

**HANDBOOK**  
**OF**  
**SOIL**  
**SCIENCE**

Editor-in-Chief

**MALCOLM E. SUMNER**

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H A N D B O O K  
— OF —  
SOIL  
SCIENCE

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Editor-in-Chief

MALCOLM E. SUMNER



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# Introduction

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## **What is Soil?**

We owe our existence to the extremely thin but precious skin, called soil, which covers the unweathered and partially weathered geological formations at the Earth's surface with a unique and extremely thin, fragile veneer. It is no longer rock or geological sediments but has been altered during soil formation by geological, topographical, climatic, physical, chemical and biological factors to form a living entity composed of an association of inorganic or mineral particles inextricably linked with organic matter, and perfused by gases. When wetted by vital water, the solvent and conveyor of nutrients, and major constituent of all living beings, this complex system becomes the fertile substrate from which all terrestrial life on this planet springs. This is the life-sustaining pedosphere zone which is a biologically active, porous, and structured medium that effectively integrates and dissipates mass fluxes and energy. In its pristine state, it is a self-regulating biological entity which slowly evolves as it continues to weather with time. It is analogous to a sponge, regulating and buffering the supply of nutrients and water for the growth of macro- and micro-flora and fauna and determining the partitioning of water into that which flows by surface paths to rivers and lakes and that which percolates to replenish subterranean groundwater reservoirs or aquifers.

Not only does it serve to promote and sustain life in its many forms, but it also acts as a living filter for the wastes generated by humans and animals. In this role, it cleanses, purifies and recycles water and detoxifies and renders harmless most toxins and pathogens which otherwise would irreparably contaminate and degrade the environment. Despite being contaminated by the remains of humans and

animals including those from epidemics of pestilence and plague, it has succeeded in rendering most vectors harmless and is seldom, if ever, involved in the transmission of diseases. On the contrary, some of its inhabitants, the microorganisms, have yielded up great antidotes to disease and infection, the antibiotics.

Catastrophic consequences have beset prior civilizations that allowed soil and water degradation to proceed beyond levels required to sustain food production. Soil resources, either directly or indirectly, impact, undergird and transcend all of society's urban, industrial and agrarian interests. It is intimately interwoven into current local, regional, national and global policies and issues on conservation and sustainability, land use, energy, environmental quality, taxation, and food, feed and fiber production.

Having said all this, a concise definition of soil is still elusive bearing in mind the highly heterogeneous nature of the soil. Suffice it to say, at this stage, that soil is an evolving, living organic/inorganic layer at the Earth's surface in dynamic equilibrium with the atmosphere and biosphere above, and the geology below. Soil acts as an anchor and purveyor of water and nutrients for roots, as a home for a vast and still largely unidentified community of microorganisms and animals, as a sanitizer of the environment, and as a source of raw materials for construction and manufacturing. Soil is the long-term capital on which a nation builds and grows. It is the basic component of ecosystems and ecosystem management. A fundamental understanding of this elastic, porous, three-phase system (solid, liquid, gas), its components, processes and reactions, is basic to support the life of plants and animals that live in and on it. Soil serves as the foundation essential for continued human welfare, the well-spring of other renewable natural resources. In the words of Roy Simonson "Soil resources are the earthen looms that shape the lives of the people. The more completely they are understood, the better can be the fabric of life woven on these earthen looms."

Every soil consists of one to several layers called horizons, a few to hundreds of centimeters thick that reflect the physical, chemical, and biological processes which have taken place. Horizons are composed of natural aggregates called peds which are made up of associations of mineral and organic particles. Peds and particles are often separated from each other by pores that vary widely in size and shape. In addition, individual peds and particles may be coated by materials such as clay, organic matter, sesquioxides or precipitated salts. Although the internal structure of peds is not readily visible to the naked eye, the spatial arrangement of peds, particles and pores, called soil architecture, greatly influences soil behavior because the organization is frequently systematic and related to macropore distribution. At the microscale, soil architecture governs soil water/solute movement and retention, soil structure/porosity, soil strength/failure, mineral synthesis/weathering, movement of toxic and nontoxic wastes, soil/root environments, root growth/proliferation, nutrient transfers, soil erosion and oxidation/reduction reactions.

