

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)

SOILS: BASIC CONCEPTS AND FUTURE CHALLENGES

This book was born as an international tribute to Fiorenzo C. Ugolini, an outstanding soil scientist who recently retired from university teaching and research. It is a fully up-to-date synthesis of the present knowledge of soils, their genesis, functions and management. It includes contributions from leading soil scientists and the result is a book that provides the basic concepts as well as the latest data and practical examples from across the discipline, including many issues that are overlooked in other treatments. The book also discusses the increasingly important role of soils in enabling the preservation of life.

Soils: Basic Concepts and Future Challenges provides the necessary keys to name soils and soil horizons. It contains a rare attempt to cross-harmonize the Reference Soil Groups of the World Reference Base of Soil Resources with the Soil Orders of the Soil Taxonomy, and presents a novel analysis of the various soil-forming factors. The book also quantifies the global extent of human-impacted soils, and the possible existence of extraterrestrial soils based on the findings from the last space missions.

This volume will be a valuable resource for researchers and students of soil science, soil conservation, geography and landscape ecology.

The Editors of this book, Giacomo Certini and Riccardo Scalenghe, are researchers at the Universities of Florence and Palermo respectively. Authors of numerous papers in international journals dealing with soil science and ecology, they have carried out studies in various European countries including Italy, Norway, Poland, Spain, Switzerland and the UK. They teach topics related to soil, water and the environment.

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)

SOILS: BASIC CONCEPTS AND FUTURE CHALLENGES

GIACOMO CERTINI

University of Florence

RICCARDO SCALENGHE

University of Palermo



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges
Giacomo Certini and Riccardo Scalenghe
Frontmatter
[More information](#)

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo
Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521851732

© Cambridge University Press 2006

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2006

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

ISBN-13 978-0-521-85173-2 hardback
ISBN-10 0-521-85173-4 hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)

‘We might say that the earth has the spirit of growth; that its flesh is the soil.’

Leonardo da Vinci

This book pays homage to Professor Fiorenzo C. Ugolini, who has recently retired from his long career as a university professor of soil science. All the authors of this book had spirited interactions with him. He is an enthusiastic and inspirational teacher and scientist, a tremendous mentor and friend, and a talented Renaissance man. We all benefited greatly from his valuable contributions through which he enriched us and our discipline, soil science. For this reason, and perhaps also for the vital energy Professor Ugolini showed on every occasion, the authors accepted with enthusiasm the invitation to contribute to this book dedicated to his career.

We hope that this text represents a useful resource for preparing future soil scientists.

Contents

<i>List of contributors</i>	<i>page xi</i>
<i>Preface</i>	xiii
<i>Acknowledgements</i>	xvi
1 Concepts of soils	1
<i>Richard W. Arnold</i>	
1.1 Some Greek and Roman concepts	2
1.2 The transition	4
1.3 The awakening	4
1.4 Genetic supremacy	5
1.5 Sampling volumes	7
1.6 Landscape systems	9
1.7 The new millennium	9
2 Pedogenic processes and pathways of horizon differentiation	11
<i>Stanley W. Buol</i>	
2.1 Horizonation processes	11
2.2 Studies of soil genesis	12
2.3 Surface horizons	14
2.4 Subsurface horizons	15
2.5 Formation of structural features in soil	21
3 Soil phases: the inorganic solid phase	23
<i>G. Jock Churchman</i>	
3.1 Description	23
3.2 Future prospects	44
4 Soil phases: the organic solid phase	45
<i>Claire Chenu</i>	
4.1 Soil organic matter complex composition	46

viii	<i>Contents</i>	
	4.2 Organomineral associations	51
	4.3 Soil organic matter dynamics	54
5	Soil phases: the liquid phase	57
	<i>Randy A. Dahlgren</i>	
	5.1 The liquid phase of soils	59
	5.2 Methods of soil solution characterization	63
	5.3 Application of soil solution studies to pedogenesis	66
	5.4 Conclusions	73
6	Soil phases: the gaseous phase	75
	<i>Andrey V. Smagin</i>	
	6.1 Gaseous components of soil	75
	6.2 Sources, sinks and transport of gases in the soil	77
	6.3 Agroecological evaluation of the soil air	84
	6.4 Gases emissions and global ecological functions of the soil	85
7	Soil phases: the living phase	91
	<i>Oliver Dilly, Eva-Maria Pfeiffer and Ulrich Irmeler</i>	
	7.1 Physiological capabilities of soil organisms	92
	7.2 The role of organisms for soil functions	95
	7.3 Aerobic and anaerobic metabolisms in soil	96
	7.4 The living phase indicates soil quality	98
	7.5 Modification of biotic communities during soil degradation	100
8	The State Factor theory of soil formation	103
	<i>Ronald Amundson</i>	
	8.1 The soil system	105
	8.2 State factors	108
	8.3 Importance of State Factor theory	111
9	Factors of soil formation: parent material. As exemplified by a comparison of granitic and basaltic soils	113
	<i>Michael J. Wilson</i>	
	9.1 Mineralogical properties	114
	9.2 Physical properties	116
	9.3 Chemical properties	119
	9.4 Conclusions	127
10	Factors of soil formation: climate. As exemplified by volcanic ash soils	131
	<i>Sadao Shoji, Masami Nanzyo and Tadashi Takahashi</i>	
	10.1 Global climate and soil formation	132

