
Soil Sampling and Methods of Analysis

Second Edition

Edited by

M.R. Carter

E.G. Gregorich

Canadian Society of Soil Science



Soil Sampling and Methods of Analysis

Second Edition

In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science, whatever the matter may be.

Lord Kelvin, Popular Lectures and Addresses (1891–1894),
vol. 1, *Electrical Units of Measurement*

Felix qui potuit rerum cognoscere causas.

Happy the man who has been able to learn the causes of things.

Virgil: Georgics (II, 490)

Soil Sampling and Methods of Analysis

Second Edition

Edited by
M.R. Carter
E.G. Gregorich

Canadian Society of Soil Science



CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2008 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-0-8493-3586-0 (Hardcover)

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

No part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Soil sampling and methods of analysis / edited by M.R. Carter and E.G. Gregorich. -- 2nd ed.
p. cm.

Includes bibliographical references and index.

ISBN-13: 978-0-8493-3586-0 (alk. paper)

ISBN-10: 0-8493-3586-8 (alk. paper)

1. Soils--Analysis. 2. Soils--Sampling. I. Carter, Martin R. II. Gregorich, E. G. III. Title.

S593.S7425 2007

631.4'1--dc22

2006102606

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

PREFACE

This volume is an update of the book, *Soil Sampling and Methods of Analysis*, first published in 1993. The aims of this second edition remain the same as those of the earlier edition—to provide a compilation of soil analytical and sampling methods that are commonly used, straightforward, and relatively easy to use. The materials and procedures for these methods are presented with sufficient detail and information, along with key references, to characterize the potential and limitation of each method.

As methods develop, so do their degree of sophistication. Taking these developments into account, the second edition includes several chapters that serve as “primers,” the purpose of which is to describe the overall principles and concepts behind a particular type or types of measurement, rather than just methods alone.

All of the chapters retained from the earlier edition have been modified and updated. The second edition also introduces new chapters, particularly in the areas of biological and physical analyses, and soil sampling and handling. For example, the “Soil Biological Analyses” section contains new chapters to reflect the growing number and assortment of new microbiological techniques and the burgeoning interest in soil ecology. New chapters are offered describing tools that characterize the dynamics and chemistry of soil organic matter. A new section devoted to soil water presents up-to-date field- and laboratory-based methods that characterize saturated and unsaturated soil hydraulic properties.

This second edition of *Soil Sampling and Methods of Analysis* comprises 7 sections and a total of 85 chapters and 2 appendices written by 140 authors and co-authors. Each section is assembled by two section editors and each chapter reviewed by at least two external reviewers. We are grateful to these people for their diligent work in polishing and refining the text and helping to bring this new volume to fruition. We particularly thank Elaine Nobbs for her support in working with the many authors involved in writing this book.

We offer this new edition of *Soil Sampling and Methods of Analysis* in the belief that it will continue as a useful tool for researchers and practitioners working with soil.

M.R. Carter and E.G. Gregorich
Editors

CANADIAN SOCIETY OF SOIL SCIENCE

The Canadian Society of Soil Science is a nongovernmental, nonprofit organization for scientists, engineers, technologists, administrators, students, and others interested in soil science. Its three main objectives are

- To promote the wise use of soil for the benefit of society
- To facilitate the exchange of information and technology among people and organizations involved in soil science
- To promote research and practical application of findings in soil science

The society produces the international scientific publication, the *Canadian Journal of Soil Science*, and each year hosts an international soil science conference. It sponsored the first edition of *Soil Sampling and Methods of Analysis* (Lewis Publishers, CRC Press, 1993) and also promoted the publication of the popular reference book *Soil and Environmental Science Dictionary* (CRC Press, 2001). The society publishes a newsletter to share information and ideas, and maintains active liaison and partnerships with other soil science societies.

For more information about the Canadian Society of Soil Science, please visit www.csss.ca.

