Soil Ecology in Northern Forests

A Belowground View of a Changing World

MARTIN LUKAC University of Reading

DOUGLAS L. GODBOLD Bangor Universtiy

ů.



Contents

Preface xi

1 Introduction 1

- 1.1 History of forest soil studies 1
- 1.2 Soil formation 3
- 1.3 Trees and soil environment 8

2 Soil properties 10

- 2.1 Physical properties 10
 - 2.1.1 Texture 10
 - 2.1.2 Soil structure 13
 - 2.1.3 Water 17
- 2.2 Chemical properties 20
 - 2.2.1 Acidity and alkalinity 20
 - 2.2.2 Cation exchange capacity and nutrient availability 22
 - 2.2.3 Salinity 24
- 2.3 Soil organic matter 25
 - 2.3.1 Litter 25
 - 2.3.2 Humus: inherited and humified organic substances 27
 - 2.3.3 Organo-mineral complexes 28
- 2.4 Soil fertility 30

3 Forest soil development and classification 32

- 3.1 Soil development 33
 - 3.1.1 Soil formation processes 33
- 3.2 Soil profile 37
 - 3.2.1 Soil horizons 38
 - 3.2.2 Soil depth 40
 - 3.2.3 Time 41

- 3.3 Soil classification 42
 - 3.3.1 History and principles of soil classification 42
 - 3.3.2 USDA classification 43
 - 3.3.3 FAO classification 47

3.4 Examples of typical temperate and boreal forest soils 50

- 3.4.1 Leptosols 52
- 3.4.2 Luvisols 53
- 3.4.3 Cambisols 53
- 3.4.4 Podzols 54
- 3.4.5 Gleysols 55
- 3.4.6 Histosols 56
- 4 Soil fungi 57
 - 4.1 Mycorrhizas 57
 - 4.1.1 Emanating hyphae and rhizomorphs 60
 - 4.1.2 Identification of mycorrhizas 62
 - 4.1.3 Determination of the extraradical and extramatrical mycelium 64
 - 4.2 Community structure 66
 - 4.2.1 Common mycelial networks 76
 - 4.2.2 Relating ectomycorrhizal community structure to ecosystem function 76

5 Soil water 78

5.1 Introduction and background 78

- 5.1.1 Water-binding forces in soils 78
- 5.1.2 Water potential 79
- 5.1.3 Soil moisture heterogeneity 80
- 5.2 Water acquisition by roots and mycorrhizas 82
- 5.3 Hydraulic redistribution 86
- 5.4 Waterlogging 90
- 5.5 Drought 93

6 Forest carbon cycle 94

- 6.1 The global carbon cycle 95
- 6.2 Formation of organic matter 96
- 6.3 Belowground carbon cycles 98
 - 6.3.1 Belowground biomass pool and fluxes 99
 - 6.3.2 Consumption: soil fauna 108
 - 6.3.3 Final stages of organic matter breakdown 109
- 6.4 Soil humus 112
 - 6.4.1 Mor and mull humus 113
 - 6.4.2 Chemical composition of humus 115
 - 6.4.3 Peat formation 116

- 7 Nutrient cycling 118
 - 7.1 Nutrient supply and uptake 119
 - 7.2 Nitrogen 124
 - 7.2.1 N cycling 124
 - 7.2.2 Importance of C:N ratios 128
 - 7.2.3 Climate change and the N cycle 130
 - 7.3 Phosphorus 133
 - 7.4 Potassium, calcium and magnesium 137
 - 7.5 Forest nutrient cycle and climate change 138
- 8 Northern forests in a high-CO₂ world 143
 - 8.1 Atmospheric CO₂ enrichment technology 143
 - 8.2 Increased forest production 146
 - 8.3 Soil C dynamics 148
 - 8.4 Soil CO₂ efflux 155
 - 8.5 High CO₂ and soil N cycle 156
 - 8.6 Diversity of soil biota 158

9 Soil acidity and heavy metal pollution 161

- 9.1 Emission, transport and deposition of pollutants 161
- 9.2 Inputs of acidity 164
 - 9.2.1 Soil acidification: nutrient loss, Al release,
 - Al in soil solutions 165
 - 9.2.2 Soil solution speciation of Al 170
- 9.3 Heavy metals in forest soils 1719.3.1 Soil solution speciation of heavy metals 174
- 9.4 Loss of base cations 174
- 9.5 Aluminium accumulation and toxicity 1799.5.1 Aluminium activity and speciation 1829.5.2 Base cations 182
- 9.6 Heavy metal effects on trees 183
- 9.7 Soil acidity effects on forest ecosystems 184
 - 9.7.1 Effects of soil acidity on roots, rooting depth and root growth 184
 - 9.7.2 Chronology of soil acidification 189
 - 9.7.3 Soil acidity and mycorrhizas 191
 - 9.7.4 Recovery from acidification 194

10 Nitrogen 195

- 10.1 Nitrogen cycle 195
- 10.2 Tree growth and biomass allocation 199
- 10.3 Changes in ground vegetation 205
- 10.4 Changes in ectomycorrhizal community structure and function 207
- 10.5 Increased susceptibility to pathogens and insects 209
- 10.6 Export of NO₃ with seepage water 210

11 Soil functioning and climate change 213

- 11.1 Effects of climate change 214
 - 11.1.1 Increasing temperature 216
 - 11.1.2 Changing rainfall 220
 - 11.1.3 Nitrogen deposition 223
- 11.2 Feedback effects of forests 226
 - 11.2.1 Contribution of northern forests to the global C cycle 227
 - 11.2.2 Forest expansion and the water cycle 229
- 11.3 Environmental benefits and ecosystem services of forest soils 232
 - 11.3.1 Carbon sequestration 233
 - 11.3.2 Water cycle 235
 - 11.3.3 Biodiversity 236

References 238

Index 253

The color plate section can be found between pages 148 and 149.