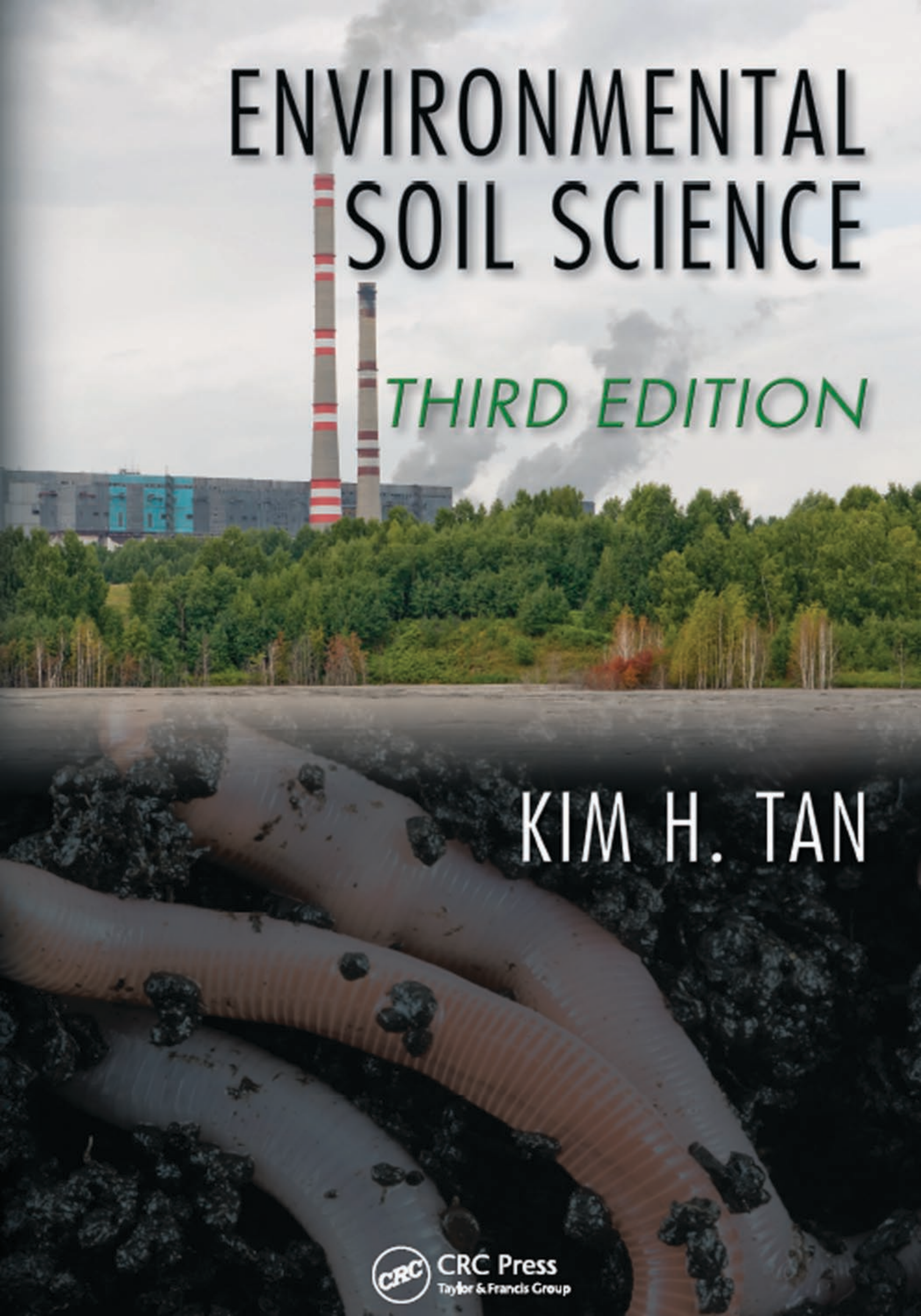

ENVIRONMENTAL SOIL SCIENCE

THIRD EDITION

KIM H. TAN

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KIM H. TAN
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CONTENTS

PREFACE TO THE THIRD EDITION

This third edition has the intention to update the book with new advances published since 2000, and address the proliferation of using the term environmental in soil science. A number of professors are equating environmental soil chemistry with environmental soil science. Soil chemistry is, next to soil physics, soil taxonomy, soil formation or pedology, mineralogy, soil fertility, edaphology, and soil biology, only one of the topics of soil science as a whole. Attempts have been made in the past to also change soil physics into physical edaphology and environmental soil physics. It would not be surprising if one day environmental soil fertility would appear, which is stretching the issue to the limit, since environmental processes are inherent factors of soil fertility. Most of the books above are discussing only the inorganic issues. By not including the biological part, the most closely related aspect with the environment, the use of the term environment seems to be overrated. For example, weathering of minerals is only described as the conventional inorganic decomposition and no mention is made of the influence of humic acids, organic acids, and live organisms. Even the carbon and nitrogen cycles seem to be ignored in many cases. Today, a new type of weathering, e.g., space weathering, is becoming more important with the rapid advancement of space technology by the National Aeronautics and Space Administration (NASA). This new idea and many more others, like genetic pollution, politicizing global warming with the controversial carbon credits, the potential destruction of the coral reef triangle by greenhouse gases, decreasing planet earth's precious biodiversity and many more, have necessitated the publication of a third edition of this book. The chapters have to be reexamined and new ones written to address the definitions of environmental science, ecology, and soil science, underscoring their combination into what it is now called environmental soil science.

The text of the third edition is still organized by examining first the inorganic, organic, liquid, and gaseous soil constituents, but includes their reactions in close relation with environmental processes. The soil properties created by the soil constituents are discussed next by underlining their significance in the environment and the soil ecosystem. Environmental changes resulting from the use of soils for food and fiber production have been enlarged with new materials on forest, soil, and biodiversity degradation, whereas desertification, pollution, and contamination have been redefined. New ideas on tillage, composting, LISA, and organic farming have been included, and the term sustainable reexamined. Aquaculture, one of the methods identified for food production without disturbing soil, has been substantially expanded to include several types of fish farming, and their effects on environmental damage, e.g., water pollution and destruction of mangrove habitats. The Law of the Sea and the issue of biopiracy are addressed. New advances in biotechnology and their controversies are addressed, e.g., the issues surrounding golden rice, flavr savr tomato, roundup ready plants, and safety of genetically modified (GM) crops. The last chapter has also been revised completely to include politics in global warming and its carbon credits in regulating CO_2 pollution. The confirmation of the ozone hole in Antarctica and the Rowland-Molina-Crutzen hypothesis for destruction of ozone are addressed in some detail.

THE CHAPTERS

Chapter 1 now starts with three new subchapters discussing the need for the name of environmental soil science and its proper relation with the definitions of environmental science and ecology. The usage of the term environmental soil science, as perceived by universities in the United States, is reexamined and a new concept suggested. The section on soil orders has been expanded to cover fertility, land use, and management practices of each of the soil orders. The issue of protecting the permafrost in gelisols and the use of tropical peats in the histosols order are discussed.

Chapter 2 has been revamped to underline the environment as a significant factor. The section Weathering of Primary Minerals has been rewritten to underscore differences between abiotic weathering and biological weathering. Biochemical and biological weathering are expanded. Two new subchapters have been created, e.g., Environmental Significance of Weathering and Space Weathering. The connection of weathering and peneplain formation is examined and the controversy of biostasis and rhexistasis of the French school in relation with pedogenic and erosion cycles addressed.

Chapter 3 has been completely rewritten, showing the environmental significance of live, nonhumified and humified soil organic constituents. A new definition of soil biomass has been added that is used more by soil and crop scientists. The cultivation effect of earthworms has been expanded and illustrated clearly by a new figure (3.1) and two others on protozoa and ganoderma fungus, respectively. The environmental and allelophatic importance of fungi as decomposers and their use as food and medicines have been expanded. Alcoholic fermentation of carbohydrates is discussed in more detail and the controversial issue of producing biofuel from corn addressed.

Chapter 4 has been reorganized more logically and a new section has been added on the alleged controversy of soil aeration contributing to global warming. The discovery of glomalin challenging the concept of humus as the storage place of organic carbon is addressed.

Chapter 5 now starts with a new section that examines the definitions of solutions, solutes and solvents, followed by types of soil water. The soil solution is dealing now with liquid (soil) and gaseous solutions. Nutrient or water pollution caused by soil solutes are addressed and there are new sections on Eutrophication, Oligotrophication, and Dystrophication, respectively. The section on the environmental aspects of dissolved oxygen has been enlarged by adding the issue of hypoxia.

