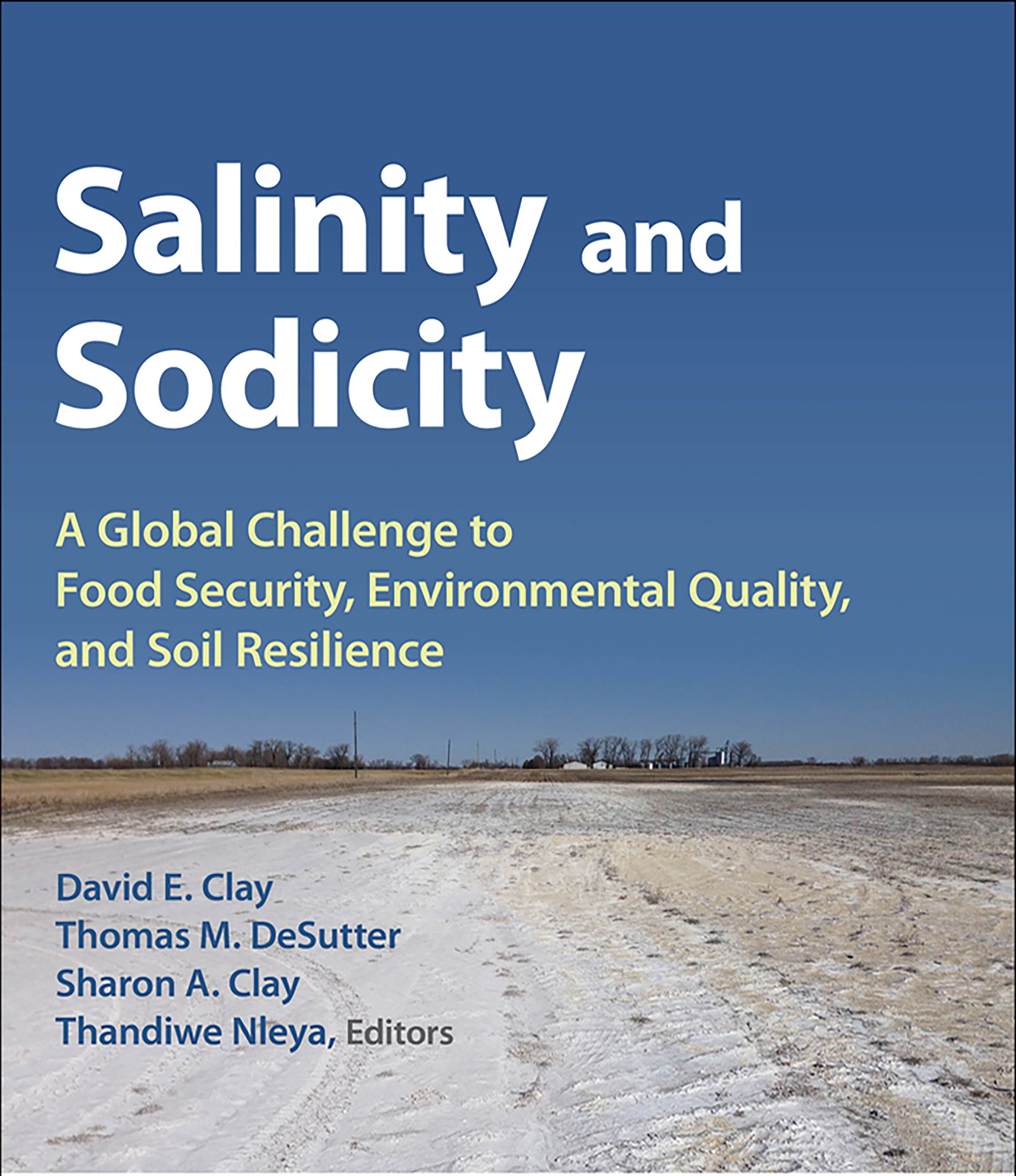

Salinity and Sodicity

A Global Challenge to Food Security, Environmental Quality, and Soil Resilience

David E. Clay
Thomas M. DeSutter
Sharon A. Clay
Thandiwe Nleya, Editors

ASA American Society of Agronomy
CSSA Crop Science Society of America
SSSA Soil Science Society of America
WILEY

Salinity and Sodicity: A Global Challenge to Food Security, Environmental Quality, and Soil Resilience

EDITORS

Dr. David E. Clay is a former President of the American Society of Agronomy (2022), Editor-in-Chief of the American Society of Agronomy (2024), Distinguished Professor Soil Biogeochemistry, and the South Dakota Corn Council Endowed Chair of Precision Soybean Research and Promotion On-Farm Research Program and has been actively involved in soil health research for 30 years He was the Editor for the Agronomy Journal and the South Dakota Corn Best Management Practice Manual, Soybean Best Management Practices Manual, and Wheat Best Management Practices manual. His research goal is to develop and test sustainable agricultural management systems that enhance environmental quality, maintain rural economies, and sustainably produce food while improving soil health. He teaches Introductory Soil Science, Environmental Soil Chemistry, and the Use of Sensors in Agriculture.

