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James G. Bockheim · Alfred E. Hartemink

The Soils of Wisconsin

Springer

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This book is dedicated to Dr. Francis D. Hole (1913–2002), eminent pedologist at the University of Wisconsin–Madison. He received his doctorate in soil science and geography at the UW Madison in 1943 and joined the Soils Department in 1946. Thirty years of soil mapping and soil research led to the publication of Soils of Wisconsin in 1976. It has been a standard reference book on soils of Wisconsin and is now a collector's item. Jim Bockheim had the pleasure of sharing field trips, including biking to the UW Arboretum, with Dr. Hole for a 27-year period. Dr. Hole was a highly creative pedologist, a relentless teacher of soil science, as well as a musician and poet:

Darkle, darkle, little grain,
I wonder how you entertain
A thousand creatures microscopic.
Grains like you from pole to tropic
Support land life upon this planet
I marvel at you, crumb of granite!

Foreword

Wisconsin is a diverse state where forests, prairie, farmland, and urban areas form a pleasant mix across the landscape. Each of these ecosystems is in part determined by the soils that nourish and shape what we see aboveground. To understand the history and economic development of Wisconsin, one must understand its soils. This book on the soils of Wisconsin provides information and insights based on decades of research and soil investigations conducted by scientists across the state.

I know something of the importance of this topic because I am the child of a soil scientist. My father graduated in 1943 from the University of Missouri and spent much of his career on agricultural and economic development in the upper Midwest. Driving trips always included lectures on the countryside outside the car windows, particularly the effects of glaciation and soil chemistry on the crops or woods that we were seeing. I admit that I did not always listen as closely as my father might have wished. Fortunately, this book provides a detailed soils history and analysis here in Wisconsin, more than filling in all that I missed during those family drives.

We need to think about the soil as a natural resource, about which we need up-to-date and relevant data for managing and planning purposes. Farms and related agricultural business in Wisconsin generate over $80 billion per year and employ more than 400,000 people. The long-term economic and ecological sustainability of these farm operations is dependent on deep knowledge of the soil resources. We know that soil information is also essential for managing our wilder regions such as forests, marshes, and grasslands. And the development of habitat around towns and cities requires soil knowledge.

I am proud that the University of Wisconsin harbors the oldest and one of the most renowned soil science departments in the world, and the contributions of its faculty and students have been key to the long-term research on Wisconsin soils. Thanks to Jim Bockheim and Alfred Hartemink for their long-term commitment to this research and for pulling together the detailed information contained here.

Soils are an essential and too often underappreciated asset for this state. It is my sincere hope that this book will help document the importance of the soil for the well-being and prosperity of all of us in Wisconsin.

Rebecca M. Blank
Chancellor
University of Wisconsin–Madison

Preface

The first book solely focusing on the soils of Wisconsin was published in 1927 by A.R. Whitson—professor of soil science at the University of Wisconsin–Madison. He described the function of soils; climate, future agriculture, and forestry; and origin and classification of Wisconsin soils and gave detailed descriptions of 23 soil series from nine soil regions. In 1947, Dr. Charles Kellogg, who later became Director of the Soil Survey Division of the USDA, Soil Conservation, published a general overview of the soils of Wisconsin as a *Preliminary Study of the Profiles of the Principal Soil Types of Wisconsin*. In 1976, the University of Wisconsin Press published *Soils of Wisconsin* that was prepared by Dr. F.D. Hole. This book contained chapters on factors of soil formation, processes of soil formation, properties of Wisconsin soils, classification of soils, and soil associations within ten soil regions of the state and an appendix with soil descriptions and analytical data. This book included a soil map at a scale of 1:710,000.

This present book in a sense constitutes the fourth edition of the *Soils of Wisconsin*. The authors have benefitted from several decades of new research and from the digital age in which official soil descriptions, laboratory characterizations, soil classification data, and the Web Soil Survey are available which enabled us to provide an up-to-date analysis of the soils of the state of Wisconsin. Despite the demand for soils information, only 3 (Michigan, Minnesota, and Wisconsin) of the 50 states in the USA have a general soil map published after 1999; and only 5 states (Arkansas, Florida, Louisiana, North Carolina, and Washington) have a book published after 1999 compiling soils data for the state.

We hope this book will serve as a written and digital account on the soils from Wisconsin, as a reference book for soil science and related courses and as a compendium for land users, policymakers, and anyone interested in our soils. On Wisconsin!