EDITORS

M.R. Carter holds degrees in agriculture and soil science from the University of Alberta and obtained a PhD in soil science from the University of Saskatchewan in 1983. Since 1977, he has held agricultural research positions with Agriculture and Agri-Food Canada (AAFC) and is currently a research scientist at the AAFC Research Center, Charlottetown, Prince Edward Island. Dr. Carter is a fellow and past-president of the Canadian Society of Soil Science, and past editor of the *Canadian Journal of Soil Science*. He edited the first edition of *Soil Sampling and Methods of Analysis*, (CRC Press, 1993) and also edited *Conservation Tillage in Temperate Agroecosystems* (CRC Press, 1994) and *Structure and Organic Matter Storage in Agricultural Soils* (CRC Press, 1996). In collaboration with Dr. Gregorich, he edited *Soil Quality for Crop Production and Ecosystem Health* (Elsevier, 1997) and *Soil & Environmental Science Dictionary* (CRC Press, 2001). Dr. Carter presently serves as editor-in-chief for the international scientific journal *Agriculture Ecosystems & Environment*.

E.G. Gregorich is a research scientist with Agriculture and Agri-Food Canada at the Central Experimental Farm in Ottawa, Canada. His work focuses on soil biochemistry, particularly carbon and nitrogen cycling in soil. He is a fellow and past-president of the Canadian Society of Soil Science, and has served the Soil Science Society of America as chair of the soil biology and biochemistry division. Dr. Gregorich has been a member of the International Panel on Climate Change, has conducted field studies in Scotland, New Zealand, and Antarctica, and directs a Canadian international development project in Vietnam. He has served as associate editor for the *Journal of Environmental Quality; Agriculture, Ecosystems & Environment; European Journal of Soil Science*; and the *Canadian Journal of Soil Science*. This is the third book on which he and Dr. Carter have collaborated as editors.

CONTRIBUTORS

D. Acosta-Mercado

Department of Biology
University of Puerto Rico
Mayaguez, Puerto Rico

J.A. Addison

School of Sustainability and Environment
Royal Roads University
Victoria, British Columbia, Canada

S.M. Adl

Department of Biology
Dalhousie University
Halifax, Nova Scotia, Canada

D.W. Anderson

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Denis A. Angers

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

H. Antoun

Department of Soils and Agrifood Engineering
Laval University
Quebec, Quebec, Canada

J.M. Arocena

College of Science and Management
University of Northern British Columbia
Prince George, British Columbia, Canada

V.L. Bailey

Biological Sciences Division
Pacific Northwest National Laboratory
Richland, Washington, United States

G.H. Baker

Entomology
Commonwealth Scientific and Industrial
Research Organization
Glen Osmond, South Australia, Australia

J.A. Baldock

Land and Water
Commonwealth Scientific and Industrial
Research Organization
Glen Osmond, South Australia, Australia

B.C. Ball

Scottish Agricultural College
Edinburgh, Scotland, United Kingdom

M.H. Beare

New Zealand Institute for Crop and Food
Research
Christchurch, New Zealand

E.G. Beauchamp

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

V.M. Behan-Pelletier

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

N. Bélanger

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Normand Bertrand

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

R.P. Beyaert

Agriculture and Agri-Food Canada
London, Ontario, Canada

H. Bolton, Jr.

Biological Sciences Division
Pacific Northwest National Laboratory
Richland, Washington, United States

Jeff Braidek

Saskatchewan Agriculture and Food
Saskatoon, Saskatchewan, Canada

E. Bremer

Symbio Ag Consulting
Lethbridge, Alberta, Canada

J.A. Brierley

Agriculture and Agri-Food Canada
Edmonton, Alberta, Canada

P.C. Brookes

Agriculture and Environment Division
Rothamsted Research
Harpenden, Hertfordshire, United Kingdom

M.S. Bullock

Holly Hybrids
Sheridan, Wyoming, United States

B.J. Cade-Menun

Department of Geological and
Environmental Sciences
Stanford University
Stanford, California, United States

C.A. Campbell

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

J. Caron

Department of Soils and Agrifood
Engineering
Laval University
Quebec, Quebec, Canada

M.R. Carter

Agriculture and Agri-Food Canada
Charlottetown, Prince Edward Island
Canada

Martin H. Chantigny

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

M.J. Clapperton

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

F.J. Cook

Land and Water
Commonwealth Scientific and Industrial
Research Organization
Indooroopilly, Queensland, Australia

F. Courchesne

Department of Geography
University of Montreal
Montreal, Quebec, Canada

H.P. Cresswell

Land and Water
Commonwealth Scientific and Industrial
Research Organization
Canberra, Australian Capital Territory
Australia