Dr. Thomas M. DeSutter received his PhD in 2004 from Kansas State University (Manhattan, KS). After completing a Post-Doc with the USDA-ARS (Ames, IA) he was hired in 2006 as an Environmental Soil Scientist by the Department of Soil Science at North Dakota State University (Fargo, ND). His primary research interests are saline and sodic soils, reclamation of energy-extraction impacted soils, and instrumentation for measuring soil physical and biological parameters. DeSutter teaches Introductory to Soil Science, Soil and Land Use, and Environmental Field Instrumentation and Sampling and is the current Editor of Agricultural & Environmental Letters.

Dr. Sharon A. Clay is an agronomist with extensive experience in weed management research. She earned her BS in horticulture from the University of Wisconsin, Madison, her MS in plant science from the University of Idaho, and her PhD in agronomy from the University of Minnesota. She has investigated crop/weed interactions, studying their physiology, genomics, and examined the yield loss of different weeds on crops based on species, density, and time of emergence. She also examined site-specific weed locations and emergence at the field level. With 35 MS students and 10 PhD students, research topics have ranged from examining weed impacts on teosinte (modern corn ancestor), mob grazing impacts to weed dynamics, and the use of perennial grasses to remediate salt-impacted soils. She is a prolific author and editor, having published more than 200 scientific papers and contributed to several books. She has received four best paper awards, and numerous recognitions, including being elected as a fellow of the American Society of Agronomy (ASA) in 2009 and serving as ASA president in 2013. She was also honored with the Gamma Sigma International Distinguished Achievement in Agriculture Award in 2017.

Dr. Thandiwe Nleya is a Professor and Agronomist working on organic crop production, and management of cereal, oilseed, bioenergy and pulse crops. Dr. Nleya has over 15 years of conducting research on dryland cropping systems in the Northern Great Plains including the incorporation of cover crops, cereals, oilseeds, and legumes in dryland rotations. Her latest research has focused on remediation of saline/sodic soils including evaluation of a wide range of plant species for salt tolerance.

CONTRIBUTORS

Beverly Alvarez Torres
North Dakota State University
Fargo, ND
Email: B.alvareztorres@ndsu.edu

Dwarika Bhattarai
South Dakota State University
Department of Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: dwarika.bhattarai@sdstate.edu

Abigail Blanchard
South Dakota State University,
Department of Natural Resource Management
Brookings, SD
Email: abigailpblanchard@gmail.com

Jose Pablo Castro Chacón
North Dakota State University,
School of Natural Resource Sciences and Soil Science
Fargo, ND
Email: jose.castrochacon@ndsu.edu

Jiyul Chang
South Dakota State University
Department of Agronomy, Horticulture and Plant Science
Brookings, SD
Email: Jiyul.chang@sdstate.edu

David E. Clay
Institution: South Dakota State University
Department: Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: David.Clay@SDSTATE.EDU

Sharon A. Clay
South Dakota State University
Department of Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: Sharon.Clay@sdstate.edu

Aaron Lee M. Daigh
University of Nebraska – Lincoln
Department Agronomy & Horticulture; Biological Systems Engineering
Lincoln, Nebraska
Email: adaigh2@unl.edu

Thomas M. DeSutter
North Dakota State University,
School of Natural Resource Sciences
Fargo, ND
Email: thomas.desutter@ndsu.edu

Krista Ehlert
South Dakota State University,
West River Research & Extension, Department of Natural Resource Management
Rapid City, SD
Krista.Ehlert@sdstate.edu

Jorge F.S. Ferreira
USDA-ARS,
Department of Agricultural Water Efficiency and Salinity Research Unit (US Salinity Laboratory)
Riverside, CA
Email: jorge.ferreira@usda.gov

Joleen C. Hadrich,
University of Minnesota,
Department of Applied Economics
St. Paul, MN
Email: jhadrich@umn.edu

Kyle P. Jore
University of Minnesota,
Department Natural Resources Science and Management & Department of Applied Economics
St. Paul, Minnesota
Email: jore0014@umn.edu