<i>Contents</i>		ix
10.2	Influences of climatic factors on soil formation based on the studies on volcanic ash soils	137
11	Factors of soil formation: topography	151
	<i>Robert C. Graham</i>	
11.1	Topographic elements of landscapes	151
11.2	External factors mediated by topography	155
11.3	Pedogenic processes linked to topography	156
11.4	Topography-based models of soil distribution	162
12	Factors of soil formation: biota. As exemplified by case studies on the direct imprint of trees on trace metal concentrations in soils	165
	<i>François Courchesne</i>	
12.1	Approach	168
12.2	Case study 1: Trace metal distribution at the soil–root interface	169
12.3	Case study 2: Trace metal patterns in organic horizons	175
12.4	In conclusion	179
13	Factors of soil formation: time	181
	<i>Ewart A. FitzPatrick</i>	
13.1	Time for horizon differentiation	182
13.2	Soil development	183
13.3	Holocene soil formation	185
13.4	Soil age and progressive change	185
13.5	Time and soil classification	190
14	Soil formation on Earth and beyond: the role of additional soil-forming factors	193
	<i>Giacomo Certini and Riccardo Scalenghe</i>	
14.1	The anthropogenic factor	194
14.2	Other factors of pedogenesis	205
14.3	Extraterrestrial soils	208
15	Soil functions and land use	211
	<i>Johan Bouma</i>	
15.1	How to deal with future demands on our soils	212
15.2	To characterize soil functions better	215
15.3	Storylines: what can the soil tell us when we listen?	219
15.4	In conclusion	221
16	Physical degradation of soils	223
	<i>Michael J. Singer</i>	
16.1	Soil compaction	224
16.2	Sealing and crusting	227
16.3	Physical soil management	229

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)

x	<i>Contents</i>	
16.4	Secondary effects	231
16.5	Conclusions	232
17	Chemical degradation of soils	235
	<i>Peter Blaser</i>	
17.1	Chemical soil degradation processes	236
17.2	Our duty	253
18	The future of soil research	255
	<i>Anthony C. Edwards</i>	
18.1	Soils and their buffering capacities	257
18.2	The soil resource	258
18.3	Soil phosphorus	258
18.4	Soil processes	260
18.5	Nitrogen cycling	261
18.6	The continued investigation of soil processes	263
	<i>Appendix: Naming soils and soil horizons</i>	265
	<i>Stanley W. Buol, Giacomo Certini and Riccardo Scalenghe</i>	
	<i>References</i>	277
	<i>Index</i>	303

List of contributors

- Ronald Amundson
Division of Ecosystem Sciences, University of California, Berkeley, USA
- Richard W. Arnold
Fairfax, Virginia, USA
- Peter Blaser
Swiss Federal Institute for Forest, Snow and Landscape, Birmensdorf, Switzerland
- Johan Bouma
Wageningen University and Research Centre, Wageningen, The Netherlands
- Stanley W. Buol
Department of Soil Science, North Carolina State University, Raleigh, USA
- Giacomo Certini
Dipartimento di Scienza del Suolo e Nutrizione della Pianta, Università degli Studi di Firenze, Firenze, Italy
- Claire Chenu
Département AGER, UMR BIOEMCO, Thiverval Grignon, France
- G. Jock Churchman
School of Earth and Environmental Sciences, University of Adelaide, Adelaide, Australia
- François Courchesne
Département de Géographie, Université de Montréal, Montréal, Canada
- Randy A. Dahlgren
Department of Land, Air and Water Resources, University of California, Davis, USA

Oliver Dilly

Lehrstuhl für Bodenschutz und Rekultivierung, Brandenburgische Technische
Universität, Cottbus, Germany

