Understanding Soil Change

Soil Sustainability over Millennia, Centuries, and Decades

Across the world, soils are managed with an intensity and at a geographic scale never before attempted, yet we know remarkably little about how and why managed soils change through time. *Understanding Soil Change* explores a legacy of soil change in southeastern North America, a region of global ecological, agricultural, and forestry significance: from the acidic soils of primary hardwood forests that covered the region until about 1800, through the marked transformations affected by long-cultivated cotton, to contemporary soils of rapidly growing and intensively managed pine forests. These well documented records significantly enrich the science of ecology and pedology, and provide valuable lessons for land management throughout the world. The book calls for the establishment of a global network of soil-ecosystem studies, similar to the invaluable Calhoun study on which the book is based, to provide further information on sustainable land management, vital as human demands on soil continue to increase.

DANIEL D. RICHTER, JR. is Professor of Soils and Forest Ecology and Co-Director of the Southern Center for Sustainable Forests at Duke University.

DANIEL MARKEWITZ is Assistant Professor at the Warnell School of Forest Resources at the University of Georgia.

Advance praise for this book:

"It is a grand tour of soil change at different temporal scales, done with elegance and scientific rigor. This story will be of interest to ecologists who have never had a soil science course, as well as to advanced pedologists, biogeochemists, agronomists, foresters, and land managers."
William Reiners and Pedro Sánchez

With reference to maintaining fertility of managed soils:

"It is time . . . to take stock of the concepts, data and methodologies that can be applied now or in the very short term to several troublesome questions."

Earl L. Stone (1979)

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DANIEL D. RICHTER, JR.
Duke University

DANIEL MARKEWITZ
University of Georgia

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Preface

Humans are increasingly living in urban and suburban environments, away from the land and apart from the soil, yet the quality of human life and the earth's environment has never depended more on soil management than it does today. Humanity's expanding systems of food, fiber, and water production are now entirely dependent on the management practiced on several billions of hectares of soil. For these reasons, soil deserves a much greater share of human attention and affection. In the recent words of one scientist, soil is "the central processing unit of the earth's environment."

Our understanding of soil's role in the great global cycles of chemical elements lags far behind our impact on these cycles. This book argues that the management of soil at local, regional, and global scales must continue to improve, but that this improvement is limited by the notable absence of long-term soil experiments from which we can learn about how soils change through time.

This book tells the story of changes in one soil: of the genesis, degradation, and renewal of a soil on a nearly forgotten farm in rural South Carolina, USA. The farm was known for many years as the Old Ray Place, after its colorful owner, Rev. Thomas Ray (1780–1862), who lies buried in the cemetery of the local Padgett's Creek Church where he was a preacher for six decades. Many writers use the southern USA to describe particular places, characters, and events; it is a region with a long history of strife, crisis, ambiguity, and enigma. This book too explores the particulars of a southern landscape as a way to learn things that are more universal about soil, ecosystems, management, nature, and time.

This book is written for anyone interested in soil, in human dependence on soil, and in how human activities affect changes in soils and ecosystems over historical time. In universities, the material comprising the book has been read by advanced undergraduate and

graduate students who reside in a variety of academic departments. At Duke University, the material has served as a source of reading and discussion for students interested in soil genesis and fertility, biogeochemistry, plant and ecosystem ecology, conservation biology, environmental history, environmental engineering and chemistry, forest and agronomic management, and sustainable development. A recommended list of readings, each matched to a chapter in the book, is found immediately after the Epilogue.

Daniel D. Richter, Jr.
Durham, North Carolina

Daniel Markewitz
Athens, Georgia

Acknowledgments

In 1957, a small group of US Forest Service researchers planted tree seedlings in two abandoned cotton fields on the Calhoun Experimental Forest, about 15 km southwest of Union, South Carolina. Little did they realize that their experimental planting would grow into a forest that would produce insights into soils and ecosystems of such interest and implication.

In 1957, land use in the southeastern United States was in transition. Cotton acreage had declined precipitously. The area of secondary pine forest was expanding. Many soils that had long been cultivated in the agricultural economy of the Old South were once again supporting forest. Reforestation of formerly plowed land grew to cover tens of millions of hectares in the region.

Since the planting of tree seedlings in 1957, the Calhoun experiment has become a significant research area for the study of pine forests in the southeastern United States. The four-decade study of soil and ecosystem change is currently the centerpiece of research on the Calhoun Experimental Forest and is the major subject of this book.