Thijs J. Kelleners
University of Wyoming,
Department of Ecosystem Science & Management
Laramie, WY
Email: tkellene@uwyo.edu

Joshua Leffler
South Dakota State University,
Department of Natural Resource Management
Brookings, SD
Email: alan.leffler@sdstate.edu

Brennan Lewis
South Dakota State University
Department of Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: Brennan.Lewis@sdstate.edu

Douglas Malo
South Dakota State University,
Department of Agronomy, Horticulture & Plant Science
Brookings, SD
Email: Douglas.Malo@SDSTATE.EDU

Chantel Mertz
North Dakota State University,
School of Natural Resource Sciences
Fargo, ND
Email: chantel.mertz@ndsu.edu

Jarrod Miller
University of Delaware,
Department Plant and Soil Sciences
Georgetown, DE
Email: Jarrod@udel.edu

Thandiwe Nleya
South Dakota State University
Department of Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: Thandiwe.Nleya@sdstate.edu

J.D. Oster,
Emeritus Soil and Water Specialist, University of California,
Department of Environmental Sciences
Riverside CA 92521
Email: james.oster@ucr.edu

Kristopher Osterloh
South Dakota State University,
Department of Agronomy, Horticulture & Plant Science
Brookings, SD
Email: Kristopher.Osterloh@sdstate.edu

Shailesh Pandit
South Dakota State University,
Department of Agronomy, Horticulture, and Plant Science,
Brookings, SD
Email: Shailesh.pandit@sdstate.edu

Lora Perkins
South Dakota State University,
Department of Natural Resource Management
Brookings, SD
Email: lora.perkins@sdstate.edu

Graig Reicks
South Dakota State University
Department of Agronomy, Horticulture, and Plant Science
Brookings, SD
Email: graig.reicks@sdstate.edu

Devinder Sandhu
USDA-ARS,
Department of: Agricultural Water Efficiency and Salinity Research Unit (US Salinity Laboratory)
Riverside, CA
Email: devinder.sandhu@usda.gov

Donald L. Suarez,
USDA-ARS,
Department of Agricultural Water Efficiency and Salinity Research Unit (US Salinity Laboratory), Riverside, CA
Email: suarez.donald@gmail.com

Shaina Westhoff
South Dakota State University,
Department of Agronomy, Horticulture, Plant Science
Brookings, SD
Email: Shaina.Westhoff@sdstate.edu

EDITORIAL CORRESPONDENCE

American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
5585 Guilford Road, Madison, WI 53711-58011, USA

Salinity and Sodicity

A Global Challenge to Food Security, Environmental Quality, and Soil Resilience

David E. Clay, Thomas M. DeSutter, Sharon A. Clay, and Thandiwe Nleya, Editors

ASA American Society of Agronomy
CSSA Crop Science Society of America
SSSA
WILEY

Copublication by American Society of Agronomy, Inc. / Crop Science Society of America, Inc. / Soil Science Society of America, Inc. and John Wiley & Sons, Inc.

Editorial Correspondence:
American Society of Agronomy, Inc.
Crop Science Society of America, Inc.
Soil Science Society of America, Inc.
5585 Guilford Road, Madison, WI 53711-58011, USA

agronomy.org • crops.org • soils.org

Registered Office:
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products, visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Library of Congress Cataloging-in-Publication Data applied for

Paperback ISBN: 9780891183983;
ePDF ISBN: 9780891184003;
ePUB ISBN: 9780891183990;
oBook ISBN: 9780891183976

Cover Design: Wiley
Cover Image: TK

Set in 9.5/12.5pt STIXTwoText by Straive, Chennai, India

Contents

Scope

In the past, there has been many educational materials and much salinity research focused on irrigated agricultural systems in dryland soil. One of the more recent publications was, "Agricultural Salinity Assessment and Management" that was published by the Environmental Water Resource Institute (Wallender & Tanji, 2012). This book provides an excellent resource for irrigating systems, and it contains reference information on the effect of salts on soils, sampling and monitoring, diagnosis of salt problems, salinity management options, and reclamation treatment options. However, Wallender and Tanji (2012) only provides limited information on greenhouse gas emissions, flooding from rising sea levels, dryland systems and their remediation, phytoremediation, the use of remote sensing to track salt-affected soils, and how climate change is impacting the expanding soil salinity/sodicity problem. In addition, Wallender & Tanji (2012) does not provide answers to common questions that can be integrated into lesson plans for undergraduate and graduate students. Our book was designed to complement as opposed to replace Wallender & Tanji (2012). Dryland non-irrigated systems are a serious problem in many areas. In many situations it is driven by climate change and the transport of water and salts from buried marine sediments to the soil surface. In many situations, the soil surveys do not provide hints that salinity and sodicity are serious problems.

