PART I

Introduction to Forest Soils

CHAPTER 1
History of Forest Soil Science and Management

OVERVIEW

In this text, forest soils are considered to be soils that presently support forest cover. These soils differ in many ways from agronomic soils: they have O horizons, organic layers that cover the mineral soil; they have diverse fauna and flora that play major roles in their structure and function; they are often wet or steep, shallow to bedrock, or have a high stone content. Soil layers that occur at great depth are important to forests. The influence of soils on forests and other vegetation was known to the ancients, although our current understanding of soils did not begin to develop until the nineteenth century. The study of forest soils is as old as soil science itself. Researchers working on forest soils made many of the early discoveries that form the foundation of modern soil science.

In the broadest sense, a forest soil is any soil that has developed primarily under the influence of a forest cover. This view recognizes the unique effects of the deep rooting of trees, the role of organisms associated with forest vegetation, and the role the litter layer (forest floor, or O horizon) and the eluviation promoted by the products of its decomposition have on soil genesis. By this definition, forest soils can be considered to cover approximately one-half of the Earth's land surface area. Essentially, all soils except those of tundra, marshes, grasslands, and deserts were developed under forest cover and have acquired some distinctive properties as a result. Of course, not all of these soils support forests today. Perhaps as much as one-third of former forest soils are now devoted to agricultural, urban, or industrial use. A better definition of forest soils might be those soils that are presently influenced by a forest cover. Currently, forests of various types cover about one-third of the world's land surface.

The need for a separate study of forest soils is sometimes questioned on the assumption that a forest soil is no different from a soil supporting other tree crops, such as citrus, pecans, olives, or even a soil devoted to agronomic crops. Persons who are not well acquainted with natural ecosystems and who have failed to note even the most obvious properties of soils associated with forests generally make this assumption. Upon close observation of forests, one notices many unique properties of forest soils. The forest cover and its resultant O horizon provide a microclimate and a spectrum of organisms very different from those associated with cultivated soils or horticultural plantations. Such dynamic processes as nutrient cycling among components of the forest community and the formation of soluble organic compounds from decaying debris, with the subsequent eluviation of mineral ions and organic matter, give a distinctive character to soils developed beneath forest cover.

When European settlers arrived in what became North America, forests covered half of the land area, another two-fifths was grassland, and the remainder was desert or tundra. The eastern seaboard was almost entirely forested, and, largely as a consequence of the difficulties of clearing new land, agricultural settlement was mostly confined to the Atlantic slope until the end of the eighteenth century. Slowly, settlement began expanding

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westward, and extensive forest clearing for agriculture began in the central portion of the continent. By the middle of the nineteenth century, more than a million hectares of virgin forests had been cleared and the land converted to permanent agricultural uses.

This area of cleared forest land gradually increased until well into the twentieth century. As new and better farmlands were opened in the Midwest and West, millions of acres of former croplands were abandoned. Especially in the eastern regions, large areas of degraded farmland reverted to forests, and by 1950 forested areas had increased until they again covered nearly one-third of the total land area. The forest land base has continued to grow, and is projected to continue to grow slightly despite the relentless pressures of increasing urban and industrial development (Alig and Butler, 2004).

Few truly virgin forests exist today in populated regions of the globe. The conversion of forests to croplands and back to forests has gone through many cycles in sections of central Europe and Asia, as well as eastern North America and portions of South America. Large areas of non-forest soil now support forests, especially in Australia, New Zealand, and southern Africa. Deforestation continues at a rapid pace, particularly in the tropics. However, even there, degraded lands that were cleared of forest for agriculture are being reforested. Many European forestlands have been managed rather intensively for centuries. At the other extreme, relatively short-term shifts in land use occur in the tropics, where "swidden" agriculture or shifting cultivation, a form of crop rotation involving 1 to 3 years of cultivated crops alternating with 10 to 20 years of forest fallow, is practiced. Such practices alter many properties of the original forest soil.

In recent years, intensively managed plantation forests have been created in several countries of the world. Among these forests are several million hectares of exotic pine and eucalypt forests in the Southern Hemisphere and an even larger area of plantations employing native species in the Northern Hemisphere. The latter includes some 8 million ha of pine plantations in the coastal plains of the southeastern United States and large areas of Douglas fir plantations in the Pacific Northwest.

Because of the alteration in certain properties of forest soils as a result of intensive management, the distinction between forest soils and agronomic soils has become progressively less evident in some areas. Although some properties acquired by soil during its development persist long after the forest cover has been removed and the soil cultivated, other characteristics are drastically modified by practices associated with intensive land use. In this text, we will generally treat forest soils in the narrow sense as soils that presently support a forest cover, but we will also address the soils of intensively managed forest plantations, many of which were not developed under forests or have seen long periods of use in agriculture. Only cursory attention will be given to genesis and classification of forest soils. Emphasis will be placed on understanding various physical, chemical, and biological properties and processes and how they influence forest dynamics and the management of forests.