Anthony C. Edwards

Peterhead, Scotland, UK

Ewart A. Fitzpatrick

Department of Plant and Soil Science, University of Aberdeen, Scotland, UK

Robert C. Graham

Department of Environmental Sciences, University of California, Riverside, USA

Ulrich Irmeler

Ökologie-Zentrum, University of Kiel, Kiel, Germany

Masami Nanzyo

Graduate School of Agricultural Science, Tohoku University, Sendai, Japan

Eva-Maria Pfeiffer

Institute of Soil Science, University of Hamburg, Hamburg, Germany

Riccardo Scalenghe

Dipartimento di Agronomia Ambientale e Territoriale, Università degli Studi di
Palermo, Palermo Italy

Sadao Shoji

Sendai, Japan

Michael J. Singer

Department of Land, Air and Water Resources, University of California, Davis,
USA

Andrey V. Smagin

Faculty of Soil Science, Moscow State University, Moscow, Russia

Tadashi Takahashi

Graduate School of Agricultural Science, Tohoku University, Sendai, Japan

Michael J. Wilson

The Macaulay Institute, Aberdeen, Scotland, UK

Preface

Soil is a dynamic natural body occurring in the upper few metres of the Earth's surface at the interface between the atmosphere, biosphere, hydrosphere and geosphere. A soil is both an ecosystem in itself, and a critical part of the larger terrestrial ecosystem. From the earliest perceptions of soils as the organic enriched surface layer to today's pedologic horizonation of profiles, there is a rich history of beliefs and understanding of this vital life-sustaining resource.

In Chapter 1 changes in perceptions of soils and their classification are explored. Chapter 2 describes some of the specific reactions that are components of the soil-forming processes that transform geologic materials into recognizable pedologic features and horizons. Solids, along with the liquids and gases that fill pore spaces between the solids, compose the three-phase soil system.

Chapter 3 treats the inorganic fraction of the solid phase, examining differences between primary minerals, derived directly from rocks, and secondary minerals, formed by pedogenic processes. Soil organic matter is discussed in Chapter 4. It is often a minor fraction of soil in quantitative terms, but exerts a major control on soil properties. Soil organic matter is complex, being a mixture of a multitude of different components. Organic matter may be tightly bound to clay surfaces by adsorption or physically protected by entrapment within aggregates. These associations modify the physicochemical and physical properties of the mineral phase and affect organic matter biodegradation rates.

The liquid phase of soil is an aqueous solution of solids and gases. It is dynamic and highly sensitive to changes occurring in the soil ecosystem. As shown in Chapter 5, studies examining soil solution chemistry can be a powerful approach to elucidate pedogenic processes, equilibrium and kinetic factors, solute transport, soil fertility, nutrient cycling, and the fate and transport of environmental contaminants. Chapter 6 provides an overview of the composition and dynamics of the soil gaseous phase. This phase has received considerable attention in recent years due to the realization that soils act as a global source,

sink and reservoir of gaseous substances that control the atmospheric composition and thus affect the global climate.

Soil biota, the biologically active powerhouse of soil, includes an incredible diversity of organisms. It has been reckoned that there may be greater than 4 trillion organisms per kilogram of soil and more than 10 000 different species in a single gram of soil! Chapter 7 examines how soil biota plays a tremendous role in a number of soil properties and processes.

Genetic soil science (pedology), espoused by Dokuchaev and colleagues in Russia in the late 1880s, described soils as independent natural bodies resulting essentially from interaction of five environmental factors: parent material, climate, topography, biota, and time. Chapter 8 outlines how Hans Jenny rigorously defined or redefined the meaning of these factors, and more importantly, added the new concept of the *soil system*, which when combined with these factors provides a powerful conceptual framework to study and understand soils.

The influence of parent material as a soil-forming factor is an inverse function of time, making it especially important in young soils. Chapter 9 focuses on the impact of dissimilar parent materials – granite and basalt, the two most widely occurring igneous rocks on the Earth's surface – on the physical and chemical properties of soils in the context of different weathering intensities.

Climate, often the predominant soil-forming factor when considering soil development over the long term, is treated in Chapter 10. Temperature and precipitation are the most important components of climate. Temperature strongly influences the rates of chemical and biological reactions while soil moisture contributes to the dissolution, neof ormation and transport of materials. Climate also determines the type and productivity of vegetation that, in turn, affect soil formation.

Topography, referring to the configuration of the land's surface, can have a major control on soil genesis. Chapter 11 examines the influence of topography on the disposition of energy and matter experienced by soils on the landscape. Slope, aspect, elevation and position modify the regional climate, causing soils to intercept more or less water and solar energy. Fine-scale topographic features may also influence pedogenesis by trapping aeolian dust, altering water infiltration patterns, modifying localized thermal regimes, and providing niches for biological activity.