J.A. Crumbaugh

Canadian Forest Service
Natural Resources Canada
Edmonton, Alberta, Canada

J.L.B. Culley

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

M.P. Curran

British Columbia Ministry of Forests
Nelson, British Columbia, Canada

Denis Curtin

New Zealand Institute for Crop and Food
Research
Christchurch, New Zealand

Y. Dalpé

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

Pauline Défossez

French National Institute for Agricultural
Research
Laon, France

J.R. de Freitas

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

C.F. Drury

Agriculture and Agri-Food Canada
Harrow, Ontario, Canada

K.E. Dunfield

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

M. Duquette

SNC-Lavalin
Montreal, Quebec, Canada

B.H. Ellert

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

J.A. Elliott

Environment Canada
Saskatoon, Saskatchewan, Canada

D.E. Elrick

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

R.E. Farrell

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Ty P.A. Ferré

Department of Hydrology and Water
Resources
University of Arizona
Tucson, Arizona, United States

C.T. Figueiredo

Department of Renewable Resources
University of Alberta
Edmonton, Alberta, Canada

T.A. Forge

Agriculture and Agri-Food Canada
Agassiz, British Columbia, Canada

C.A. Fox

Department of Renewable Resources
Agriculture and Agri-Food Canada
Harrow, Ontario, Canada

J.J. Germida

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Tee Boon Goh

Department of Soil Science
University of Manitoba
Winnipeg, Manitoba, Canada

C.D. Grant

School of Earth and Environmental Sciences
University of Adelaide
Glen Osmond, South Australia, Australia

E.G. Gregorich

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

M. Grimmett

Agriculture and Agri-Food Canada
Charlottetown, Prince Edward Island
Canada

P.H. Groenevelt

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

Umesh C. Gupta

Agriculture and Agri-Food Canada
Charlottetown, Prince Edward Island
Canada

C. Hamel

Agriculture and Agri-Food Canada
Swift Current, Saskatchewan, Canada

X. Hao

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

S.C. Hart

School of Forestry and Merriam-Powell
Center for Environmental Research
Northern Arizona University
Flagstaff, Arizona, United States

A. Hartmann

National Institute of Agronomic Research
Dijon, France

W.H. Hendershot

Department of Renewable Resources
McGill University
Sainte Anne de Bellevue, Quebec, Canada

Ganga M. Hettiarachchi

School of Earth and Environmental Sciences
University of Adelaide
Glen Osmond, South Australia, Australia

D.W. Hopkins

Scottish Crop Research Institute
Dundee, Scotland, United Kingdom

H.H. Janzen

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

R.G. Kachanoski

Department of Renewable Resources
University of Alberta
Edmonton, Alberta, Canada

Klaus Kaiser

Soil Sciences
Martin Luther University
Halle-Wittenberg, Halle, Germany

Karsten Kalbitz

Soil Ecology
University of Bayreuth
Bayreuth, Germany

Y.P. Kalra

Canadian Forest Service
Natural Resources Canada
Edmonton, Alberta, Canada

A. Karam

Department of Soils and Agrifood
Engineering
Laval University
Quebec, Quebec, Canada

Thomas Keller

Department of Soil Sciences
Swedish University of Agricultural Sciences
Uppsala, Sweden

J. Kimpinski

Agriculture and Agri-Food Canada
Charlottetown, Prince Edward Island
Canada

Peter J.A. Kleinman

Pasture Systems and Watershed
Management Research Center
U.S. Department of Agriculture
University Park, Pennsylvania
United States

C.G. Kowalenko

Agriculture and Agri-Food Canada
Agassiz, British Columbia, Canada

D. Kroetsch

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

H. Lalonde

Department of Renewable Resources
McGill University
Sainte Anne de Bellevue, Quebec, Canada

David R. Lapen

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

F.J. Larney

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

R. Lessard

Environmental Division
Bodycote Testing Group
Edmonton, Alberta, Canada

B.C. Liang

Environment Canada
Gatineau, Quebec, Canada

N.J. Livingston

Department of Biology
University of Victoria
Victoria, British Columbia, Canada

D.H. Lynn

Department of Integrative Biology
University of Guelph
Guelph, Ontario, Canada

J.D. MacDonald

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

D.G. Maynard

Pacific Forestry Centre
Natural Resources Canada
Victoria, British Columbia, Canada

R.A. McBride

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

W.B. McGill

College of Science and Management
University of Northern British Columbia
Prince George, British Columbia
Canada

G.R. Mehuys

Department of Renewable Resources
McGill University
Sainte Anne de Bellevue, Quebec, Canada