FOREST SOILS DIFFER IN MANY WAYS FROM CULTIVATED SOILS

The soil is more than just a medium for the growth of land plants and a provider of physical support, moisture, and nutrients. The soil is a dynamic system that serves as a home for myriad organisms, a receptor for Nature's wastes, a filter for toxic substances, and a storehouse for scarce nutrient ions. The soil is a product as well as an important component of its environment. Although it is only one of several environmental factors controlling the distribution of vegetation types, soil can be the most important one under some conditions. For example, the farther removed a tree is from the region of its climatic optimum, the more discriminating it becomes with respect to its soil site. This means that the range of soil conditions favorable to the growth of a species narrows under unfavorable climatic conditions for that species.

Many properties and processes characteristic of forest soils will be discussed in detail in later chapters. At this time, it will suffice to point out a few properties of forest soils that differ from those of cultivated soils. These differences derive, in part, from the fact that often the most "desirable" soils have been selected for agronomic use and the remainder left for native vegetation such as forests and grasslands. Fortunately, soil requirements for forest crops generally differ from those for agronomic crops. It is not unusual to find that productive forest sites are poor for agronomic use. Nevertheless, they may be used for agriculture because of their location with respect to markets or centers of population. Poor drainage, steep slopes, or the presence of large stones are examples of soil conditions that favor forestry over agriculture. However, the choice of land use often results from differences in crop requirements. Good examples are the wet flatlands of many coastal areas around the world. These important forest soils cannot be effectively used for agricultural purposes without considerable investments in water control, lime, and fertilizers.

Not all forest soils are nutrient poor. Some soils with excellent productive capacity for both trees and agronomic crops remain in forests today. This is generally because of location, size of holdings, ownership patterns, or landowner objectives. The fact that many forest soils contain a high percentage of stones by volume has a profound effect on both water and nutrient relations. Water moves quite differently through stony soil than it does through stone-free soil, and the volume of stones reduces proportionally the volume of water retained per meter of soil depth. Likewise, although stones contain weatherable minerals that release nutrient ions to the soil, the volume of stones reduces proportionally the soil's ability to provide nutrients for plant growth.

Forest trees customarily occupy a site for many years. Their roots frequently penetrate deeply into the subsoil and even into fractured bedrock (Fisher and Stone, 1968). During this long period of site occupancy, considerable amounts of organic material are returned to the soil in the form of fallen litter and decaying roots. As a result, a litter layer forms and exerts a profound influence on the physical, chemical, and biological properties of the soil.

The tree canopy of a forest shades the soil, keeping the soil cooler during the day and warmer during the night than cultivated soils. The presence of forest vegetation and the litter layer also results in more uniform moisture conditions, producing a soil climate nearly maritime in nature.

The physics of both overland and subsurface flow of water in steep forest soils are quite different from those in cultivated soils. Steep slopes under forests have their surfaces protected by the litter layer, their shear strength increased by the presence of roots, and their infiltration capacity enhanced by old root channels.

The more favorable climate of forest soils also promotes more diverse and active soil fauna and flora than are to be found in agronomic soils. The role of these organisms as mixers of the soil and intermediaries in nutrient cycling is of much greater importance in forest soils than in agronomic soils.

The deep-rooted character of trees leads to another unique feature of forest soils. Although the great majority of roots occur at or near the soil surface, deep roots also take up both moisture and nutrients. Thus, deep soil horizons, of little importance to agronomic crops, are of considerable importance in determining forest site productivity.

Agronomic soils may be described as products of human activity, in contrast to forest soils, which are natural bodies and exhibit a well-defined succession of natural horizons. This was certainly a valid contrast a few decades ago, and it continues to be valid in most areas today. But the contrast has diminished greatly in the exotic forests of the Southern Hemisphere and in the short-rotation forests of the southeastern United States, the Pacific Northwest, and much of western Europe. Clear-cut harvesting of trees disturbs the surface litter, resulting in short-term changes in the temperature and moisture regimes of the surface soil. Seedbed preparation by root raking or shearing, disking or plowing, and sometimes bedding incorporates the litter layer with the mineral soil, often enhancing microbial activity. Fertilization increases the nutrient level of the surface soil but may also affect the rate of breakdown of the organic layer. These practices influence the characteristics of forest soil and render it more like agronomic soil. However, most of these changes are relatively temporary, existing only until a forest cover becomes well established. With the development of the forest canopy and a humus layer, the soil again acquires the properties that distinguish it from cultivated soils.

