

WEIL
BRADY

THE NATURE AND PROPERTIES OF SOILS

FIFTEENTH
EDITION

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RAY R. WEIL
NYLE C. BRADY

PEARSON

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FIFTEENTH EDITION

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*To all the students and colleagues in soil science who have
shared their inspirations, camaraderie, and deep love of the Earth.*



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NOTE: Every effort has been made to provide accurate and current Internet information in this book. However, the Internet and information posted on it are constantly changing, and it is inevitable that some of the Internet addresses listed in this textbook will change.

Nyle C. Brady 1920–2015

On 24 November 2015 soil science lost one of its giants. Nyle C. Brady passed away at the age of 95. Dr. Brady was a global leader in soil science, in agriculture, and in humanity. He was born in 1920 in the tiny rural town of Manassa, Colorado, USA. He earned a BS degree in chemistry from Brigham Young University in 1941 and went on to complete his PhD in soil science at North Carolina State University in 1947. Dr. Brady then served as a member of the faculty at Cornell University in New York, USA for 26 years, rising from assistant professor to professor and chair of the agronomy department and finally to Assistant Dean of the College of Agriculture. During this period, he was elected President of both the American Society of Agronomy and of the Soil Science Society of America.

Soon after arriving at Cornell University he was recruited by Professor Harry O. Buckman to assist in co-authoring the then already classic soil science textbook, *The Nature and Properties of Soils*. The first edition of this textbook to bear Nyle Brady's



name as co-author was published in 1952. Under Nyle's hand this book rose to prominence throughout the world and several generations of soil scientists got their introduction to the field through its pages. He was the sole author of editions published between 1974 in 1990. He continued to work on revised editions of this book with co-author Ray Weil until 2004. In recognition of his influence on the 15th edition, Dr. Brady continues to be listed as co-author of this textbook and his name is widely known and respected throughout the world in this capacity.

Dr. Brady was of that generation of American soil scientists that contributed so much to the original green revolution. He conducted research into the chemistry of phosphorus and the management of fertilizers and he was an early researcher on minimum tillage. Known for his active interest in international development and for his administrative skills, he was recruited in 1973 to be the third Director General of the International Rice Research Institute (IRRI) in the Philippines. Dr. Brady pioneered new cooperative relationships between IRRI and the national agricultural research institutions in many Asian countries, including a breakthrough visit to China at a time when that country was still quite closed to the outside world. He oversaw the transition to a second-generation of green revolution soil management and plant breeding designed to overcome some of the shortcomings of the first generation.

After leaving IRRI, he served as Senior Assistant Administrator for Science and Technology at the U.S. Agency for International Development from 1981 to 1989. He was a fierce champion of international scientific cooperation to promote sustainable resource use and agricultural development.

During the 1990s Dr. Brady, then in his 70s, served as senior international development consultant for the United Nations Development Programme (UNDP) and for the World Bank, in which capacity he continued to promote scientific collaboration in advances in environmental stewardship and agricultural development.

Dr. Brady was always open-minded and ready to accept new truths supported by scientific evidence, as can be seen by the evolution of the discussion of such topics as pesticide use, fertilizer management, manure utilization, tillage, soil organic matter, and soil acidity management in *The Nature and Properties of Soils* under his guidance. Nyle Brady had a larger-than-life personality, a deep sense of empathy,

and an incredible understanding of how to work with people to get positive results. He was the kind of person that friends, associates, and even strangers would go to for advice when they found themselves in a perplexing position as a scientist, administrator, or even in their personal life. Dr. Brady is survived by his beloved wife, Martha, two daughters, a son (a second son preceded him in death), 22 grandchildren, and 90 great grandchildren. He will be very much missed for a long time to come by his family and by all who knew him or were touched by his work.

Preface

By opening this 15th edition of *The Nature and Properties of Soils*, you are tapping into a narrative that has been at the forefront of soil science for more than a century. The first version, published in 1909, was largely a guide to good soil management for farmers in the glaciated regions of New York State in the northeastern United States. Since then, it has evolved to provide a globally relevant framework for an integrated understanding of the diversity of soils, the soil system, and its role in the ecology of planet Earth. This latest edition is the first to feature *full color illustrations* throughout.

If you are a student reading this, you have chosen a truly auspicious time to take up the study of soil science. This new edition was completed as the United Nations and countries around the world celebrated the International Year of Soils (2015). Soils are now widely recognized as the underpinning of terrestrial ecosystems and the source of a wide range of essential ecosystem services. An understanding of the soil system is therefore critical for the success and environmental harmony of almost any human endeavor on the land. This importance of soils and soil science is increasingly recognized by business and political leaders, by the scientific community, and by those who work with the land.

Scientists and managers well versed in soil science are in short supply and becoming increasingly sought after. Much of what you learn from these pages will be of enormous practical value in equipping you to meet the many natural-resource challenges of the 21st century. You will soon find that the soil system provides many opportunities to see practical applications for principles from such sciences as biology, chemistry, physics, and geology.