## **What is Soil Science?**

Soil science is that spectrum of earth science that deals with soils as very slowly renewable natural resources on the earth's surface. It involves the study of soil formation, classification and mapping, the physical, chemical, biological and mineralogical properties of soil from microscopic to macroscopic scales of resolution as well as the processes and behavior of soil systems and their use and management. It is an integrative science that interlinks knowledge of the atmosphere, biosphere, lithosphere and hydrosphere. Soil science provides the tools to integrate the components of earth science systems, to understand the causes and consequences of spatial variability, and to take a more holistic approach to the dynamic processes affecting ecosystems.

Soil science focuses primarily on near-surface processes that govern the quality and distribution of soil resources relative to landform evolution (geomorphology), geochemical environment (geochemistry), and organismal habitat (ecology/biology). These pedogenic processes are interactively conditioned by lithology, climate and relief through geologic time. Soils are welded together into landscapes like chains; processes which perturb and impact higher topographic surfaces directly affect processes on adjacent lower surfaces. Pedologists and other soil scientists study the energy flows and mass fluxes, which are the dynamic driving forces of pedogenesis through and over the three-dimensional soil system. They also quantify renewal and transfer vectors for biomass production, rainfall and dusts which counter constituent losses through drainage water, lateral interflow and downslope migration or erosion products.

Soil science has its parentage in geology, chemistry, and biology, but for the past 100 years, has evolved as an independent body of knowledge with strong underpinnings to agriculture. Because of the unparalleled success that soil science has enjoyed in helping to bring ample food, fiber, feed, and fuel to the world, the development of basic soil science has come primarily as a byproduct of research in agriculture, engineering, and the environment. There is growing evidence that the complexity of these problems requires a much broader approach to the science of the soil than can be stimulated by applied research alone. Soil science is taking its place alongside basic research efforts in the biosciences, geosciences, and atmospheric sciences to provide the reservoir of fundamental knowledge needed to develop lasting solutions to the challenges of balanced use and stewardship of the Earth. Despite the knowledge accumulated over the past century, Leonardo da Vinci's statement that "We know more about the movement of the celestial bodies than about the soil underfoot" is as true today as it was then. There is need for much more investigation of our most precious resource to stave off the fate that befell our ancestors in the ancient empires of Babylon, Egypt, China, Europe and the Americas where soil erosion, salinization and siltation laid waste to their land resources. They were constrained by having only limited knowledge of the system, but we will be judged by generations to come based on the quality and stewardship of our land resources.

Modern parallels of soil and land degradation continue in both developing and industrialized countries. In addition to the problems facing the ancients which are still prevalent, chemical toxicities, irreversible land use conversion, environmental pollution and desertification are the modern plagues. Sustainability of today's culture is threatened by loss of biodiversity, population growth and land degradation leading to enhanced greenhouse gas emissions which may result in global climate change. Land degradation is a complex technical, socioeconomic and political issue without simple answers. Soil scientists can provide technical solutions but without implementation as public policy, they are likely to be futile. Currently, public attention is focusing on soil, air and water quality in efforts to maintain a clean environment. Soil science has a major role to play in this arena.