There are few plant–soil experiments in the world that possess the temporal continuity and rigorous statistical design of the Calhoun Forest Experiment. Ecologists, soil scientists, foresters, agronomists, and land managers are indebted to the foresighted scientists who gave us the opportunity to examine the long-term soil and ecosystem data presented here. Dr. Carol G. Wells, in particular, deserves special recognition for initiating the soil and ecosystem study, continuing its sampling, and assembling the soil archive from 1962 to 1982. This book is dedicated to Dr. Wells for his long-term persistence and perspective of the soil resource.

Gratefully acknowledged also are USDA Forest Service scientists, many of whom were stationed at the Calhoun Experimental Forest in

the 1950s and early 1960s. In the mid-1960s, these researchers were transferred to forest science laboratories in Charleston, SC, and the Research Triangle Park and Coweeta Hydrologic Laboratory, North Carolina. These scientists have supported this long-term research in many ways, and include not only Dr. Lou Metz who organized the planting of the Calhoun experiment but also Drs. William R. Harms, Marilyn Buford, Dean DeBell, Jim Douglass, Jacques Jorgensen, and Thomas Lloyd.

Many other colleagues have contributed to the overall conduct, sampling, analyses, and interpretation of the Calhoun experiment. Most especially these include P. Heine, M. Hofmockel, B. Megonigal, and J. Raikes, for enormous commitments to outstanding chemical analyses and data presentation. Dan Binkley and three anonymous readers offered many useful suggestions in reviews of the manuscript. Some of the many others who have had an important hand in this work include H.L. Allen, R. April, W. Arthur, N. Bethala, S. Billings, W.D. Billings, B. Browne, S.W. Buol, E. Burroughs, A. Caldwell, N.L. Christensen, B.J. Cosby, C. Craft, K.H. Dai, C. Davey, E.P. Davidson, K. Davis, A.T. Davison, J. Dillon, A. Duke, J. Dunscomb, J. Edeburn, D. and J. Evans, S. Fox, C. Gnau, J. Haggard, P. Halpin, M. Hanchey, K. Hetts, C. Hoglen, Z. Holmes, E. Ingham, V. Jin, E. Jabocoby, K. Johnsen, D.W. Johnson, G. Katul, J. Kertz, K. Kipping, M.S. Knowles, K. Korfmacher, J. Krishnaswamy, I. Lepsch, S.E. Lindberg, D. Livingstone, T. Lookingbill, T. Moriya, L.A. Nelson, L.E. Nelson, B. Nettleton, R. Newton, N.-H. Oh, K. O'Neill, R. Oren, J. Powers, R. Puckett, R. Qualls, C.W. Ralston, C. Reinhart, D. Ricalde, C.J. Richardson, F. Sanchez, P.A. Sánchez, W.H. Schlesinger, D. Shoch, T. Shouse, R. Singh, P. Smith, E.L. Stone, T. Strickland, A. Stuanes, W.T. Swank, J.L. Swanson, G.L. Switzer, R. Tabachow, K. Tian, S. Trimble, S.A. Trumbore, D. Urban, J.B. Urrego, J. Vilas, M. Vinson, J. Vose, L. West, M. Williams, S. Williams, and J.C. Woodwell.

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The book is dedicated to Dr. Carol G. Wells, originator of the Calhoun soil-ecosystem experiment, and to four most worthy professors, Drs. Lyle E. Nelson, Charles W. Ralston, Earl L. Stone, and George L. Switzer. We also dedicate this book to our families: Susan Adam, Daniel, Christina, and Benjamin; and Jane Raikes; and parents, Nancy and Daniel, and Ahuva and Moshe.

Foreword

Historical effects often underlie otherwise puzzling observations in nature so that history is an essential element for understanding the ecological status of a place. Similarly, a historical perspective is essential for understanding soils. The great pedologist, Hans Jenny, made "time" one of a series of variables determining the state of particular soils. Ecology and soil science are parallel sciences in many ways, as well as being inextricably linked through reciprocal relationships between biota and soil condition.

Both soil scientists and ecologists seek to interpret the immediate state of ecosystems and soils (the latter considered part of the former by ecologists) through historical perspectives. For example, ecologists will attempt to understand the regrowth of a logged forest as a short-term phenomenon in the perspective of longer-term phenomena of primary succession, climate change over the span of thousands of years, migration of species, and changing status of soils. The experienced ecologist attempts to interpret vegetation dynamics in the context of soil change, but usually assumes, sometimes erroneously, that vegetation and other parts of the ecosystem's biota change more rapidly than do the underlying soils. Soil scientists are taught soil genesis in a theoretical way, but most practice their profession at time scales too short to expect change in soil formation.