Chapter 6 has been completely revised and the section Soil Texture has been changed to Particle Size Distribution, clearly differentiating the concepts of soil separates, soil texture, and soil classes into separate sections. This term is not only the modern version but agrees better with the textural soil concept that revolves around soil separates as the basics. Soil texture is now defined as a property derived from volume calculations of soil separates, whereas soil classes are interpreted now for being soils, characterized by different types of soil textures. Section 6.6 has been revised into a new section, "Thermal Properties of Soils," emphasizing issues on soil temperature, heat capacity, thermal conductivity, and thermal diffusivity of soils. Since soil physics were developed for mineral soils, many of the properties are not applicable in organic soils and a new section has been written to cover the issues of soil physics in histosols.

Chapter 7 has been rewritten to underline the environmental aspects of electrochemistry of inorganic and organic soil constituents. A new topic on cation exchange capacities of plants has been added and the last section of the chapter elevated into Section 7.6 to bring attention to the art of creating ornamental plants, brilliantly colored by artificially inducing micro nutrient toxicity and deficiency.

Chapter 8 has been drastically overhauled and Section 8.1 is now composed of three separate sections, addressing (1) Deforestation and forest degradation, (2) Opening New Lands for Crop Production, and (3) Nutrient Cycling or Biogeochemical Cycling and the ecological benefits of forest litter. Soil degradation examines the issue of the French school on retrogression as an evolutionary cycle in soil formation. Biodiversity has two new sections, e.g., Terrestrial Biodiversity and Marine Biodiversity. The kelp forest and fragile coral reefs' ecology, especially in the coral reef triangle, are examined in relation to possible destruction by global warming. No-till or residue farming contains new materials on strip- and hybrid-tillage. Organic farming has been revised to address the 2005 guidelines of the International Federation of Organic Agriculture Movement (IFOAM) and the U.S. National Standard on Organic Production and Handling (NOP), prohibiting the use of GM materials. The section on LISA also presents the 1987 U.S. Congressional Act for its development. The definitions and feasibilities of sustainable and low-input agriculture are reexamined.

The hydroponic section of Chapter 9 has been expanded with separate chapters on kelp and spirulina cultivation and their ecological and human health benefits. Aquaculture, considered the blue revolution, has been enlarged in the freshwater section, addressing high-value and low-value fish farming. Carp and tilapia farming have been added and their origin, types, economic and ecological benefits underlined. Marine aquaculture now contains three separate sections, each detailing cultivation of high-value fish and shrimp and the fish industry. The economic and ecological benefits of shrimp farming, e.g., destruction of mangrove habitats, are examined. Raising sharks in confinement has been added, for "shark steak" and the skin for production of purses and other leather goods in Indonesia. The concept of salmon ranching in the United States is compared with true farming methods in Norway, Chile, Scotland, Canada, and Japan. Channel catfish farming has been enlarged and now contains the origin of domestic and foreign catfish and their high-tech cultivation, using spawning, nurseries, and outgrow ponds. The issue of shark catfish of Thailand and the walking catfish of Indonesia raised in ponds receiving manure are addressed. Finally, the Law of the Sea is expanded to include the definitions of Territorial Waters and Exclusive Economic Zones (EEZ) that many fear will end the freedom of fishing in the high seas.

Chapter 10 is practically new and starts with addressing the concepts of biotechnology in soil science and agriculture. "Food Biotechnology" now contains four separate sections on production of fermented food, beer and light beer, food additives and sweeteners, and ethnic food. Agricultural biotechnology examines efforts in crop production, creation of golden rice, favr savr tomatoes, roundup ready plants, ecofriendly pesticides, and the safety of GM products. Cloning is underscored in the section of tissue cultures, whereas "Soil Biotechnology" explains the significance of biofertilizers and the controversy surrounding effective organisms (EMs). A discussion on the increasing attention from the industry is included on the benefits of biomedicines from peat and humic acids, and genetic engineering of soil microorganisms in search of a superbug for the cleanup of nondegradable hydrocarbons and radionuclides.

Chapter 11 has been overhauled to address the forms of pollution, differentiating the common types from those created by modern technology, such as thermal, noise, light, and genetic pollution. Agricultural waste has been redefined in view of its usefulness in biofuel production. The safety levels of the pesticide section now shows examples of ADI (Acceptable Daily Intake) levels or the amount of pesticide residues consumed in mg/kg body weight without ill effects.

Compost and composting are expanded considerably and include the method of vermicomposting, use of worm tea, and Trichoderma for rapid decomposition of lignocellulose. Soil remediation addresses separate sections of physical, chemical, bio-, phytoremediation, and natural attenuation. Their differences and effectiveness are underscored. Mustard and sunflower plants are used as examples in cleaning the soil from heavy metals, and canna plants for transforming pesticides into nontoxic forms. This detoxification is called the green liver model process because of its similarity in function to a human liver. The section on the greenhouse effect now covers the carbon credit issue, providing new dimensions in carbon pollution trading. Methods for controlling acid rain, including the flue gas desulfurization (FDG) process, are addressed. The section on destruction of the ozone shield now also examines the Rowland-Molina-Crutzen hypothesis. The startling discovery of the large ozone hole by the 1985 British Antarctica Survey, as confirmed by the U.S. expeditions at McMurdo Station, Antarctica and NASA stratospheric flights in the Antarctic sky, is discussed.

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PREFACE TO THE SECOND EDITION

This second edition of an essential textbook, employed by numerous universities around the world, has been completely rewritten. Environmental Soil Science was the textbook for many years at the University of Georgia for the senior-level undergraduate and graduate course in Environmental Soil Science. It was found very useful by a great number of students, especially those majoring in environmental health science and those at the School of Forestry. The first edition of the book has been used at the Universidad Nacional del Sur, Bahia Blanca, Argentina, the University of North Sumatra, Medan, and the University of Andalas, Padang, Indonesia. I have used the book in my Environmental Soil Science course presented in the fall semester of 1998 at the University of North Sumatra, where it is to be translated into the Indonesian language, and am planning to use it again in the fall semester 2000 at the University of Andalas.

This second edition is intended to bring the book up-to-date, by adding the most recent advances, and by incorporating suggestions and recommendations of a range of readers, including former students, teachers, professors, and scientists from universities in the United States, Indonesia, Argentina, Canada, and Europe. The organization of the book remains the same as in the first edition. However, the environmental aspect is highlighted by integrating soils with the environment. This issue relates soil with the environment, by incorporating fundamental soil principles as well as state-of-the-art applications in environmental processes vital for continuation of life, into a stimulating, information-packed resource. It discusses soil properties as products of the environment, and at the same time addresses their effect on the environment. The primary use of soils for food and fiber production is examined in close relation to the consequent environmental changes.

Chapter 1 starts by presenting the major soil groups. A new soil order, the gelisol, has been added, and the discussion on andisols has been expanded, featuring recent advances, including coadsorption or Al-bridging processes, which I advance for accumulation of humus and P-fixation. The issue of nomenclature is addressed, and the environmental significance of distribution of soils is stressed according to latitudinal and altitudinal variations.

Chapter 2 has been expanded, highlighting the key role of primary minerals not only in soils and agriculture, but also in their effect on the environment and use in industry. The discussion of the weathering of primary minerals has been rewritten, differentiating abiotic from biochemical processes and stressing the central role organisms play in decomposition and neoformation of soil minerals. The anti-allophanic process by soil organic matter advanced in Japan is addressed.

Chapter 3 has been overhauled, and now features the beneficial effects of soil organic matter and allelophaty, fundamentals in plant toxicity, and environmental and human health. New topics on humus, enzymes, plant roots, and rhizosphere have been added, underscoring the fundamental role of the macroflorae. The macrofaunae are examined in a new light, and the environmental significance of the microfaunae and microflorae has been given a new dimension. The carbon and nitrogen cycle sections have been rewritten, emphasizing their significance in nature, and the text on organic compounds has been expanded exposing clearly their environmental importance, using as examples the production of biofuel from organic trash containing carbohydrates, and the hydrophobic properties induced by lipids. A new section featuring the key role of humic acids in production of biomedicines is presented, underscoring the role of mud baths offered at modern health spas.

The topic of soil air has now been enlarged substantially in Chapter 4 to emphasize the role of soil aeration and seasonal variation in O_2 and CO_2 content in tropical and temperate region soils in response to changing respiration. Redox potentials are presented, underscoring their usefulness in soil formation and issues of proper aeration for environmental health. The biochemistry of anaerobic and aerobic soils has been reassessed, and a new concept has been added on the critical value of O_2 content fundamental to root growth.