## **What is the Purpose of this Book?**

This Handbook presents the first comprehensive reference on the discipline of soil science as practiced today. It contains definitive descriptions of each major area in the discipline, including its fundamental principles, appropriate methods to measure each property, many examples of the variations in properties in different soils throughout the world, and guidelines for the interpretation of the data for various applications (agricultural, engineering, environmental, biological, regulatory, educational, hydrological, biogeochemical). This Handbook assembles the core of knowledge from all fields encompassed within the discipline of soil science and provides a resource-rich database which will give professional soil scientists, agronomists, engineers, ecologists, biologists, naturalists, and students

their point of first entry into a particular aspect of soil science. The contributions also serve those professionals seeking specific, factual reference information. The Handbook provides a thorough understanding of soil science principles and practices based on a rigorous, complete, and cutting-edge treatment of the subject compiled by leading scientists in each field. It is designed as a desk reference book.

This Handbook is divided into eight Sections dealing with Soil Physics, Soil Chemistry, Soil Biology and Biochemistry, Soil Fertility and Plant Nutrition, Pedology, Soil Mineralogy, Interdisciplinary Aspects of Soil Science and Soil Databases. The Section on Soil Physics opens with a description of the basic physical properties of soils followed by a treatment of their dynamic properties in relation to tillage and disturbance by machinery. All aspects of soil water are discussed including content/potential relationships, its movement and transfer to the atmosphere both directly and through the plant and the cotransport of solutes in moving water. The nature of soil structure and its bearing on soil behavior are explored followed by an examination of gas movement under unsaturated conditions. The role of macropores as the superhighway for bypass transport of water and solutes is considered. Finally, the heterogeneity of soils is described culminating in an evaluation of its spatial variability. After an initial description of the chemical composition of soils, the Section on Soil Chemistry elucidates the nature and dynamics of soil organic matter. The importance of the soil solution as the highway for transport and reactions in soil is then highlighted followed by an evaluation and description of the kinetics of reactions in soils. The reactions taking place when oxygen becomes limiting are then explored followed by a detailed account of soil colloidal phenomena important in predicting the behavior of the finest soil fraction. Ion exchange, sorption and precipitation reactions are quantitatively treated as a framework to evaluate the behavior of labile constituents in soils. Catalytic reactions promoted by soil and its constituents are examined followed by an account of the effects of acidity and alkalinity on soil reactions and behavior. The Section on Soil Biology and Biochemistry opens with a discussion of bacteria, fungi, cyanobacteria and algae followed by that of soil fauna comprising protozoa, nematodes, micro- and macroarthropods, enchytriads and vertebrates. The nature, function and life cycles of each are described. Then the processes mediated by these organisms including nutrient transformations are discussed. A major portion of the discussion is devoted to nitrogen transformations because of their importance in soils. The bioavailability of macro- and micronutrients as well as their interactions are discussed in the Section on Soil Fertility and Plant Nutrition prior to evaluating methods for estimating their potential availability to crops and methods of application as fertilizers. Finally, the efficiencies of nutrient and water use are discussed. Following a discussion of the pedogenic processes and models involved in soil formation, descriptions of the systems used to classify soils are given in the Section on Pedology as a framework in which to discuss the Soil Orders in Soil Taxonomy. The structure and properties of the minerals in the active clay fraction of soils are discussed in the Section on Soil Mineralogy following an introduction to mineral weathering processes. Thereafter various Interdisciplinary Aspects of Soil Science such as salinity, sodicity, hardsetting, wetland biogeochemistry, acid sulfate soils, soils and environmental quality, soil erosion by wind and water, land application of wastes, soil quality and conservation tillage are discussed. Finally, the Soil Databases available to assess worldwide soil resources are presented and discussed.

# Preface

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The *Handbook of Soil Science* is a comprehensive reference work on the discipline of soil science as practiced today. It contains definitive descriptions of each major area in the discipline, including its fundamental principles, appropriate methods to measure each property, many examples of the variations in properties in different soils throughout the world, and guidelines for the interpretation of the data for various applications (agricultural, engineering, environmental).