Chapter 12 deals with the effects of biota on soil formation. Two field studies that illustrate the direct impact of trees on the spatial distribution of trace metal concentrations in uncontaminated forest soils are described.

The length of time needed to convert geological material into a soil varies, depending on the nature of the material and its interaction with climate,

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)*Preface*

xv

topography and living organisms. A given period of time may produce large changes in one soil and have little effect on another soil. Some horizons differentiate before others, especially those at the surface which may take only a few decades to form in unconsolidated deposits. Middle horizons differentiate more slowly, particularly when a considerable amount of translocation of material or weathering is necessary, some taking several millennia to develop. Chapter 13 examines the evolution of soil properties over time.

Pedogenesis is also possible in the absence of biota, as documented in some ice-free areas of the Arctic and Antarctic regions. On this basis, the physically and chemically weathered substrata of the Moon and Mars must be considered soils. Chapter 14 discusses extraterrestrial soils, as well as a variety of factors that can affect soil genesis on Earth, in addition to the five soil-forming factors first proposed by Dokuchaev.

Soil functions and land uses are described in Chapter 15. Several ideas are provided that will allow soil scientists to be better prepared for collaboration in the interdisciplinary arena. The pressure of a constantly growing population along with its demands and activities increasingly threaten the soil as a slowly renewable resource. Major problems arise from the cumulative use of land for living space, infrastructure, food and industrial production. Chapter 16 examines the most common issues due to physical degradation of soil, while Chapter 17 discusses the various forms of chemical degradation and their causes. The non-linearity of many soil processes and the spatial and temporal variability associated with their kinetics is particularly worthy of further investigation. Some of the questions that more urgently need an answer from soil science are discussed in Chapter 18.

Finally, this book includes an Appendix that provides: (a) the rudiments for naming genetic horizons, (b) a list of diagnostic horizons, properties and soil materials of the World Reference Base for Soil Resources (WRB) with their Soil Taxonomy (ST) equivalents, (c) description of the 32 WRB Reference Soil Groups, and (d) an approximate correlation of the WRB Reference Soil Groups with the 12 Soil Orders of Soil Taxonomy.

Acknowledgements

G.J. Churchman thanks P. Rengasamy, R.C. Graham and M.J. Wilson, as reviewers, for useful suggestions regarding various drafts of this manuscript.

A.V. Smagin thanks the Russian Science Support Foundation.

R.C. Graham thanks K. Kendrick for advice on and drafting of the figures, and D.H. Yaalon and M.J. Wilson for reviewing the chapter.

O. Dilly, E.-M. Pfeiffer and U. Irmler thank the Ecology-Centre of the University of Kiel and the Institute of Soil Science of the University of Hamburg for their support in the preparation of this chapter.

S. Shoji, M. Nanzyo and T. Takahashi thank K. Minami, T. Makino, Y. Shirato, and R.J. Engel for their valuable information and suggestions.

F. Courchesne thanks N. Kruyts, P. Legrand, S. Manna and V. Séguin because the data presented in his chapter are part of the work accomplished by these graduate students or post-doctoral fellows. Data were also contributed by R.R. Martin, S.J. Naftel, S. Macfie and W.M. Skinner. B. Cloutier-Hurteau, N. Gingras, H. Lalande and J. Turgeon are sincerely thanked for their help with field and laboratory work. A special thanks to M.-C. Turmel, for managing the information originating from all of the above. Financial support for the researchers cited was provided by the Fonds Québécois de la Recherche sur la Nature et les Technologies (FQRNT), the Metals in the Environment Research Network (MITE-RN) and the National Science and Engineering Research Council of Canada (NSERC).

G. Certini and R. Scalenghe thank R. Amundson, R.A. Dahlgren, A.C. Edwards and B. Sundquist for critically reviewing the manuscript and T. Osterkamp for providing useful information.

P. Blaser thanks I. Brunner, B. Frey, F. Hagedorn, J. Innes, J. Luster, W. Shotyk, and R. A. Dahlgren for fruitful discussions and critically reviewing the manuscript. Figures 17.1 and 17.2 were provided by I. Brunner, while Figure 17.3 was provided

Cambridge University Press

978-0-521-85173-2 - Soils: Basic Concepts and Future Challenges

Giacomo Certini and Riccardo Scalenghe

Frontmatter

[More information](#)

Acknowledgements

xvii

by B. Frey and C. Sperisen (Swiss Federal Institute for Forest, Snow and Landscape Research, WSL).

S.W. Buol, G. Certini and R. Scalenghe thank R.J. Engel for critically reviewing the Appendix.

The Editors especially thank D.H. Yaalon, S. Francis, E.J. Pearce and J. Robertson