A.R. Mermut

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

J.C. Michel

INH-INRA-University of Angers
Angers, France

Jim J. Miller

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

J.O. Moir

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

D.D. Myrold

Department of Crop and Soil Science
Oregon State University
Corvallis, Oregon, United States

R. Naasz

Department of Soils and Agrifood
Engineering
Laval University
Quebec, Quebec, Canada

I.P. O'Halloran

University of Guelph
Ridgetown, Ontario, Canada

D.C. Olk

U.S. Department of Agriculture
Agriculture Research Service
National Soil Tilth Laboratory
Ames, Iowa, United States

D. Paré

Natural Resources Canada
Canadian Forest Service
Quebec, Quebec, Canada

L.E. Parent

Department of Soils and Agrifood
Engineering
Laval University
Quebec, Quebec, Canada

G.W. Parkin

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

G.T. Patterson

Agriculture and Agri-Food Canada
Truro, Nova Scotia, Canada

Dan Pennock

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Caroline Preston

Pacific Forestry Centre
Natural Resources Canada
Victoria, British Columbia, Canada

D. Prévost

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

P. Qian

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

D. Reyes

Department of Renewable Resources
McGill University
Sainte Anne de Bellevue, Quebec, Canada

W.D. Reynolds

Agriculture and Agri-Food Canada
Harrow, Ontario, Canada

Guy Richard

French National Institute for Agricultural
Research
Olivet, France

Philippe Rochette

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

L. Rock

Agriculture and Agri-Food Canada
Lethbridge, Alberta, Canada

P.M. Rutherford

College of Science and Management
University of Northern British Columbia
Prince George, British Columbia, Canada

S. Sauvé

Department of Chemistry
University of Montreal
Montreal, Quebec, Canada

J.J. Schoenau

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Andrew N. Sharpley

Crop, Soil and Environmental Sciences
University of Arkansas
Fayetteville, Arkansas, United States

S.C. Sheppard

ECOMatters Inc.
W.B. Lewis Business Centre
Pinawa, Manitoba, Canada

B.C. Si

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

Myrna J. Simpson

Department of Physical and Environmental
Sciences
University of Toronto
Toronto, Ontario, Canada

J.O. Skjemstad

Land and Water
Commonwealth Scientific and Industrial
Research Organization
Glen Osmond, South Australia, Australia

J.L. Smith

U.S. Department of Agriculture
Agriculture Research Service
Washington State University
Pullman, Washington, United States

Y.K. Soon

Agriculture and Agri-Food Canada
Beaverlodge, Alberta, Canada

P. St-Georges

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

C. Swyngedouw

Environmental Division
Bodycote Testing Group
Calgary, Alberta, Canada

M. Tenuta

Department of Soil Science
University of Manitoba
Winnipeg, Manitoba, Canada

Y.-C. Tien

Agriculture and Agri-Food Canada
London, Ontario, Canada

H. Tiessen

Inter-American Institute for Global
Change Research
Sao Jose dos Campos
Sao Paulo, Brazil

E. Topp

Agriculture and Agri-Food Canada
London, Ontario, Canada

G. Clarke Topp

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

T. Sen Tran

Institute of Research and Development
in Agroenvironment
Quebec, Quebec, Canada

M.-C. Turmel

Department of Geography
University of Montreal
Montreal, Quebec, Canada

A.J. VandenBygaart

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

Ken C.J. Van Rees

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

R.P. Voroney

Department of Land Resource Science
University of Guelph
Guelph, Ontario, Canada

C. Wang

Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada

Jennifer L. Weld

Department of Crop and Soil Sciences
The Pennsylvania State University
University Park, Pennsylvania, United States

G. Wen

Lemington, Ontario, Canada

O.O.B. Wendroth

Department of Plant and
Soil Sciences
University of Kentucky
Lexington, Kentucky, United States

J.P. Winter

Nova Scotia Agricultural College
Truro, Nova Scotia, Canada

N. Wypler

Leibniz-Centre for Agricultural
Landscape Research
Institute for Soil Landscape Research
Müncheberg, Germany