Chapter 5 has been expanded by featuring new topics on movement of water in the liquid and gas phase, highlighting Darcy's law, the importance of relative humidity for microbial life, and the environmental significance of leaching and percolation as essential processes in nature. Water loss has been added to stress the necessity of evapotranspiration and the importance of mulch. The section on dissolved substances and soil colloids in the soil solution was reassessed to highlight their environmental importance.

Chapter 6 is a new chapter featuring the major physical properties of soils in close relation to their environmental importance. Soil texture is presented, stressing its central role in issues on soil compaction, soil impedance and pore spaces, fundamental in root growth and penetration and percolation. Soil structure is discussed in light of biological activity, inorganic and organic cementing agents, and effectiveness of artificial soil conditioners against surface sealing. Soil density and pore spaces are examined in relation to cropping systems and the cultivation effect of soil macro- and microfaunae. The Atterberg's plasticity index forms the core of the section on soil consistence, highlighting the significance of plasticity in the environment and its fundamental role in the ceramic industry. Thermal properties in soils are examined in relation to the effect of plant canopies and the usefulness of mulch.

The electrochemical properties of soil constituents in Chapter 7 provide a clear distinction between permanent negative and permanent positive charges. The nomenclature of these charges and that of the ZPC are reassessed. A new concept of counter ion bridging is advanced by the author in the electric double layer theory to give a better reason for flocculation of clay. Positive and negative adsorption are added in the section on anion exchange, underscoring the significance of exchange alkalinity and the effect of negative adsorption on eutrophication. The environmental significance of organic substances has been reexamined as illustrated by the capacities of amino acids in coadsorption or metal bridging, and those of humic acids in hydrophobic bonding with extracellular polysaccharides and in biodegradation of pesticide residues. A new section has been added to stress the importance of producing sickly plants, which are sometimes highly regarded as beautiful ornamental plants. Like the induced stunted and crooked condition of bonsai plants, plants experiencing micronutrient deficiency or toxicity often produce brilliant colors.

The primary use of soils for food and fiber production has been reexamined in Chapter 8. A new section was added addressing the beneficial and harmful effects of deforestation. Soil degradation, divided into physical, chemical, and biodegradation, is highlighted as an essential process of aging in nature. Growing old accelerated by human interference brings with it the usual harmful sicknesses of old age. Similarly, a new section on desertification is presented to underscore the natural process of sand dunes' migration that is caused by wind action but is often accelerated in arid regions by human interference. A new controversial theory is offered that considers it a myth that increased CO_2 production is causing the greenhouse effect and global warming. Low-input sustainable agriculture (LISA) was added, stressing differences between no-till and organic farming.

Alternative methods for food production without using soils are examined in Chapter 9, and the water and nutrient requirements in hydroponics are reassessed to highlight the significance of the transpiration ratio and threshold value, including MAC and MAL, of micronutrients. The issues of crop yields and importance of food production by hydroponics are given new dimensions in the new sections on nutrient film technique and artificial soil. The aquaculture section has been rewritten, stressing the importance of the Law of the Sea, and the significance of salmon ranching. Channel catfish farming in the United States is highlighted where advantage has been taken of cultural eutrophication. Growing plants not for food but as ornaments also required for human health is underscored by the new section on orchid culture.

Chapter 10, on biotechnology in food production, has been enlarged to include a new section on environmentally friendly pesticides, emphasizing the need for development of inexpensive pesticides for human health, such as the successful pyrethrum coils burned as incense effective in killing mosquitoes. New concepts are introduced in the discussion of soil biotechnology, examining the importance for production of biofertilizers and biomedicines. The issue of genetic engineering in producing new crops for food, and the public's suspicion of genetically altered crops are addressed.

Chapter 11, discussing the production of waste from agricultural and industrial operations, has been rewritten and expanded, and now shows the distinction between contamination and pollution, and the importance of cometabolism, ADI, and NOEL of pesticide residues. Soil Remediation and Natural Attenuation are new sections, underscoring physical, chemical and bioremediation or attenuation as fundamental but different processes in detoxification of soils and the environment. The greenhouse effect and global warming and the issues of fishkill and forest dieback are reexamined to address the controversial effects of CO_2 and acid rain.

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Kim H. Tan

PREFACE TO THE FIRST EDITION

The tremendous pressure on our soils and the environment by the industrial and agricultural expansion in the last few decades has created a new burst of understanding in environmental quality. The intensive use and misuse of our soil, water, and air resources due to population pressures and increased standard of living, have increased the hazard of declining productivity and increasing pollution. The use of fertilizers, insecticides, and herbicides in agriculture has expanded tremendously, and pollution of streams, lakes, and contamination of soils and groundwater with toxic chemicals has become more eminent than before. This has resulted in an increased sense of awareness in environmental issues, and a large amount of information has accumulated on environmental problems, soil conservation, and the use of soil for disposal of industrial and agricultural wastes. However, a book on soil science relating the principles of environmental issues is still missing. Environmental soil science is hardly a new science. It can be defined as the "science of soils in relation to the environment." Soils are the product of the environment, and their properties are closely associated with environmental factors. Scientists, students, and professionals acquainted with environmental principles in soil science will be more competent to prevent or recognize an environmental problem when it arises, and find ways to solve it intelligently.

Therefore, this book is written with the purpose to relate environmental principles with soil science in plain language, easy to comprehend by a wide range of scholars, students, scientists, growers, and professionals. The text starts with an attempt to show the effect of environmental factors in formation of different kinds of soils, and the dominant impact of climate and vegetation in determining the distribution of these soils in the world. This is followed by Chapters 2, 3, 4, and 5, in which the soil constituents in the solid, liquid, and gas phase are discussed in association with their properties and reactions of importance for the environment. The effect of environmental factors on weathering of primary minerals and formation of clay minerals are stressed in Chapter 2. The organic components, biochemical reactions, and interrelationships with environmental issues are highlighted in Chapter 3. Gaseous components, biochemical reactions in aerobic and anaerobic conditions, and their implications in pollution of soil and atmospheric air are featured in Chapter 4. Soil water, dissolved macro- and micronutrients and their reactions in close association with environmental issues, for example, eutrophication, are discussed in Chapter 5. The reactions of dissolved inorganic and organic solids, and dissolved CO_2 and O_2 gas are included as an important part affecting environmental quality. Chapter 6 discusses the electrochemical properties of clay and humic acids and their significance in pollution. Chapter 7 examines the efforts in crop production and the consequent changes they bring to the environment, whereas Chapters 8 and 9 summarize alternative methods in crop production, for example, soilless agriculture and biotechnology. The final chapter is about soil and pollution, in which agricultural and industrial wastes and their implications to environmental quality are assessed.

I want to thank Dr. Harry Mills, Professor of Horticulture, University of Georgia, and Dr. J. B. Jones, Jr., Director M.M.I., Inc., Athens, Georgia, for their encouragement and constructive criticism. Appreciation is extended to Ms. Nicky Whitehead for reading and editing the manuscript, and to Mr. John Rema for his assistance with the laser printer in the development of the draft of this book. Thanks are extended to the many unnamed persons who have assisted in the development of the book. Finally, I want to acknowledge the support and understanding of my wife, Yelli, who has stood by with great enthusiasm and a lot of encouragement.

Kim H. Tan

CHAPTER 1

SOILS AND THE ENVIRONMENT

1.1 THE BIRTH OF ENVIRONMENTAL SOIL SCIENCE

The idea finds its origin during the period of increasing awareness and public concerns about deteriorating environmental quality of Mother Earth, facing the debilitating effect of acid rains and global warming during the early 1970 and 1980s. In the melee to add the term environmental to almost anything in science, soil science was no exception. Fearful of losing its momentum in the already decreasing students' interest in soil science, environmental soil science was born at that time. For many universities, it was a tool to enhance their declining enrollment in soil science, and therefore a variety of interpretations are available for the meaning of environmental soil science. To some it is the science of human interactions with the pedo-, bio-, litho-, hydro-, and atmosphere, whereas to others it is the science of mixing-linking soil science with physics, life and environmental sciences, as exemplified by the public statements of enrollments at the Department of Crop and Soil Sciences, Pennsylvania State University, and the Department of Plant and Soil Sciences of the University of Delaware (Fritton, 2007; Sparks, 2004). A better formulated concept so far is perhaps from the College of Agricultural, Human, and Natural Resource Sciences of Washington State University that defines its environmental soil science course as the basic principles of soils in their role as the components of agricultural and natural ecosystems in affecting the quality of the environment (William, 2007). These are just a few examples, and many other variations available are not mentioned here for fear of becoming long-winded, since they all are practically bringing the same message. Some of them are narrow in scope and others are using only the term environmental science for emphasizing soil and land use problems and their effects on surface and subsurface waters. In a very narrow scope, environmental soil science is often interpreted as the study of remediation of soils and waters degraded by pollution and contamination. A good example in this respect is perhaps the concept of environmental soil science at Purdue University, where it is perceived as the study on how toxic and hazardous wastes, sludges, metals, fertilizers, and pesticides may affect the environment. However, these are only just a few among the many components, which Hillel (2004) tries to sum up nicely in his book. All these components together with still many others, as will be pointed out below, will make up the science that we call today environmental soil science. The term e.soil science, proposed by Pennsylvania State University (Fritton, 2007), is perhaps somewhat out of context, since "e" is commonly used today for "electronic," such as in e-mail, e-book, etc.

