Sites
N. Bartsch and E. Röhrig

22.1 An Introduction to European Beech 425
22.1.1 Geographic Range and Current Distribution 425
22.1.2 Environmental Amplitude 427
22.1.3 Growth 429
22.1.4 Crown Damages and Tree Mortality 431

22.1.5 Wood Quality 431
22.2 Common Forest Management Practices for European Beech 432
22.2.1 Regeneration 432
22.2.2 Soil Scarification 437
22.2.3 Liming 437
22.2.4 Thinning 438
22.3 Specific Silvicultural Characteristics and Treatments of the Three Beech Ecosystems 438
22.3.1 Solling 439
22.3.2 Göttinger Wald 440
22.3.3 Zierenberg 441
22.4 Naturalness of the Forest Management Practices 442
22.5 Effects of Forest Management Practices on C- and N-Dynamics 444
22.6 Conclusions 449
References 450

Part D Synthesis

23 Stand, Soil and Nutrient Factors Determining the Functioning and Management of Beech Forest Ecosystems: A Synopsis
R. Brumme and P.K. Khanna

23.1 Background and Issues 459
23.2 Productivity, C Stocks, C Balances, and Their Relations to Soil Chemical State of Three Beech Ecosystems 460
23.3 N Stocks and N Balances at Three Beech ecosystems 463
23.4 Nutrient Status and Productivity of European Beech Ecosystems in a Changing Environment 466
23.5 N-Status and Its Significance for European Forest Ecosystems .. 469
23.5.1 Forests of the Accumulation Type 471
23.5.2 Forests of the Degradation Type 474
23.5.3 Forests of the (quasi-) Steady State Type 475
23.6 Dynamics of C and N Sequestration in European Forests 476
23.7 Bioturbation as a Central Process of C and N Dynamics: Role of Soil Biota 479
23.8 Forest Management Strategies: Future Perspectives 482
23.9 Conclusions 484
References 487

Index 491