X.M. Yang

Agriculture and Agri-Food Canada
Harrow, Ontario, Canada

Thomas Yates

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan,
Canada

N. Ziadi

Agriculture and Agri-Food Canada
Quebec, Quebec, Canada

TABLE OF CONTENTS

I. SOIL SAMPLING AND HANDLING

Section Editors: G.T. Patterson and M.R. Carter

- | | | |
|----|--|----|
| 1. | Soil Sampling Designs | 1 |
| | <i>Dan Pennock, Thomas Yates, and Jeff Braidek</i> | |
| 2. | Sampling Forest Soils | 15 |
| | <i>N. Bélanger and Ken C.J. Van Rees</i> | |
| 3. | Measuring Change in Soil Organic Carbon Storage | 25 |
| | <i>B.H. Ellert, H.H. Janzen, A.J. VandenBygaart, and E. Bremer</i> | |
| 4. | Soil Sample Handling and Storage | 39 |
| | <i>S.C. Sheppard and J.A. Addison</i> | |
| 5. | Quality Control in Soil Chemical Analysis | 51 |
| | <i>C. Swyngedouw and R. Lessard</i> | |

II. DIAGNOSTIC METHODS FOR SOIL AND ENVIRONMENTAL MANAGEMENT

Section Editors: J.J. Schoenau and I.P. O'Halloran

- | | | |
|-----|--|-----|
| 6. | Nitrate and Exchangeable Ammonium Nitrogen | 71 |
| | <i>D.G. Maynard, Y.P. Kalra, and J.A. Crumbaugh</i> | |
| 7. | Mehlich 3-Extractable Elements | 81 |
| | <i>N. Ziadi and T. Sen Tran</i> | |
| 8. | Sodium Bicarbonate-Extractable Phosphorus | 89 |
| | <i>J.J. Schoenau and I.P. O'Halloran</i> | |
| 9. | Boron, Molybdenum, and Selenium | 95 |
| | <i>Ganga M. Hettiarachchi and Umesh C. Gupta</i> | |
| 10. | Trace Element Assessment | 109 |
| | <i>W.H. Hendershot, H. Lalonde, D. Reyes, and J.D. MacDonald</i> | |
| 11. | Readily Soluble Aluminum and Manganese in Acid Soils | 121 |
| | <i>Y.K. Soon, N. Bélanger, and W.H. Hendershot</i> | |
| 12. | Lime Requirement | 129 |
| | <i>N. Ziadi and T. Sen Tran</i> | |
| 13. | Ion Supply Rates Using Ion-Exchange Resins | 135 |
| | <i>P. Qian, J.J. Schoenau, and N. Ziadi</i> | |
| 14. | Environmental Soil Phosphorus Indices | 141 |
| | <i>Andrew N. Sharpley, Peter J.A. Kleinman, and Jennifer L. Weld</i> | |
| 15. | Electrical Conductivity and Soluble Ions | 161 |
| | <i>Jim J. Miller and Denis Curtin</i> | |

III. SOIL CHEMICAL ANALYSES

Section Editors: Y.K. Soon and W.H. Hendershot

- | | | |
|-----|---|-----|
| 16. | Soil Reaction and Exchangeable Acidity | 173 |
| | <i>W.H. Hendershot, H. Lalonde, and M. Duquette</i> | |

17.	Collection and Characterization of Soil Solutions <i>J.D. MacDonald, N. Bélanger, S. Sauvé, F. Courchesne, and W.H. Hendershot</i>	179
18.	Ion Exchange and Exchangeable Cations <i>W.H. Hendershot, H. Lalonde, and M. Duquette</i>	197
19.	Nonexchangeable Ammonium <i>Y.K. Soon and B.C. Liang</i>	207
20.	Carbonates <i>Tee Boon Goh and A.R. Mermut</i>	215
21.	Total and Organic Carbon <i>J.O. Skjemstad and J.A. Baldock</i>	225
22.	Total Nitrogen <i>P.M. Rutherford, W.B. McGill, J.M. Arocena, and C.T. Figueiredo</i>	239
23.	Chemical Characterization of Soil Sulfur <i>C.G. Kowalenko and M. Grimmett</i>	251
24.	Total and Organic Phosphorus <i>I.P. O'Halloran and B.J. Cade-Menun</i>	265
25.	Characterization of Available P by Sequential Extraction <i>H. Tiessen and J.O. Moir</i>	293
26.	Extractable Al, Fe, Mn, and Si <i>F. Courchesne and M.-C. Turmel</i>	307
27.	Determining Nutrient Availability in Forest Soils <i>N. Bélanger, D. Paré, and W.H. Hendershot</i>	317
28.	Chemical Properties of Organic Soils <i>A. Karam</i>	331