1.2 CONCEPT OF ENVIRONMENTAL SCIENCE

Now we know how environmental soil science is perceived by the scientific society, let us examine the term environmental soil science more closely and see whether the different concepts above will agree with the results of our analysis. The term is essentially coined from environmental science and soil science. The dictionary defines environmental science as "the complex of climatic, edaphic and biotic factors that act upon an organism or ecological community and ultimately determine its form and survival" (Merriam Co., 1973). In our context, the ecological community, stated in the definition, can be perceived as the soil with the vegetation cover, whereas the edaphic factor is the factor edaphology or the study of soils for crop production. The biotic factor refers to a system of living organisms. From the above, it appears that the soil is not only a component of the environment but at the same time also influenced by the environment. Therefore, by combining together environmental science and soil science, it is perhaps justifiable to provide an addendum to the definition of environmental science, transforming it into environmental soil science, as follows: “the complex of climatic, edaphic and biotic factors acting upon the soils ecosystem.” In other words, it is still soil science, but flavored by environmental issues, isn’t it? Interesting to note that ecology, as pointed out above, is considered a different field of science, though closely related to environmental science. By definition, it is the “study of organisms in close relations to the environment.” People studying effects of contaminants on populations, be it human or wildlife, and also addressing biodiversity, endangered species and issues of habitats, are often called ecologists. These topics, of course, overlap with those in environmental science, but the latter is usually of broader scope and may also include oceanography with, for example, issues on importance of coral reefs as habitats for marine life, concerns on over-fishing, pollution by offshore drilling for fossil fuel and accidental oil spills by giant tanker ships. It also deals with atmospheric science, including meteorology, issues on greenhouse gasses and other airborne pollutants. People who try to understand and make the world realize about all the above and the dangers of global warming, the welfare of our public lands, and the importance of the world’s rain forest that stretches across the equator through Asia, Africa, and Latin America are called environmentalists. They are not called ecologists. This rain forest, as part of the vegetation factor, is also considered as an ecosystem. It has given shelter to many indigenous people and lost tribes, and is also the home for thousands of plant, insect and animal species. The recent problems we have with the so-called El Niño or ENSO for El Niño Southern Oscillation, creating havoc with the weather along the Atlantic and Gulf Coast of the United States, and the pollution of air caused by burning tons of fossil fuel, especially in our huge metropolitan cities, are also hot issues of environmentalists. This is then a brief and simplified picture of environmental science, which is in fact a very complex, rather ill-defined, entity of science.

1.3 CONCEPT OF ECOLOGY

Ecology, on the other hand, is in fact an older, more established science than environmental science. The name ecology was introduced first in 1866 by Ernst Haeckel, a German botanist, but was formulated properly into a science by Eugenius Warming, a Danish botanist, who is often considered as the founder of ecology (Warming, 1909; Goodland, 1975). The term, spelled as ökologie in German, is coined from the Greek oikos = household and logos = logic. It is the science of living organisms and their interrelationships with the environment. The organisms can be at the molecular, cellular or species level to levels of the ecosystems or biosphere. At the ecosystem level, they are often recognized as (1) producers, such as organisms capable of photosynthesis or chemosynthesis, (2) consumers, organisms such as herbivorous, carnivorous, and omnivorous animals, and (3) decomposers, such as bacteria and fungi, needed for the decomposition and mineralization of organic residues, processes of utmost importance for nutrient cycling in soils. The question is then how an ecosystem can be defined. According to the dictionary, an ecosystem is a system in which the organisms are interacting with the various factors of the environment in which they are living (Merriam Co., 1973). It can apply to a system the size of dead leaf, a pond, a soil unit or to a system the size of a rain forest or even bigger. The organisms in the ecosystem are connected to each other by the food chain. The group, called producers above, is converting solar energy by photosynthesis into carbohydrates and other types of photosynthates, which are accumulated in the various plant parts. The latter are consumed by the herbivores, who in turn become food for the carnivores. In the process, organic matter is incorporated into the body of the living organisms, who eventually will die and become available to the decomposers and mineralizers. Through biochemical cycles, such as the carbon, nitrogen and nutrient cycles, the organic and inorganic nutrients are then returned to the system. The disappearance of one species of organisms will usually result in disrupting the food chain, affecting further the survival of other organisms in the ecosystem. This is then in brief a simplified picture of ecology and the ecosystems in nature.

As can be noticed from the discussions above on environmental science and ecology, several, if not many, overlaps exist between the two sciences. For instance, are global warming and destruction of the ozone layer in the stratosphere issues belonging to environmental science or ecology? By examining the two definitions, it may appear that these are issues skewed to the domain of environmental science. Both sciences are also claiming jurisdictions over deforestation and desertification. In this case, the problems are more related to forest and desert ecosystems. Another tricky issue is the disastrous oil spill in 1989 by the Exxon Valdez tanker destroying the coast of Alaska and its wildlife. It seems that this is the domain of environmental science, but, on the other hand, ecology has also a valid claim. It depends perhaps on where the emphasis is laid, on the overall effect on the landscape or on the destruction of local ecosystems, the readers be the judges.

Since the purpose of this book is to discuss environmental soil science, for completeness, it is deemed necessary to give below also the concept of soils, after which the components of the soil ecosystem will be discussed. The impact of environmental factors on the soil ecosystem and alternative methods of land use, crop production and remediation of polluted environments are included at the end, as outlined in detail in the preface. Such an outline corresponds then closely to the definition of environmental soil science as formulated earlier. This book is not on soils in the environment, which, in essence, is basic soils that has been published by many authors in the past (Brady, 1990; Foth, 1990; Miller and Gardiner, 1998; Hillel, 2004). The soils are, in fact, located in the environment.

1.4 DEFINITION AND CONCEPT OF SOILS

Soil is a term understood by almost everyone, yet the meaning of this term may vary between different people, and soil can be defined in many ways (Brady, 1990; Foth, 1990). The farmer, engineer, chemist, geologist, and layman bring different viewpoints or perspectives to their concepts of soil. Environmentalists may even define soil differently than soil scientists. With the introduction of the pedological concept in soil science during the beginning of the 20th century, these differences have diminished considerably. Yet, even now, a commonly accepted definition of soil is still missing, notwithstanding the fact that most people agree that soils are products of the environment. Of the several definitions of soils that can be found in the literature, the definitions of Kellogg (1941) and the United States Department of Agriculture, Soil Survey Staff (1951; 2006b) perhaps most closely reflect the relationship of soils to the environment. According to these definitions: "Soils are considered natural bodies, covering parts of the earth surface that support plant growth, and that have properties due to the integrated effect of climate and organisms acting upon the parent material, as conditioned by relief, over a period of time." Several soil scientists, notably Buol et al. (1973), may object to this definition, but the definition does show the dependency of soils on several environmental factors. It may be noted that this definition does not recognize moon or lunar material as soil. Lunar material, which is not affected by organisms, is excluded from the definition, but it may qualify as a parent material or regolith (Ming and Henninger, 1989).

The above definition of soils agrees closely with an earlier formulation of soils. In his famous book, Factors of Soil Formation, Hans Jenny (1940) reported that soils could be characterized by the formula:

$$S = f\,(cl, o, p, r, t)$$

In this equation, S = soils, f = function, cl = climate, o = organisms, p = parent material, r = relief, and t = time.

Climate, organisms, parent material, relief, and time are considered the five major factors in soil formation. According to such a formulation, these environmental factors are the main variables that determine the state of the soil. In other words, soils are formed by the combined effect of the factors. The nature of soils can be changed only when the variables, cl, o, p, r, and t, change individually or in combination. In such a formula the factor S (soil) cannot be changed to modify such variables as climate, organisms, or parent material, which is in practice true to a certain extent. For example, a change in the nature of soils will not result in a change of the parent material. However, it may apply to the variable o, organisms. Under certain cases, a deterioration of soil conditions brings about drastic changes in vegetation and/or other organisms. It is more difficult, however, to show a clear-cut relationship with the variable cl, climate, but a change in the nature of soils may sometimes result in a change in climate. A good illustration of this type of change is the formation of desert and savannah type of climates due to deforestation and the consequent degradation of soils in tropical regions of Africa.