Our book covers a range of topics that include the origins of dryland salinity and sodicity, assessing the economic potential of remediation, problems with relying on soil mapping to identify problem areas quantification methods and procedures, management strategies, practical calculations, and more. The book also features special items including example problems set out as questions that are answered. These items are intended to empower the reader with new and updated knowledge about the growing problems caused by soil salinity and sodicity. The purpose of this book is to increase the problem-solving abilities of students, soil professionals, certified crop advisors, and other practicing professionals.

Reference

Wallender, W. W., & Tanji, K. K. (2012). *Agricultural salinity assessment and management*, Second Edition ASCE Manual and Reports on Engineering Practices No. 71. ASCE American Society of Civil Engineers, Reston Virginia.

1

An Introduction to Salinity and Sodicity

Shaina Westhoff, David E. Clay, Kristopher Osterloh, Sharon A. Clay, Thomas M. DeSutter, Thandiwe Nleya, Jorge F. S. Ferreira, Donald L. Suarez, and Devinder Sandhu

Chapter Overview

Rising sea levels, increasing land use intensification, declining fresh water supplies, and climate variation are accelerating the development of saline and sodic soils worldwide. This chapter defines the issue and discusses the global extent of salt-affected soils. Subsequent chapters are focused on saline/sodic soil economics (Chapter 2), formation and classification (Chapter 3), chemical analysis (Chapter 4), measurement with soil sensors (Chapters 5 and 6), monitoring salinity with models (Chapter 7), remote sensing (Chapter 8), plant responses to salt stress and phytoremediation (Chapters 9–11), chemical amendments (Chapter 12), rising sea levels (Chapter 13), greenhouse gas emissions (Chapter 14), and case studies (15). Chapter 16 provides answers to common questions.

Introduction

Salinity and sodicity are prevalent worldwide and have severe negative agronomic and environmental ramifications. Soil salinity is an accumulation of dissolved minerals and salts in soil that often includes Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, HCO_3^{-}, and NO_3^{-}. The sources of these salts are the dissolution of salt-bearing minerals such as marine shales and halite, or human management that can add salts or accelerate soil genesis or lead to the accumulation of salts in to the surface soil. Salinity risks are generally assessed by measuring soil electrical conductivity (EC). However, because the critical EC levels are soil- and crop-specific, salinity management is closely tied to water, soil, and crop management. Soil sodicity relates to the proportion of clay binding sites specifically filled by Na^{+}. High concentrations of Na^{+} on the soil cation exchange (CEC) sites can contribute to soil dispersion and increase erosion, negatively affecting soil health and plant growth. Erosion not only leads to the loss of soil, but also the loss of any agronomic fertilizers or pesticides applied to the field. Therefore, erosion can be highly detrimental to surrounding ecosystem services while also severely reducing the producer's return on investment for impacted areas.

The management of salinity and sodicity have challenged communities since the beginning of agriculture (Jacobsen & Adams, 1958; Lowdermilk, 1953; Montgomery, 2007). One early challenge to food security was human-induced salinization where the use of salt-laden irrigation water reduced Sumerian harvests in the delta plain of the Tigris and Euphrates Rivers to one-third of original production between 3000 and 1800 BCE (Montgomery, 2007). For these communities, farmers had the choice of abandoning the land or managing the problem. Because early farmers had an abundance of land but limited information/technology, many chose to move to new lands. Today the situation has changed with most of the earth's suitable land already in agricultural production, and with an increasing world population, management and reclamation are the only viable options for most communities.

Research suggests that if we do not mitigate this expanding problem, the combined impact of drought and salinity/sodicity have the potential to reduce yields on over 50% of global arable land by 2050 (Wang et al., 2003). Salt-induced yield decreases are important because agriculture is the world's most essential industry and accounts for 27% of the world's labor force. Globally, between 2013 and 2018, the agricultural industry received almost $630 billion (US) in annual governmental support. Continued loss of arable lands due to salinity and sodicity will further strain global economies.

Salinity and Sodicity: A Global Challenge to Food Security, Environmental Quality, and Soil Resilience, First Edition.
Edited by David E. Clay, Thomas M. DeSutter, Sharon A. Clay, and Thandiwe Nleya.

Published 2024 by John Wiley & Sons, Inc.