IV. SOIL BIOLOGICAL ANALYSES

Section Editors: E. Topp and C.A. Fox

29.	Cultural Methods for Soil and Root-Associated Microorganisms <i>J.J. Germida and J.R. de Freitas</i>	341
30.	Arbuscular Mycorrhizae <i>Y. Dalpé and C. Hamel</i>	355
31.	Root Nodule Bacteria and Symbiotic Nitrogen Fixation <i>D. Prévost and H. Antoun</i>	379
32.	Microarthropods <i>J.P. Winter and V.M. Behan-Pelletier</i>	399
33.	Nematodes <i>T.A. Forge and J. Kimpinski</i>	415
34.	Earthworms <i>M.J. Clapperton, G.H. Baker, and C.A. Fox</i>	427
35.	Enchytraeids <i>S.M. Adl</i>	445
36.	Protozoa <i>S.M. Adl, D. Acosta-Mercado, and D.H. Lynn</i>	455
37.	Denitrification Techniques for Soils <i>C.F. Drury, D.D. Myrold, E.G. Beauchamp, and W.D. Reynolds</i>	471
38.	Nitrification Techniques for Soils <i>C.F. Drury, S.C. Hart, and X.M. Yang</i>	495

39.	Substrate-Induced Respiration and Selective Inhibition as Measures of Microbial Biomass in Soils	515
	<i>V.L. Bailey, H. Bolton, Jr., and J.L. Smith</i>	
40.	Assessment of Soil Biological Activity	527
	<i>R.P. Beyaert and C.A. Fox</i>	
41.	Soil ATP	547
	<i>R.P. Voroney, G. Wen, and R.P. Beyaert</i>	
42.	Lipid-Based Community Analysis	557
	<i>K.E. Dunfield</i>	
43.	Bacterial Community Analyses by Denaturing Gradient Gel Electrophoresis	567
	<i>E. Topp, Y.-C. Tien, and A. Hartmann</i>	
44.	Indicators of Soil Food Web Properties	577
	<i>T.A. Forge and M. Tenuta</i>	

V. SOIL ORGANIC MATTER ANALYSES

Section Editors: E.G. Gregorich and M.H. Beare

45.	Carbon Mineralization	589
	<i>D.W. Hopkins</i>	
46.	Mineralizable Nitrogen	599
	<i>Denis Curtin and C.A. Campbell</i>	
47.	Physically Uncomplexed Organic Matter	607
	<i>E.G. Gregorich and M.H. Beare</i>	
48.	Extraction and Characterization of Dissolved Organic Matter	617
	<i>Martin H. Chantigny, Denis A. Angers, Klaus Kaiser, and Karsten Kalbitz</i>	
49.	Soil Microbial Biomass C, N, P, and S	637
	<i>R.P. Voroney, P.C. Brookes, and R.P. Beyaert</i>	
50.	Carbohydrates	653
	<i>Martin H. Chantigny and Denis A. Angers</i>	
51.	Organic Forms of Nitrogen	667
	<i>D.C. Olk</i>	
52.	Soil Humus Fractions	675
	<i>D.W. Anderson and J.J. Schoenau</i>	
53.	Soil Organic Matter Analysis by Solid-State ¹³ C Nuclear Magnetic Resonance Spectroscopy	681
	<i>Myrna J. Simpson and Caroline Preston</i>	
54.	Stable Isotopes in Soil and Environmental Research	693
	<i>B.H. Ellert and L. Rock</i>	