1.5 PEDOLOGIC CONCEPT OF SOILS

Soil science is sometimes divided into edaphology, the science of soils as media for plant production, and pedology, the science of soils as biochemically synthesized bodies in nature (Brady, 1990). The concepts of these two branches in soil science are embraced by the preceding definitions of soils. The difference between them is only in their application or use. Edaphology applies soil science mainly in crop production, as indicated earlier, whereas pedology studies the characterization, genesis, morphology and taxonomy of soils. Nevertheless, the basic concept of soils in pedology still constitutes the key for perception of soils in edaphology.

1.5.1 Soil Profile and Pedon

According to the pedologic concept, the soil is a three-dimensional body in nature, showing length, width, and depth. An individual soil body, briefly called soil, occurs in the landscape side by side with other soils like the pieces of a jigsaw puzzle. Each soil is considered an independent body with a unique morphology as reflected by a soil profile. The soil profile is defined by specific series of layers of soils, called soil horizons, from the surface down to the unaltered parent material. It is formed by the integrated effect of soil formation factors. Measured by area, the soil can be small in size or a few hectares in extent. It is common and more convenient in analysis to deal with a small representative part of the soil, and the smallest representative

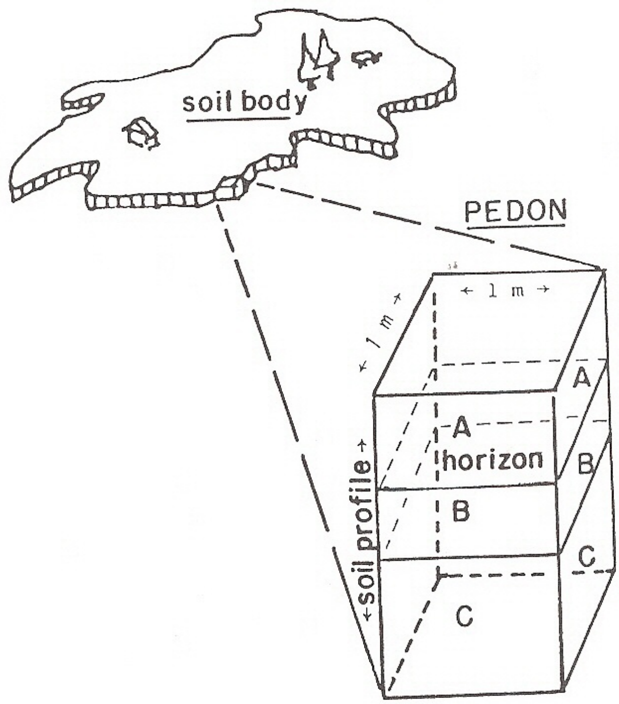

Figure 1.1 The relationship of a pedon to a soil body.

unit of a soil body is called a pedon (Figure 1.1). A pedon has three dimensions and is comparable in some ways to the unit cell of a crystal. One soil body consists of contiguous similar pedons. This group of contiguous similar pedons in one soil body is called a polypedon. The polypedon or soil body is bordered on all sides by other pedons with different characteristics. The size of a pedon is measured by its surface area, with the smallest measuring 1 m^2. A pedon is bordered on its sides by vertical sections of soils, called the soil profiles (Figure 1.2). Each soil profile, extending from the surface down to the parent material, is composed of several soil horizons. The soil profile

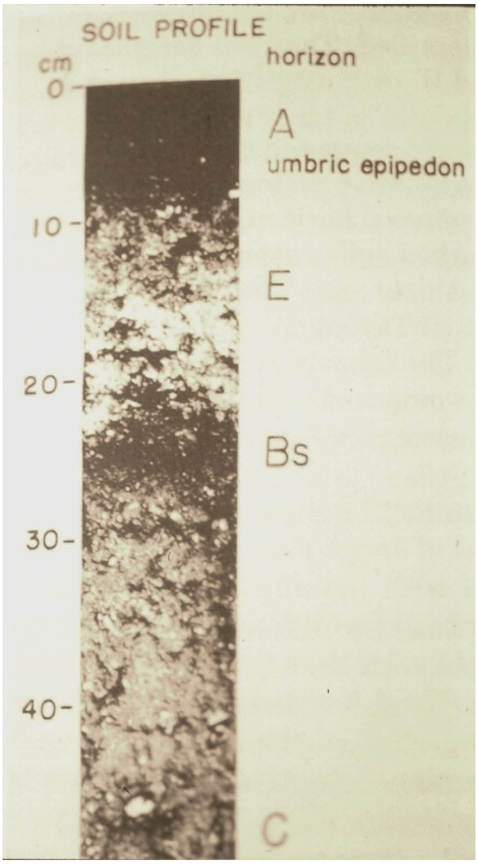

Figure 1.2 A soil profile of a sandy, mixed, frigid Entic Haplorthod (spodosol), showing the effect of the environment in its formation. The soil profile is characterized by an A horizon, rich in humus, underlaid by an E horizon, which is bleached in color because of eluviation of humus and iron. The Bs horizon is dark in color because of illuviated humus and iron. The C horizon is the parent material.

characterizes the pedon; hence, it identifies the soil. The horizons tell much about the soil properties. They provide information on color, texture, structure, permeability, drainage, biological activity, and other attributes of importance in soil characteristics, formation, fertility, crop production, and engineering. Six main groups of horizons, called master horizons, have been identified. They are designated by the symbols O, A, E, B, C, and R, respectively.

1.5.2 Master Horizons and Diagnostic Epipedons

1. O horizons are organic deposits composed of dead, partially decomposed and undecomposed vegetative material. This horizon, lying on the surface above the mineral horizon, is in many cases very thin, and only in undisturbed soils covered by vegetation can it assume considerable thickness. The name for this horizon, assigned by the U.S. Soil Taxonomy, is histic (Gr. histos, tissue) epipedon (Soil Survey Staff, 2006a,b). The O horizon can be subdivided into O_i (non- to slightly decomposed), O_e (intermediately decomposed), and O_a (highly decomposed) horizons.

2. A horizons are the topmost mineral horizons lying below the O horizon. They are composed of large amounts of inorganic material, e.g., sand, silt, and clay, intimately associated with humified organic matter. Because of its organic matter content, the A horizon is usually darker in color than the horizons below. In the absence of an O horizon, the A horizon is frequently the surface horizon. When the properties of the A horizon result from cultivation or related human activities, the horizon is designated by the symbol Ap (p = plow).

In the U.S. Soil Taxonomy, a number of A horizons are considered diagnostic for classifying soils. They are called diagnostic epipedons, from the Greek words epi = over and pedon = soil. According to the Keys to Soil Taxonomy (Soil Survey Staff, 2006b), the epipedon is not a synonym for the A horizon because it may include part or the entire illuvial B horizon if the darkening by organic matter extends from the surface into or through the B horizon. Seven major diagnostic epipedons are of importance in soils of the United States. The first one is the mollic epipedon, a thick, dark-colored A horizon, which is rich in organic matter, and has a base saturation >50% and a strong structure. Umbric epipedon is the second epipedon, and is similar to a mollic, except for the presence of a base saturation that is lower than 50%. The third is the ochric epipedon, a light colored A horizon, which is low in organic matter content and may be hard and massive when dry. The fourth epipedon, histic epipedon, has been defined earlier as a surface horizon (above the A horizon) rich in organic matter. This epipedon may be wet during some part of the year. The fifth diagnostic epipedon, plaggen epipedon, of importance in Western Europe, is a human-made surface layer, more than 50 cm thick, that has been formed by long, continued manuring. The sixth epipedon, anthropic epipedon, is an ill-defined epipedon, and is said to conform to all requirements of the mollic epipedon except (1) the limits on acid-soluble P_2O_5, with or without the base saturation, or (2) the length of the period during which it has available moisture. Additional data on anthropic epipedons from several parts of the world are expected to generate improvements in the definition (Soil Survey Staff, 1996). A seventh epipedon, melanic epipedon (Gr. melas-anos, black), has recently been added to meet the requirements of andisols. It is defined as a thick black horizon at or near the surface, containing high amounts of organic matter, usually associated with short-range-order minerals or aluminum-humus complexes. The intense black color is believed to be caused by the presence of type A humic acid, formed mainly by the decomposition of roots from graminaceous vegetation. This type of humic acid can be distinguished from that developed under a forest vegetation (type P) by using the melanic index. A melanic index of <1.70 is indicative for the presence of type A humic acid (Tan, 1998a; 2003a).