Madison, WI, USA
November 2016

James G. Bockheim
Alfred E. Hartemink

Acknowledgements

This work is based on decades of soil research and the data collected by soil scientists with the Wisconsin Geological and Natural History Survey (WGNHS) and the many surveyors and scientists from USDA Natural Resources Conservation Service (NRCS) at Madison, Wisconsin, and Lincoln, Nebraska. Without their dedicated surveying, mapping and research this book could not have been written. WGNHS allowed use color images depicting the natural resources of Wisconsin. We are grateful to David Evans, Michael Notaro, and Yakun Zhang for producing the soil, land use, and climatic maps. Unless indicated, the soil profile and landscape pictures were taken by Alfred Hartemink. Jim Bockheim acknowledges his wife, Julie, as a steady source of encouragement. We are grateful to Dr. Robert Doe, Suresh Rettagunta, and Corina van der Giessen of Springer for help in producing this book and to the chancellor of the University of Wisconsin–Madison for her support and the foreword to this book.

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About the Authors

Dr. Jim Bockheim was professor of Soil Science and of Forest and Wildlife Ecology and at the Nelson Institute for Environmental Studies at the University of Wisconsin from 1975 until his retirement in 2015. He has conducted research in forest soils and pedology throughout the state and in the Upper Peninsula of Michigan. His previous books include *Pedodiversity* (2013; with J.J. Ibáñez); *Soil Geography of the USA: a Diagnostic-Horizon Approach* (2014); *Cryopedology* (2015); and *The Soils of Antarctica* (2015).

Dr. Alfred Hartemink has been a professor of Soil Science at the University of Wisconsin since 2011 where his research focusses on digital soil morphometrics, soil mapping, and soil C. Prior to his current position, he was senior researcher at ISRIC–World Soil Information (The Netherlands) and coordinator of the GlobalSoilMap project. He has worked as pedologist and soil fertility specialist in Tanzania, DR Congo, Indonesia, Kenya, Australia, and Papua New Guinea. He was (Deputy) Secretary General of the IUSS between 2002 and 2014 and has edited and written several books.

Summary

This is the fourth book on of the soils of Wisconsin published over the past 90 years.[1] This version benefits from an additional 40 years of insights, soil mapping and research in the state, the development of geographic information systems, and the access to digital data by the Natural Resources Conservation Service.

In Chap. 1, it is noted that soils of Wisconsin have been investigated for 120 years. The number of soil series identified in the state has increased exponentially from a dozen in the early 1900s, to more than 700 in 2016. Ten broad soil regions have been identified in Wisconsin based on geographic location, topography, parent materials, soil texture, vegetation, and major soil groups. The soils can also be divided into 11 Major Land Resource Areas (MLRAs) that are based on a variety of natural resources and land use.

Since the early 1960s, the soils have been classified using *Soil Taxonomy* (ST). This hierarchical system delineates soils into orders, suborders, great groups, subgroups, families, and series. Diagnostic surface and subsurface horizons (natural soil layers containing defined properties) are of key importance in classifying the soils, of which there are five surface horizons and seven subsurface horizons in soils of Wisconsin. Seven[2] of the 12 orders are present in Wisconsin, including from most to least (on an area basis): Alfisols (mildly acidic, clay-enriched soils formed under forest), Spodosols (strongly acidic, iron-enriched soils formed under forest), Entisols (young soils), Mollisols (soils with a thick organic-enriched topsoils formed under prairie vegetation), Histosols (organic soils formed in wetlands), and Inceptisols (weakly developed soils).

Wisconsin has a long history of soil studies, and this is reviewed in Chap. 2; some of the major achievements of Wisconsin soil scientists are discussed. The geologist T.C. Chamberlin prepared the first map of soils in Wisconsin (1882); F.H. King wrote one of the first soil science textbooks in 1895 and was the first chair of the Department of Soil Science at the University of Wisconsin–Madison (1889); H.H. Bennett conducted research in the Driftless Area and was the first director of the Soil Erosion Service (1933), later to the Soil Conservation Service (1935) and then the Natural Resources Conservation Service (1994); S.A. Wilde wrote the earliest forest soils textbook in the USA (1946); and F.D. Hole published the first color soils map of Wisconsin and the third version of *Soils of Wisconsin* (1968). He also was instrumental in getting the Antigo Silt Loam recognized as Wisconsin's state soil.