VI. SOIL PHYSICAL ANALYSES

Section Editors: Denis A. Angers and F.J. Larney

55.	Particle Size Distribution	713
	<i>D. Kroetsch and C. Wang</i>	
56.	Soil Shrinkage	727
	<i>C.D. Grant</i>	

57.	Soil Density and Porosity	743
	<i>X. Hao, B.C. Ball, J.L.B. Culley, M.R. Carter, and G.W. Parkin</i>	
58.	Soil Consistency: Upper and Lower Plastic Limits	761
	<i>R.A. McBride</i>	
59.	Compaction and Compressibility	771
	<i>Pauline Défossez, Thomas Keller, and Guy Richard</i>	
60.	Field Soil Strength	783
	<i>G. Clarke Topp and David R. Lapen</i>	
61.	Air Permeability	803
	<i>C.D. Grant and P.H. Groenevelt</i>	
62.	Aggregate Stability to Water	811
	<i>Denis A. Angers, M.S. Bullock, and G.R. Mehuys</i>	
63.	Dry-Aggregate Size Distribution	821
	<i>F.J. Larney</i>	
64.	Soil Air	833
	<i>R.E. Farrell and J.A. Elliott</i>	
65.	Soil-Surface Gas Emissions	851
	<i>Philippe Rochette and Normand Bertrand</i>	
66.	Bulk Density Measurement in Forest Soils	863
	<i>D.G. Maynard and M.P. Curran</i>	
67.	Physical Properties of Organic Soils and Growing Media: Particle Size and Degree of Decomposition	871
	<i>L.E. Parent and J. Caron</i>	
68.	Physical Properties of Organic Soils and Growing Media: Water and Air Storage and Flow Dynamics	885
	<i>J. Caron, D.E. Elrick, J.C. Michel, and R. Naasz</i>	

VII. SOIL WATER ANALYSES

Section Editors: W.D. Reynolds and G. Clarke Topp

69.	Soil Water Analyses: Principles and Parameters	913
	<i>W.D. Reynolds and G. Clarke Topp</i>	
70.	Soil Water Content	939
	<i>G. Clarke Topp, G.W. Parkin, and Ty P.A. Ferré</i>	
71.	Soil Water Potential	963
	<i>N.J. Livingston and G. Clarke Topp</i>	
72.	Soil Water Desorption and Imbibition: Tension and Pressure Techniques	981
	<i>W.D. Reynolds and G. Clarke Topp</i>	
73.	Soil Water Desorption and Imbibition: Long Column	999
	<i>W.D. Reynolds and G. Clarke Topp</i>	
74.	Soil Water Desorption and Imbibition: Psychrometry	1007
	<i>W.D. Reynolds and G. Clarke Topp</i>	
75.	Saturated Hydraulic Properties: Laboratory Methods	1013
	<i>W.D. Reynolds</i>	
76.	Saturated Hydraulic Properties: Well Permeameter	1025
	<i>W.D. Reynolds</i>	

77.	Saturated Hydraulic Properties: Ring Infiltrometer <i>W.D. Reynolds</i>	1043
78.	Saturated Hydraulic Properties: Auger Hole <i>G. Clarke Topp</i>	1057
79.	Saturated Hydraulic Properties: Piezometer <i>G. Clarke Topp</i>	1065
80.	Unsaturated Hydraulic Conductivity: Laboratory Tension Infiltrometer <i>F.J. Cook</i>	1075
81.	Unsaturated Hydraulic Properties: Laboratory Evaporation <i>O.O.B. Wendroth and N. Wypler</i>	1089
82.	Unsaturated Hydraulic Properties: Field Tension Infiltrometer <i>W.D. Reynolds</i>	1107
83.	Unsaturated Hydraulic Properties: Instantaneous Profile <i>W.D. Reynolds</i>	1129
84.	Estimation of Soil Hydraulic Properties <i>F.J. Cook and H.P. Cresswell</i>	1139
85.	Analysis of Soil Variability <i>B.C. Si, R.G. Kachanoski, and W.D. Reynolds</i>	1163

APPENDIX

A.	Site Description <i>G.T. Patterson and J.A. Brierley</i>	1193
B.	General Safe Laboratory Operation Procedures <i>P. St-Georges</i>	1197

INDEX		1205
--------------	--	------

I. SOIL SAMPLING AND HANDLING

Section Editors: G.T. Patterson and M.R. Carter

- [Magic Kingdom for Saleâ€”Sold! \(Magic Kingdom of Landover, Book 1\) pdf](#)
- [read The Risen: Remnants pdf](#)
- [Perfumes: The A-Z Guide online](#)
- [read online The Puppeteer's Apprentice](#)

- <http://diy-chirol.com/lib/Magic-Kingdom-for-Sale---Sold---Magic-Kingdom-of-Landover--Book-1-.pdf>
- <http://unpluggedtv.com/lib/Historical-Dictionary-of-Latin-American-Literature-and-Theater--Historical-Dictionaries-of-Literature-and-the-Arts->
- <http://interactmg.com/ebooks/Thoreau-s-Walden--Images-of-America-.pdf>
- <http://aneventshop.com/ebooks/Visual-Studio-2010-Best-Practices.pdf>