The *Handbook of Soil Science* assembles the core of knowledge from all fields encompassed within the discipline of soil science. It is a resource rich in data which will provide professional soil scientists, agronomists, engineers, ecologists, biologists, naturalists, and students with their point of first entry into a particular aspect of soil science. The contributions serve those professionals seeking factual reference information on a particular aspect. The *Handbook* provides a thorough understanding of soil science principles and practices based on a rigorous, complete, and up-to-date treatment of the subject compiled by the leaders in each field. In general, the following critical elements are present in each subsection: description of concepts and theories, definitions, approaches, methodologies and procedures, data in tabular and figure forms, and extensive references.

The *Handbook* is organized into eight sections, covering the six traditional areas of soil science together with the interdisciplinary aspects and a final section on databases:

Soil Physics	Soil Chemistry
Soil Biology and Biochemistry	Soil Fertility and Plant Nutrition
Pedology	Soil Mineralogy
Interdisciplinary Aspects of Soil Science	Soil Databases

The subdivision of each section into a series of chapters was made by the associate editors and in some cases may appear to be somewhat arbitrary. The chapters have been arranged in such a way as to produce a thread running through each section. A complete table of contents is provided at the front of the book and gives a general outline of the scope of the covered subject material. In addition, a comprehensive subject index is provided at the back of the book.

The chapters of the *Handbook* have been written by many authors, all experts in their own fields and peer-reviewed by at least two reviewers. The eight sections have been carefully edited and integrated by the associate editors, all distinguished soil scientists in their fields. This *Handbook* is a tribute to the dedication of the authors, associate editors, the publisher and its editorial associates and my editorial assistant, Mrs. Pam Wilson and research coordinator, Mr. Gene Weeks who have worked diligently on this project. I wish to thank all the authors for their valuable contributions, the reviewers for their useful and helpful comments and criticisms, and the associate editors for all the hard work that they have put in. I also wish to recognize Ms. Marsha Baker who enticed me to undertake this task and Mr John Sulzycki who continued the management of this project. Finally, I would like to thank my wife, Priscilla, for her patience, sacrifice, understanding, support, and encouragement without which this project would not have been possible.

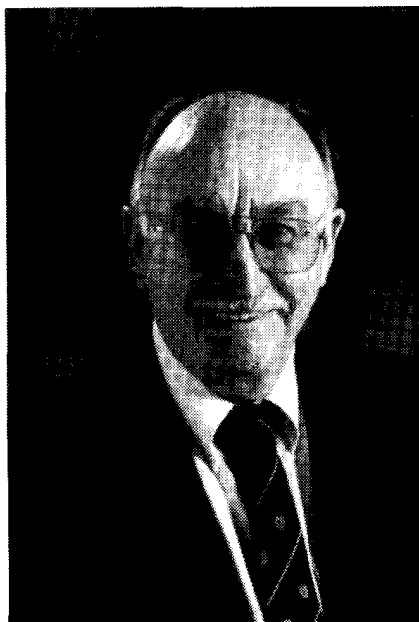
Malcolm E. Sumner  
Editor-in-Chief



# About the Editor

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**Dr. Sumner** is the Regents' Professor of Environmental Soil Science in the Department of Crop and Soil Sciences at the University of Georgia, Athens, GA. He received a B.Sc. Agric. degree (1954) in Chemistry and Soil Science and an M.Sc. Agric. (*cum laude*) (1957) degree in Soil Physics from the University of Natal, South Africa, and a D.Phil. degree (1961) in Soil Chemistry from the University of Oxford, UK. His *Alma Mater*, the University of Natal awarded him an Honorary Doctor of Science degree in recognition of his career contributions to Soil Science. Before coming to the University of Georgia, he was Professor and Head of the Department of Soil Science and Agrometeorology at the University of Natal, South Africa. He has spent sabbatical leaves at the Agricultural University (Wageningen, Netherlands), University of Missouri (Columbia), University of Wisconsin (Madison), University of Newcastle-upon-Tyne (United Kingdom), Vista University (South Africa), University of Adelaide (Australia) and the Commonwealth Scientific and Industrial Research Organization

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