Chapter 3 discusses the factors that influence the nature, properties, and distribution of soils in Wisconsin, including climate, organisms, topography, initial material, time, and human activities. Climate and vegetation have had pronounced effects on the distribution of soils in the state. Spodosols exist under mixed coniferous and deciduous forests in the northern third of the state; Hapludalfs (Alfisols) are present under broad-leaved forests dominated by oaks in the southern third of the state; and Glossudalfs (Alfisols) are present in a broad zone extending northwest to southeast across the state, to the north of the "tension zone." The line separating soils in the frigid and mesic soil-temperature classes (8 °C mean annual soil temperature at the

[1]First version by A.R. Whitson, *Soils of Wisconsin* (1927); second version by R.J. Muckenhirn and N.P. Dahlstrand, Soils of Wisconsin (1947); and third version by F.D. Hole, *Soils of Wisconsin* (1976).

[2]A relict Ultisol has been identified in Wisconsin. The Ultisols are strongly leached soils with relatively low native fertility that are often under forest and commonly occur in southeastern USA.

50 cm depth) extend across the tension zone. Prairies, possibly encouraged by periodic fires, exist in southern and western Wisconsin and are underlain by Mollisols. Marshes are found throughout the state and feature organic soils (Histosols). The poorly developed Inceptisols exist in areas where bedrock is close to the surface and where drainage is restricted. Poorly developed Entisols occur mainly on sandy materials in former lake basins and outwash plains. The topographic factor is the main factor distinguishing soils at the landscape scale.

Nearly 80% of the state is covered with glacial deposits that differ in texture, composition, thickness, and age. The upper 1 m of soil is primarily loess (34%), followed by till (14%), alluvium (13%), outwash (12%), organic sediments (10%), and other materials (17%). The "Driftless Area" has not been glaciated but is covered with loess (windblown silt-enriched material) and outwash from the Wisconsin River. There is a strong relationship between the soils and parent materials. Glossudalfs occur on clayey glaciolacustrine deposits and silty till; Spodosols occur on pitted outwash; Entisols exist on sandy lake sediments and pitted and unpitted outwash; and Hapludalfs occur on loess and calcareous drift in southern Wisconsin.

Most of the soils of Wisconsin are derived from drift of Late Wisconsinan age (9500–30,000 year BP). However, soils have been developed on pre-Late-Wisconsinan to Illinoian drift (>30,000–300,000 year BP) and on pre-Illinoian drift between 780,000 and 2,400,000 year BP. The red clay pediment material in the Driftless Area may be even older. Finally, human activities influenced the soils through cultivation, irrigation, fires, clearcutting, urbanization, and other land-management practices. The history of human impacts on soils in Wisconsin extends back approximately 13,500 years ago, but became intensified during the Late Woodland Tradition (1600–500 year BP) when fires were used to clear land and further intensified in the mid-1800s when European settlers arrived and land clearing and large-scale crop production begin.

Soil processes are discussed in Chap. 4. Ten soil-forming processes are common in Wisconsin soils: argilluviation (movement of clay); biological enrichment of base cations (retention of Ca, Mg, and K in the system by vegetation); gleization (the effects of poor drainage on Fe and Mn compounds); cambisolization (early stages of soil formation whereby the structure and color of the parent material are altered); paludification and ripening (the accumulation and decomposition of organic materials in organic soils); melanization (the accumulation of well-humified organic matter near the soil surface); podzolization (the accumulation of Fe and Al compounds complexed with humic substances); base cation leaching (translocation and removal of Ca, Mg, and K from leaching); ferrallitization (residual accumulation of Fe compounds in a clayey matrix from previous weathering episodes); and pedoturbation (mixing of soils by plants, animals, frost, and other mechanisms).

A discussion of the general soil regions of Wisconsin is given in Chap. 5. This includes modifications in soil regions and the recognition of more than twice as many soil series as when F.D. Hole prepared his version of *Soils of Wisconsin*.