3. E horizons are mineral horizons located under the A horizon. They are the zones of maximum leaching or eluviation — zones of removal of soil constituents, e.g., clay, humus, Fe and Al compounds. E horizons are white, pale, light or bleached in color. White E horizons are called albic horizons in soil taxonomy. A horizons grading into E horizons are transitional horizons and carry the symbols AE. Similarly, E horizons grading into underlying B horizons are designated by the symbols EB.

4. B horizons are located underneath E horizons. In the absence of an E horizon, the A horizon lies directly above the B horizon. B horizons, frequently referred to as subsoil, are the zones of illuviation (accumulation) of soil materials removed from A and E horizons. Illuvial concentrations of silicate clays, Fe, Al, or humus alone or in

combination may be present. B horizons grading into underlying C horizons are transitional horizons and carry the symbols BC.

Many of the B horizons are also diagnostic for characterizing soils. They are called diagnostic subsurface horizons. Some of the most important diagnostic subsurface horizons are the (1) argillic horizon (Bt), a B horizon enriched with silicate clays; (2) spodic horizon (Bh or Bhs), a horizon enriched with humus and Fe and Al oxides; (3) cambic horizon (Bw), a young B horizon, recently changed by physical and chemical reactions; and (4) oxic horizon, a highly weathered B horizon, containing Fe, Al oxides and 1:1 lattice type (kaolinitic) clays. A fifth subsurface horizon, kandic horizon, should be added to meet the requirements of low activity clay soils. It is in essence a Bt horizon with a CEC $\leq$ 16 cmol/kg clay (by 1N NH_4OAc pH 7) and an ECEC $\leq$ 12 cmol/kg clay (sum of bases extracted with 1N NH_4OAc pH 7 plus 1N KCL extractable Al). For a complete list of these diagnostic horizons and their characteristics reference is made to Keys to Soil Taxonomy (Soil Survey Staff, 1992, 1996, 2006b).

5. C horizons are located under the B horizons and are considered parent materials of soils. They are mixtures of weathered rocks and minerals and are largely unaffected by soil formation processes. These materials may rest upon the rocks from which they have been formed, or they may lie upon an unrelated geologic formation.

6. R horizons are the underlying solid rock formation with little evidence of weathering. The bedrock is sometimes called an R layer.

Soils may differ from one another in the nature and arrangement of horizons. The kind and sequence of horizons determine the soil orders and soil series in Soil Taxonomy. A farm may be composed of several soil series, each of which responds differently to soil cultivation. By studying soil profile characteristics, these differences can be identified and inferences made as to the proper management practice. In general, road banks or preserved soil sections, called soil monoliths, can be used to examine soil profiles. One can also dig a pit, exposing a vertical section of the pedon, for this purpose.

1.6 SOIL ORDERS

As discussed in the preceding pages, soil profiles are also important in identifying soil orders. The order is the highest (broadest) category in the U.S. Soil Taxonomy system (Soil Survey Staff, 2006a). This classification system divides orders into suborders, suborders into great groups, great groups into subgroups, subgroups into families, families into series, and the latter into soil types. The system also recognizes soil phases, but these are mapping units and not taxonomic units. The orders, suborders, and great groups are considered the higher categories, whereas the families, series, and types are the lower categories in the U.S. soil classification system.

Many other soil classification systems are available in the world. Some are applicable only to soils of that country, whereas others try to attempt to cover soils worldwide. Such a system is for example the soil classification system of the Food and Agricultural Organization (FAO) of the United Nations. This system does not group soils into higher or lower categories, but recognizes only individual taxa. These soil taxa are the basis for the FAO soils world map, showing a distribution of about 5000 soil units. Each soil taxon in the FAO system can be correlated with a soil order or suborder, but sometimes it relates more closely to the great group category of the U.S. Soil Taxonomy (Table 1.1). This will be addressed in some detail in the following subsections on the individual soil orders below. Lately, the FAO system has tried to integrate the U.S. concept of diagnostic horizons in its system, perhaps because many of their soil scientists are U.S. trained scientists.

Twelve groups of soil orders are now recognized in the US Soil Taxonomy (Table 1.1). Placement in a particular soil order is based on differences in soil formation processes, as reflected in the nature and sequence of soil horizons. Each soil order contains soil profiles with similar or almost similar properties. The names of these orders are derived from Latin or Greek terms and have a common suffix: sol, for soil. The connecting vowel "o" is supposed to be used with Greek formative elements. Of the twelve orders only spodosols and histosols, both derived from the Greek spodos and histos, respectively, carry the connecting vowel "o." The names of the remaining orders contain the connecting vowel "i." The latter is to be restricted for use with Latin

Table 1.1 Soil Orders and FAO Equivalent Names

Order names	Derivation/ meaning	Formative elements[1] carried to suborders	FAO equiv.
Entisols	Recent, young	ent	Lithosols
Gelisols	Gk. gelid = very cold, pergelic soil temp. regime	el	Gelosols
Inceptisols	L. inceptum = beginning	ept	Cambisols
Mollisols	L. mollis, soft, friable	ol	Chernozem
Spodosols	Gk. spodos, woodash	od	Podzols
Alfisols	Al = aluminum, fi for Fe = iron	alf	Luvisols
Ultisols	L. ultimus, ultimate weathering	ult	Acrisols
Oxisols	oxidation, highly oxidized	ox	Ferralsols
Aridisols	L. aridus	id	Xerosols
Vertisols	L. verto, turn, invert	ert	Vertisols
Andisols	from Andosols, Japanese an = black, do = soil	and	Andosols
Histosols	Gk. histos, tissue	ist	Histosols

[1]Formative elements are abbreviations from order names, and are used as suffixes in suborder names, e.g., psamm<u>ent</u>, aqu<u>ept</u>, ust<u>ol</u>, hum<u>od</u>, etc.

formative elements, such as in inceptisols, mollisols, ultisols, aridisols, and vertisols. However, entisols, alfisols, oxisols, an disols, and especially gelisols, all carrying the connecting vowel "i," are not derived at all from Latin terms. The name gelisols was coined even from the Greek term gelid, hence should be properly called gelosols, as the name given for these kind of soils by the FAO system. Apparently, the nomenclature in the U.S. Soil Taxonomy has been developed more on the basis of being consistent rather than following the rules. If being consistent was the objective in the creation of the names of the soil orders, then the use of the names spodisols and histisols would serve the purpose better.

1.6.1 Entisols

Entisols are young and shallow soils, and hence are characterized by A/C or A/R profiles. They are immature soils and have profiles in which B horizons have not yet developed. The soils do not have many horizons for various reasons, e.g., time of formation is too short, occurrence on steep slopes, actively eroding slopes, receiving frequent deposits from flooding, etc. Environmental factors not conducive for formation of soil horizons, such as the frigid climate in the permafrost areas of the arctic region, are other compelling factors. Entisols may vary from deep sand or river sediments of stratified clay beds to dry, arid lake bottoms and recent volcanic ash deposits. The soils with A/C profiles are the entisols over sand deposits. They are placed at the suborder level as psamments, which are equivalent to the FAO soil taxa regosols. In the United States, entisols occupy approximately 12.5% of the country. They occur extensively in the coastal plains of south Georgia, Florida, and Alabama. In contrast, entisols with A/R profiles are entisols over hard rocks, called orthents at the suborder level. The FAO soil equivalent name is lithosols. These entisols are more common in the Rocky Mountains and other regions where rock formations can be found, such as the Blue Ridge Mountains and the Piedmont Plateau. Entisols, as a whole, are estimated to cover 16% of the earth's surface and only inceptisols are believed to occur more widely in the world.

The fertility of entisols varies considerably depending on the conditions from very low to very high. For instance, the alluvial floodplains of the Mississippi River are composed of fertile entisols, whereas the coastal plains of the United States have entisols with low fertility because of their high contents of quartz sand. The presence of water for irrigation and periodic flooding, contributing to a continuous buildup of nutrient supply for crop production, are some of the reasons for the formation of fertile entisols in the Mississippi River deltas and floodplains. Similarly, the entisols alongside the Ganges and Indus rivers in India, Bangladesh, and Pakistan, and the Mehkong, Yangtze, and Hoang Ho rivers in Southeast Asia and China, have proved to be rich soils where human population can thrive by growing sufficient amounts of crops.