Few cases exist for understanding the long-term process of soil development. The patterns of long-term change are known from the Mendocino Terraces of California, formerly glaciated terrain of Glacier Bay, Alaska, dunal terrain around Lake Michigan, and volcanic flows of Hawaii. These documented examples provide benchmarks by which we have gained insight into long-term soil development and its ecological implications. Likewise long-term agronomic research spanning decades to over one century, notably Rothamsted in the UK, Illinois' Morrow

plots and shorter, but decadal ones in the tropics, has provided valuable knowledge about the chemical and physical dynamics of soils and plant growth.

Richter and Markewitz open up another such example with their sweeping treatise of the Ultisols of the southeastern USA. They give us another benchmark example for a large region having very high agricultural and forestry significance. Building on the work of earlier scientsts from decades ago, Richter and Markewitz examine soil change on the South Carolina Piedmont on multiple temporal scales: decades, centuries, and millennia. The authors carefully guide us through two interacting strands of historical narrative: pedogenesis of the old, geomorphologically stable, uplands of the southeastern Piedmont, and land-use change on the Old Ray Place, Union Co., South Carolina. The combination of these two narratives builds a fascinating story of interaction between land use and soil condition. It also leads to some important conclusions about the consequences of industrial forestry. Erosion, weathering, leaching, translocation, planters, slaves, tenant farmers, and modern foresters all play roles in this dual saga of the Old South.

This work is also of extreme importance to the tropics, even though South Carolina lies squarely in the warm temperate region. Ultisols and related soils cover vast areas of the tropics with similarly low inherent fertility, coarse-textured surface soils, and low-activity clays. For example, the main difference between most Ultisols of the study area and similarly classified ones in the tropics is the different soil temperature regime. In addition, there are strong linkages in the human influence. The history described by Richter and Markewitz is a classic saga of shifting cultivation, which was the first agricultural system in forested areas of the United States and Europe and is the prevalent system nowadays in the humid tropics, most of it on Ultisols. While few places in the tropics have gone through such a stage of agricultural intensification as has the southeastern United States, resulting in this case in millions of hectares of productive secondary forests, this book provides valuable insights on the processes involved in the transformation of slash and burn agriculture into a modern rural scene where farms are scattered in a landscape dominated by forests, which is typical of much of today's South.

Building on the long-term observations of earlier scientists, these authors show how Ultisols, a very important soil order world-wide, come into being through natural weathering, leaching, and accumulation processes. They then discuss data on the impacts of forest clearing, mixed crops and cotton farming, liming, and fertilization on these old

soils. Finally, they evaluate the impacts of pine-forest growth on these old fields. The results are impressive and sometimes surprising.

This story comes to us as a result of long-term observations and systematic sampling, analyses and archiving. Unfortunately, such sustained observations are rare in the world and we must be grateful to the authors for synthesizing the data in such a palatable form. In the same vein, the authors issue a challenge to all of us. While espousing the value of synthesized, long-term studies like this, they ask why such efforts should be so rare, and whether we as a modern society concerned about long-term sustainability can commit to expansion of these scientific activities more broadly. They make a strong case for institutionalizing long-term studies at Calhoun Experimental Forest where these records were made, and for representative sites in different biomes and major soil orders elsewhere in the world.

Richter and Markewitz have combined the dedication and perspective of the early giants of soil science such as Dokuchaev, Hilgard, Kellogg, Lutz, Chandler, Jenkinson, and Jenny with modern techniques, methods, and language to produce a well woven tale of change. This tale is extraordinarily useful to ecologists and soil scientists alike as well as highly relevant to planners and managers of the New South and other parts of the world where Ultisols and similar soils underlie present and future human activities.

Not since he read the classic book *The Soil under Shifting Cultivation* (written by Peter Nye and Dennis Greenland by candlelight in Ghana in the late 1950s) has Sánchez enjoyed and learned so much about the dynamics of acid soils as from this book. It is a grand tour of soil change at different temporal scales, done with elegance and scientific rigor. This story will be of interest to ecologists who have never had a soil science course, as well as to advanced pedologists, biogeochemists, agronomists, foresters, and land managers.

William A. Reiners and Pedro A. Sánchez
June 2000

One generation passeth away, and another generation cometh:
but the earth abideth for ever.
The sun also ariseth, and the sun goeth down, and hasteth to
the place where it arose.
The wind goeth toward the south, and turneth about unto the
north; it whirleth about continually, and the wind
returneth again according to its circuits.
All the rivers run into the sea; yet the sea is not full; unto the
place from whence the rivers come, thither they return
again.

Ecclesiastes 1:4–7