Chapter 6 discusses the diagnostic horizons and soil taxa. There are 8 epipedons (surface horizon) in *Soil Taxonomy* of which 3 are common in Wisconsin: ochric, mollic, and histic. An ochric epipedon is the most common diagnostic surface horizon (76% of state's land area) and averages 24 cm in thickness. A mollic epipedon is found in 10% of the land area; it averages 39 cm in thickness. Histic epipedons cover 9% of the state and average 95 cm in thickness. Only six soil series in the state have an umbric epipedon, which averages 36 cm in thickness. The argillic horizon is the most common diagnostic subsurface horizon in the soils of Wisconsin. It covers 60% of the land area and averages 62 cm in thickness. The spodic horizon covers 18% of the state area and averages 30 cm in thickness. The third most extensive diagnostic subsurface horizon is the cambic horizon, which covers 9% of the state area and averages 48 cm in thickness. The glossic horizon occurs in conjunction with an argillic horizon or with argillic and spodic horizons, covering 25% of the state's land area and averaging 33 cm in thickness. The albic horizon covers 35% of the state soil area and averages 13 cm in thickness. Only ten soil series in Wisconsin contain a fragipan, which averages 62 cm in thickness and covers 1.2% of state's land area. Fragipans are restricted to the northern tier of counties in the state.

Wisconsin soils are included in seven orders, 15 suborders, 32 great groups, 142 subgroups, 425 families, and 741 soil series. More than half of the soil series were originally reported in Wisconsin; 40% occur only in Wisconsin; and 18% are unique and are considered endemic soils. More than half (52%) of the soils have a frigid soil-temperature regime, and 42% have a mesic soil-temperature regime. Eighty-seven percent of the soil series have a mixed mineralogy, meaning that the soils contain a variety of minerals in the fine-earth (<2 mm) fraction. Nearly half (48%) of the soils are in loamy particle-size classes, 22% are sandy, 18% are silty, 10% are clayey, and 2% are comprised of organic materials. Half (50%) of the soils have a superactive cation-exchange capacity, meaning that they have clay-size minerals with a high nutrient-holding capacity. About 83% of the soil area of Wisconsin contains soils that are very deep (>150 cm) to a restricting layer or bedrock, and 40% of the soil area is well drained.

In Chap. 7, we recognize 16 taxonomic soil regions (primarily great groups) in Wisconsin, including (from most to least in area) Hapludalfs (25%), Glossudalfs (16%), Haplorthods (15%), Haplosaprists–Haplohemists (9.6%), Udipsamments–Udifluvents (8.3%), Argiudolls (5.5%), Aquolls (3.0%), Aqualfs (2.6%), Aquods (2.4%), Hapludolls (2.0%), and six other regions that collectively comprise 8.6% of the state area (Paleudalfs, Udepts, Aquepts, Aquents, Quartzipsamments, and Fragiorthods).

Chapters 8 through 13 review the distribution, properties and processes, and use and management of each of the seven soil orders present in Wisconsin, along with order, suborder, and great group maps and images and data of representative soil series.

The paleosols ("soils of the past") of Wisconsin are described in Chap. 14. Paleosols may be buried, relict (remain at the surface as ground soils), or exhumed (previously buried material eroded from the surface). These soils can be divided into five age groups: (i) Holocene burials; (ii) relict soils on pre-Late Wisconsinan to Illinoian till; (iii) relict soils on pre-Illinoian till; (iv) loess over clayey pedisediments containing a buried soil over sandstone bedrock; and (v) loess over clayey pedisediments containing a buried soil over dolomitic or limestone bedrock. The oldest paleosols in Wisconsin include the red clays (*terra rossa*) of mid-Miocene age on saprolite from dolomitic limestone in the Driftless Area that has been covered by loess.

Endemism refers to plant or animal species or soils that occur naturally and are confined to a particular geographic area (Chap. 15). About 132 soil series in Wisconsin qualify as being endemic. Fifteen of these soils (11% of total endemic soils) occur in Bayfield County, which contains a diversity of parent materials, elevations, and proximity to Lake Superior. Two-thirds (67%) of these soils are considered rare; i.e., each has an area of less than 10,000 ha; 58% may be considered endangered and only occur in Wisconsin.

Chapter 16 focuses on the distribution of soils in the state in relation to past and present climates. By 2050, Wisconsin will experience a temperature increase of 3.3–3.8 °C and an approximate 25% increase in winter precipitation. A key climatic factor in Wisconsin pertains to the amount of snowfall. Soils will cool as the climate warms in the Great Lakes region, because of a thinner snowpack which will reduce the insulation from soil freezing. The impact of warming on fire frequency will influence soil-forming rates in Wisconsin. It will also result in land use changes that affect soil properties.

In Chap. 17, we examine the yield potential of Wisconsin soils. We observe highly significant correlations between economic parameters, such as agricultural land value sales and adjusted gross income to soil great groups on a county-wide basis.

In the final chapter, we identify issues that will need resolution in the near future that pertain to the mapping, classification, and organization of soil databases in Wisconsin.