1.6.2 Gelisols

This is the newest soil order added to the U.S. Soil Taxonomy to cover soils in the tundra region of Alaska developed under the influence of a frigid and pergelic soil temperature regime. Today, gelisols have been reported to occur also in Siberia, Tibet, Northern Scandinavia, Greenland, Antarctica and some parts of the Andes. The FAO-UN and Canadian soil classification systems have already recognized such soils under the taxa gelosols and cryosols, respectively. The name gelisols is allegedly derived from the Greek term gelid, meaning very cold (see Miller and Gardner, 1998, Chapter 7, page 222, Detail 7-2, Gelisols — A Twelfth Order?). The choice to name these soils gelisols would then violate the rules set up by the U.S. Soil Taxonomy itself. As discussed earlier, Greek terms were supposed to be connected with the vowel "o," whereas Latin terms with the vowel "i." However, recently the USDA-National Resources Conservation Service indicates that the name comes from the Latin term gelare = to freeze (Soil Survey Staff, 2006b) that would then justify using the name gelisols. Because of the confusion above, the following version of the origin of "geli"-sol is added here. The term gelid is apparently an adjective, composed of gel and id. The suffix, id, can originate from both Greek and Latin words. For example, it can be borrowed from the Greek perseid or attalid (Greek ides-id) or Latin terms, e.g., fetid, pallid, arachnid (Latin idus). However, gel, a noun, is from the Latin gelû (or gelatus, but not gelare) meaning frozen, cold and ice. In chemistry, a gel is a network of colloids in a liquid, and can be both inorganic and organic in nature. Not much is known yet about gelisols and the information currently available indicates that the USDA-NRCS central concept is that they are soils that have permafrost within 100 cm of the soil surface and/or have gelic materials within 100 cm of the soil surface and/or have permafrost within 200 cm. Gelic materials are mineral or organic materials that have evidence of cryoturbation (frost churning) and/or ice segregation in the active layer (seasonal thaw layer) and/or the upper part of the permafrost. As can be noticed, the long sentences, often connected several times with "and/or," are the trademark of the U.S. Soil Taxonomy, which makes it very confusing reading them. Generally, gelisols are then shallow soils with dark organic surface layers (A horizons) on top of thin mineral layers, underlaid by permafrost. The organic layer is presumably composed of tundra peat, derived from moss, lichens, and/or other tundra vegetation. The permafrost is commonly within the 100 cm depth. Though in general the soils have massive soil structures due to freeze–thaw pressures and desiccation processes, granular, platy and vesicular structures are often present in the surface horizons. Because of mixing due to cryoturbation, the soil profile consists of irregular broken horizons, in which organic matter and stones are incorporated (Miller and Gardiner, 1998). The dominant suborders are histels, orthels and turbels.

Land use of gelisols is limited by the presence of the permafrost, making them very susceptible to human operations. In Alaska the soils are mainly used for wildlife reserve or oil drilling as conducted by British Petroleum in the Prudhoe Bay area. However, building heavy structures on top of gelisols may result in thawing of the frozen earth, causing the building or oil platform to collapse or subside. To prevent melting of the permafrost, the base of the infrastructure is often built on stilts, drilled in a very thick gravel bed. A possible more beneficial use of gelisols is perhaps reindeer farming, which may not only increase meat production of the world, but does the least damage on the soil ecosystem. Reindeer meat is not known to have religion-based restrictions, such as do pork and beef. It appears to be safe for consumption by Muslims, Jewish groups, as well as Hindi people. The best option is still to maintain the soils as wildlife refuge.

1.6.3 Inceptisols

Inceptisols mark the beginning of a mature soil and are characterized by A/Bw/C profiles. The B horizons are in the stage of formation and are called cambic horizons (Bw). As such, these soils are in a more advanced stage of development than are entisols. Whether these kinds of soils can be equated with the FAO soil taxa cambisols is in the author's opinion debatable. Though the name cambisols has also been coined from the Latin term cambiare = change, the FAO's interpretation is that of a far more mature soil than would be reflected by the U.S. inceptisols.

Large areas of inceptisols are found in the United States in the Blue Ridge Mountains and the Piedmont Plateau. In some of the states, they occur in large acreages, for example in Pennsylvania with an estimated 600,000 ha, located mostly in the ridge and valley regions of the Allegheny Mountains, High Plateau and Pittsburgh Plateau. Inceptisols are reported to be also widely distributed in the world and rank third in area of the soil orders. Such information raises some questions, because many soils are erroneously counted as inceptisols, e.g., lithosols by Brady (1984) and paddy soils by Miller and Gardiner (1998). Waterlogging, required for growing paddy rice, has provided redox conditions for the development of soil horizons, characteristic for paddy soils (Tan, 1968, 1998), completely different to properties of inceptisols. Globally, inceptisols are in fact less known and less understood, especially in the tropics, where the warm and humid climate favors the process of drastic weathering in soils, which is not conducive to formation of a cambic horizon. An exception to this is the development of Bw horizons in andosols and brown forest soils in the upland regions of the humid tropics in Indonesia (Tan, 2008). The natural fertility of inceptisols also varies widely. Inceptisols in New York and Pennsylvania are low in fertility, whereas those in the U.S. Pacific Northwest are quite fertile (Brady, 1990). In Pennsylvania, the soils are used for pasture and hay production or for woodland, consisting mainly of mixed stands of northern hardwoods, e.g., oak, hickory, maple and black cherry. In the upland regions ($\geq$ 600 m above sea level) of Indonesia, the inceptisols are considered very fertile soils supporting a variety of agronomic and horticultural crops. They are the soils for growing tropical as well as cool climate vegetables (Tan, 2008).

1.6.4 Mollisols

Mollisols are mature soils characterized by A/Bk/C profiles. The A horizon is typically a mollic epipedon, whereas the B horizon is usually a calcic B horizon, which carries the symbols Bk (k for accumulation of calcium carbonates). Mollisols develop by a soil formation process, called calcification, under semihumid climates and tall grass vegetation. They are important grassland soils and occur extensively in the Great Plains west of the Mississippi River. For example, it is perhaps the most important soils in Illinois and Kansas, where acreages as large as 607.000 ha and 1.6 million ha, respectively, have been reported (Reed and Sparks, 2000) Large areas of mollisols are also found in the great plains of Canada, the steppes of Mongolia, the pampas of Argentina and in the Ukraine, where they are called chernozems, from the Russian terms chern = black, and zemlja =

earth. It was Dokuchaiev who proposed this name for the first time for the black fertile soils in the steppe of the Ukraine. His studies, indicating the intimate influence of environmental factors on the development of the mollisol profile, started the pedologic concept in soil science. The name chernozem has been adopted as the official name by the FAO's soil classification system. Mollisols in the dryer region of the Great Plains in the United States are called ustolls at the suborder level, which perhaps can be equated with the FAO's soil taxa kastanozems (L. castaneo = chestnut, and Russian zemlja = earth).

Mollisols are very fertile and are considered to be among the world's most important agricultural soils. The environmental factors affecting formation of these soils, especially the tall grass vegetation and the semihumid condition, insure an annual turnover of abundant amounts of organic matter and a small degree of leaching. Hence, among the twelve soil orders, mollisols have the highest organic matter content, consequently also the highest nitrogen content. Only the andisols will match them in soil organic matter content. These characteristics together with a base saturation of ≥ 50% (mostly occupied by Ca) give them the best chemical properties a soil can ask for. The physical properties, including a strong structure and friable consistence, are also considered excellent. In Illinois, the soils are considered prime farmlands for growing corn and soybean, whereas in Kansas they are used for wheat, grain sorghum and silage production. For decades, these soils have been highly productive for growing corn and wheat and have contributed to the development of the cornbelt in the United States, and the wheatbelts in Canada and Russia.

1.6.5 Spodosols

Spodosols are mature soils with profiles characterized by a sequence of A/E/Bh or Bhs/C horizons. They are formed by a soil formation process called podzolization, typically in cool humid regions under a coniferous or mixed conifer-hardwood vegetation. Exceptions to the above may be present, like the occurrence of spodosols in Florida and in the plains of the Amazon River in Brazil. Under the influence of acid leaching, Al and Fe compounds and/or humus are translocated to the B horizon, creating a spodic B horizon. When this

B horizon is enriched mainly with humus, a Bh horizon is formed. This type of spodosol is called a humod (hum = humus, and od = formative elements from spodosol) in the U.S. Soil Taxonomy. On the other hand, when a mixture of Al and Fe compounds and humus is accumulated in the B horizon, a Bhs horizon is formed. Under certain conditions, Fe is the dominant illuvial constituent, and in this case a Bs horizon is formed. A spodosol with a Bs horizon is called a ferrod in the U.S. Soil Taxonomy. The FAO equivalent taxon for spodosols is podzols (Russian pod = under, and zola = white layer of ash).