This newest edition of *The Nature and Properties of Soils* strives to explain the fundamental principles of Soil Science in a manner that you will find relevant to your interests. Throughout, the text emphasizes the soil as a natural resource and soils as ecosystems. It highlights the many interactions between soils and other components of forest, range, agricultural, wetland, and constructed ecosystems. This book will serve you well, whether you expect this to be your only formal exposure to soil science or you are embarking on a comprehensive soil science education. It will provide both an exciting, accessible introduction to the world of soils and a reliable, comprehensive reference that you will want to keep for your expanding professional bookshelf.

If you are an instructor or a soil scientist, you will benefit from changes in this latest edition. Most noticeable is the use of full-color throughout which improves the new and refined figures and illustrations to help make the study of soils more efficient, engaging, and intellectually satisfying. Every chapter has been thoroughly updated with the latest advances, concepts, and applications. Hundreds of new key references have been added. This edition includes in-depth discussions on such topics of cutting edge soil science as the pedosphere concept, new insights into humus and soil carbon accumulation, sub-aqueous soils, soil effects on human health, principles and practice of organic farming, urban and human engineered soils, cycling and plant use of silicon, inner- and outer-sphere complexes, radioactive soil contamination, new understandings of the nitrogen cycle, cation saturation and ratios, acid sulfate soils, water-saving irrigation techniques, hydraulic redistribution, cover crop effects on soil health, soil food-web ecology, disease suppressive soils, soil microbial genomics, indicators of soil quality, soil ecosystem services, biochar, soil interactions with global climate change, digital soil maps, and many others.

In response to their popularity in recent editions, I have also added many new boxes that present either fascinating examples and applications or technical details and calculations. These boxes both *highlight* material of special interest and allow the

logical thread of the regular text to flow smoothly without digression or interruption. Examples of applications boxes or case study vignettes include:

- “Dirt for Dinner”
- “Subaqueous Soils—Underwater Pedogenesis”
- “Practical Applications of Unsaturated Water Flow in Contrasting Layers”
- “Char: Is Black the New Gold?”
- “Where have All the Humics Gone?”
- “Tragedy in the Big Easy—A Levee Doomed to Fail”
- “Costly And Embarrassing Soil pH Mystery”
- “Gardeners’ Friend not Always so Friendly
- “Soil Microbiology in the Molecular Age”
- “The Law of Return Made Easy: Using Human Urine”

Boxes also are provided to explain detailed calculations and practical numerical problems. Examples include:

- “Estimating CEC and Clay Mineralogy”
- “Calculating Lime Needs Based on pH Buffering”
- “Leaching Requirement for Saline Soils”
- “Calculation of Percent Pore Space in Soils”
- “Calculating Soil CEC From Lab Data”
- “Toward a Global Soil Information System”
- “Calculation of Nitrogen Mineralization”
- “Calculating a Soil-Quality Index for Plant Productivity”

As the global economy expands exponentially societies face new challenges with managing their natural resources. Soil as a fundamental natural resource is critical to sustained economic growth and the prosperity of people in all parts of the world. To achieve balanced growth with a sustainable economy while improving environmental quality, it will be necessary to have a deep understanding of soils, including their properties, functions, ecological roles, and management. I have written this textbook in a way designed to engage inquisitive minds and challenge them to understand soils and actively do their part as environmental and agricultural scientists, in the interest of ensuring a prosperous and healthy future for humanity on planet Earth.

This understanding must include the role of healthy soils in agricultural applications and the pressing need for increasing food production. However, it must also include knowledge of the many other ecosystem services provided by soils. In this textbook I have tried to take a broad view of soils in the environment and in relation to human society. In so doing, the book focuses on six major ecological roles of soil. Soils provide for the growth of plants, which, in turn, provide wildlife habitat, food for people and animals, bio-energy, clothing, pharmaceuticals, and building materials. In addition to plant production, soils also dramatically influence the Earth’s atmosphere and therefore the direction of future climate change. Soils serve a recycling function that, if taken advantage of, can help societies to conserve and reuse valuable and finite resources. Soils harbor a large proportion of the Earth’s biodiversity—a resource which modern technology has allowed us to harness for any number of purposes. Water, like soil, will be a critical resource for the future generations. Soils functions largely determine both the amount of water that is supplied for various uses and also the quality and purification of that water. Finally, knowledge of soil physical properties and behavior, as well as an understanding of how different soils relate to each other in the landscape, will be critical for successful and sustainable engineering projects aimed at effective and safe land development.

For all these reasons it will be essential for the next generation of scientists, business people, teachers, and other professionals to learn enough about soils to appreciate their importance and to take them into full consideration for development projects and all activities on the land. It is my sincere hope that this book, early editions of which have served so many generations of soil students and scientists, will allow new generations of future soil scientists to benefit from the global ecological view of soils that this textbook expounds.

Dr. Nyle Brady, although long in retirement and recently deceased, remains as co-author in recognition of the fact that his vision, wisdom, and inspiration continue to permeate the entire book. Although the responsibility for writing the 15th edition was solely mine, I certainly could not have made all of the many improvements without innumerable suggestions, ideas, and corrections contributed by soil scientists, instructors, and students from around the world. The 15th edition, like preceding editions, has greatly benefited from the high level of professional devotion and camaraderie that characterizes the global soil science community.

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