Large areas of spodosols are found in Florida, the northeastern part of the United States, Canada, and in northern Europe, Russia, and Siberia. In Florida, the soils are called aquods, because of the influence of fluctuating ground water levels in their formation. With an estimated acreage of 600,000 ha, it is the most extensive flatwood soil in Florida (Reed and Sparks, 2000). In Europe, the soils are called podzols and in Russia they are found underneath the Taiga forest that stretches from east to western Siberia towards the sea of Okhotsk. The soils are very acidic in reaction, and adequate fertilization and liming are required for crop production. In the northern part of the United States they are used for pastures in dairy farming, whereas in the south blueberries are grown without liming (Miller and Gardiner, 1998). Limited spodosol areas in northern Maine are used successfully for potato production (Brady, 1990). The acid condition appears to control the potato-scab disease. In Michigan, with a reported 300,000 ha of spodosols, the soils are used for growing hardwood timber, e.g., sugar maple and yellow birch, and specialty crops, such as Christmas trees, strawberries and potatoes (Reed and Sparks, 2000).

1.6.6 Alfisols

Alfisols are mature soils with profiles characterized by a sequence of A/E/Bt/C/ horizons. They are formed by a combination of podzolization and laterization processes in cool to warm-temperate humid regions, usually under hardwood forest. These soils are affected by a more drastic leaching process than mollisols and are, therefore, in a more advanced stage of profile development. The surface soil varies in color from gray-brown to reddish brown. Alfisols with gray-brown surfaces were called in the past gray-brown podzolic soils. This name is still used in Canada, Australia, and parts of Europe. Because of the eluviation process, the B horizon is enriched with illuvial clay and is called an argillic horizon (Bt). This is perhaps one reason why the soils are called luvisols (L. luo = to wash, meaning illuvial clay) in the FAO soil classification system. Alfisols are highly productive soils with a percentage base saturation in the subsoil of >35%, which ranks them medium in fertility. However, sometimes these soils are considered unfavorable for crop production, because of the presence of an illuvial clay layer. When the surface horizon is eroded, exposing the argillic horizon to become the surface soil, this clay layer appears to inhibit plant growth. In Arkansas, with 81,000 ha of alfisols, the soils are used for rice production, because of the slow permeability caused by the argillic horizon. However, in Kentucky with 202,000 ha of alfisols, the soils are considered productive farmlands for corn, soybean, small grain and hay crops Liming is frequently required to neutralize the moderately acidic reaction of the surface soil in order to get the best results in crop production.

1.6.7 Ultisols

Ultisols are mature soils with A/E/Bt/C profiles. They are formed by a combination of laterization and podzolization, with the emphasis on laterization, in warm humid temperate regions to the humid tropics, where leaching processes are very pronounced. Under these conditions, the soils are highly weathered, and the A horizons may accumulate varying amounts of Fe oxides, which impart their yellow to red colors. Enrichment of the B horizon with illuvial clay has also caused the formation of argillic horizons (Bt). Because of the drastic leaching process, the soils exhibit a very low base status, with a percentage base saturation in the subsoil amounting to <35%.

Ultisols occur extensively in the southern region of the continental United States, Hawaii, and Puerto Rico, where hardwood mixed with pines is the common natural vegetation cover. In other parts of the world, e.g., northern Australia, these soils are called yellow podzolic, redyellow podzolic, or red podzolic soils according to the color of the surface soil. Because of their acidic condition and low base status, these soils have a very low fertility. They also exhibit a low degree of stable aggregation and are therefore sensitive to erosion. Nevertheless, with adequate liming, the addition of organic matter, fertilizer application, and proper management, these soils can become quite productive, as is the case in the southern region of the United States. For example, the Cecil soil, one of the well-known series of ultisols of the Southern Piedmont region, responds quite well to management practices. The soil is reported to also contain higher amounts of K than other ultisol series, because of its mica content. Extending from Virginia south to Georgia and Alabama, the soil is often used for growing southern pine needed for the pulp industry. More specifically in Georgia is located the Tifton soil, another important series of the ultisols. Covering an estimated 810,000 ha in south Georgia, the soils are considered highly productive farmlands. The humid climate, providing sufficient amounts of rain, and the long periods of frost-free condition are favorable for crop production. However, pests and diseases may become more serious because of the humid conditions. Cotton, peanuts, soybean, corn, and sweet potatoes as well as pine for timber and pulpwood production are today the most common crops.

1.6.8 Oxisols

Oxisols are mature soils with A/B/C profiles. Formed by a laterization process in warm humid and tropical regions, they are typically highly weathered, even more than the ultisols. The B horizons of oxisols are oxic horizons, defined earlier as subsurface horizons containing large amounts of hydrous-oxide clays or sesquioxides and 1:1 layer (kaolinitic) types of clays. The oxic horizon is sometimes also called oxic endopedon by some soil scientists (Miller and Gardiner, 1998). Plinthite can be present in the subsoil of many oxisols. Because the electrical charges of the clays in oxisols are highly variable, the soils are sometimes referred to as soils with variable charges (Theng, 1980; Tan, 2008). Many alfisols and ultisols are frequently included in this group of soils. Large areas of oxisols occur in Central and South America, and in Africa, Southeast Asia, and Australia. They are highly leached; therefore, they are acidic in reaction and low in bases. Nevertheless, the potential of many of these soils for agricultural production is far in excess of that currently realized, as has been demonstrated in central Africa and Brazil (Brady, 1990). Although they have very high clay contents, these soils have stable granular structures and are frequently nonsticky, loose and friable. Often they can be cultivated even under heavy tropical downpours. However, depending on the iron content, some oxisols can be converted into laterites, in which the formation of iron pans may inhibit the growth of plants. Most of the oxisols usually occur under a tropical rain forest, where the fertility of the surface soil is maintained by a process called nutrient cycling. When this native vegetation cover is removed by burning, as is the case in shifting cultivation, this cycle is destroyed and nutrients from the ash may only last for a year or two. The exposed soil will be affected by erosion and may gradually harden to become impossible for further cultivation. Therefore, oxisols, especially those containing plinthite, must be kept under vegetation by growing coffee, tea, rubber, or other tree crops to prevent them from drying and irreversible hardening (Tan, 2008). The use of organic mulches and ground-cover crops is recommended. Because daylight in the tropics seldom exceeds 12 hours daily through the year, crop yield is less than yields in the temperate regions where the average daylight is 14 to 15 hours daily during the growing season. According to Miller and Gardiner (1998), the oxisols are highly productive for crops yielding carbohydrates and oil, because the latter are mostly derived from air and water rather than from soil mineral nutrients. The authors also believe that the oxisols are less productive for growing crops producing protein, since these crops require large amounts of mineral nutrients, such as nitrogen and sulfur. Apparently the authors above ignore the fact that large amounts of potassium are required by crops mainly grown for producing carbohydrates. In the humid tropics, the best hevea (rubber) and oil palm plantations are also found on oxisols and ultisols (Tan, 2008).

1.6.9 Aridisols

Aridisols are mature soils with profiles characterized by a sequence of A/Bk, Bn, or Btn/C horizons. They are called xerosols (from the Greek xeros = dry areas) or yermosols (Gr. yermo = desert area) in the FAO system. Ardisols are formed in arid and semiarid regions of the world, where the long dry periods favor the accumulation of salts and other compounds in the surface and subsoil, a soil formation process called salinization, sodication, and alkalinization in the past. When the B horizon is enriched with illuvial carbonates, it is called a Bk horizon. If sodium is the illuvial soil constituent, it is called a Bn (n = natrium, European for sodium) horizon. When both clay and sodium have accumulated in the subsoil, the horizon is designated by the symbols Btn. Lime cemented hardpans, called duripans or caliche, may sometimes be present. The soils are covered by a vegetation characteristic of arid regions, composed of scattered desert shrubs, such as short grasses, creosote bush, mesquite, and sagebrush. Since aridisols also occur in cold desert regions, the vegetation here may differ significantly from that in the hot desert regions.

These soils occur in the western part of the United States, where they are sometimes called white alkali soils, when a white crust is present on the surface composed of salt crystals, and black alkali soils, when black or darker colors are present. Extensive areas of aridisols are also found in the Sahara desert of Africa, in the Gobi and Taklamakan deserts of China, and in the deserts of Turkestan, the Middle East, and Australia. In Russia, the soils are called solonchaks, which are the equivalent of white alkali soils, and solonetz, the equivalent of black alkali soils. The limiting factor for cultivation of aridisols is frequently water. In areas where irrigation can be provided, such as with the center-pivot irrigation in arid regions of the United States, the soils can be made productive. In northern Nevada, where there are 145,000 ha of aridisol, the soils are still considered to be good farmlands when irrigated for growing winter wheat and barley, alfalfa and grass for hay or pastures (Singer, 2003). Since the aridisols are generally characterized by a slightly to moderately basic reaction (pH = 7 to 8.5), micronutrient deficiencies are common. Because of the basic reaction, most of the Fe, Cu, Zn, and Mn are