FOREST SOIL SCIENCE IS AS OLD AS SOIL SCIENCE ITSELF

That trees and other plants are intimately related to the soil on which they grow seems rather obvious, but it took a long time for science to perceive this and even longer for us to understand the relationship. It is difficult to say just when perception occurred, but our scientific understanding of soils began with Aristotle (384–322 B.C.) and later Theophrastus (372–297 B.C.), both of whom considered soil in relation to plant nutrition. Cato (234–149 B.C.), Varo (116–27 B.C.), and Virgil (70–19 B.C.) also considered the relationship between plant growth, including trees, and soil properties. However, the knowledge of soils accumulated by Aristotle and the natural philosophers who followed him vanished with the fall of Rome and was unknown to Western scholars for over 1500 years.

Pliny the Elder (A.D. 23–79) gave the most complete account of the ancients' understanding of soil as a medium for plant growth. Pliny spoke not only of crops but also of forests and grasslands. He, like Cato, was a chronicler and recounted folk wisdom and other empirically derived information, much of which is incorrect in light of modern discoveries. Oddly, while the wisdom of the natural philosophers was lost to Western science, much of the traditional knowledge that Pliny chronicled persisted among the agrarian population throughout the Dark and Middle Ages. For example, many farmers recognized that certain crops were more productive on certain sites or soils, and the value of legumes in improving soil was widely known. It was not until the fifteenth century that science (natural philosophy) again turned its attention to the mystery of plant growth. Even then, much of the work in this regard was carried out by the learned nobility, and there was little sharing of knowledge among the various thinkers. In 1563 Bernard de Palissy published his landmark treatise *On Various Salts in Agriculture*, in which he stated that soil is the source of mineral nutrients for plants. However, his work was little known at the time.

The period 1630 to 1750 saw the great search for the principle of vegetation. During this time, any one of five "elements" – fire, water, air, earth, and niter – was considered, from time to time, to be the active ingredient in vegetable matter. It was during this period that Van Helmont (1577–1644) conducted his classic experiment with a willow (*Salix*) tree. He grew 164 pounds of willow tree in 200 pounds of soil, and only 2 ounces of soil were consumed. Since only water had been added during the experiment, he concluded that the 164 pounds of willow had come from water alone. Van Helmont may not have been the first to conduct this experiment and draw the wrong conclusion – some believe that a similar experiment was conducted and similar conclusions drawn by Nicholas of Cusa (1401–1446) – nor was he the last. Robert Boyle repeated the experiment with *Cucurbita*, obtained similar results, and reached a similar erroneous conclusion. It was not until 1804 that de Saussure successfully explained the experiment when he found that most of the mass of the plant was carbon derived from the carbon dioxide of the air.

Despite the experiments of Van Helmont and Boyle, the quest for the principle of vegetation continued. John Woodward (1699) grew *Mentha* in rainwater, River Thames water, Hyde Park Conduit effluent, and effluent plus garden mold. He found that the plants grew better as the amount of "sediment" increased and concluded that "certain peculiar terrestrial matter" was the principle of growth. Frances Home experimented and reached similar conclusions in the 1750s; however, he noted that "exhausted soils recovered from exposure to the air alone" and therefore concluded that the air must be the ultimate source of the essential materials.

The work of de Saussure and Boussingault in France in the early nineteenth century began a period of rapid scientific advancement. In 1840, Justus von Liebig in Germany published *Chemistry Applied to Agriculture and Physiology*, and modern soil science began. Liebig helped dispel the theory that plants obtained their carbon from the soil and developed the concept that mineral elements from the soil and added manure are essential for plant growth. However, he continued to believe, erroneously, that plants received their nitrogen from the air. It remained for de Saussure to show that plants' source of nitrogen was the soil. Lawes and Gilbert put these European theories to test at the now-famous Rothamsted Experiment Station in England and found them to be generally sound.

Following the work of these chemists, scientists in many different fields including geology (Dokuchaev, Hilgard, Glinka), microbiology (Beijerinck, Winogradsky), and forestry (Grebe, Ebermayer, Muller, Gedroiz) contributed to the development of what today is termed "soil science." Most of the early research on soils was directed to its use for agricultural purposes because Europe had a critical food shortage; however, the importance of soils to the natural forest ecosystem was recognized by several early scientists.

In 1840, Grebe, a German forester, recognized the importance of soil to forest growth, stating, "In short, almost all of the forest characteristics depend on the soil, and hence, intelligent silviculture can only be based upon a careful study of the site conditions." Pfeil echoed this thought in 1860, and it became a central theme of European forestry (Fernow, 1907). Hilgard (1906) recognized a relationship between vegetation and soils in North America similar to the relationship that had been noted in Europe. The work of Grebe, Pfeil, Hilgard, and others, perhaps unintentionally, laid the foundations of forest ecology. In North America, early ecologists such as Merriam (1898), Cowels (1899), and Clements (1916) knew that soil was important in vegetation dynamics, but none of them understood soils well. Toumey (1916) noted the importance of soils in American silviculture for the first time.

Early research in forest soils was dominated by basic scientific studies. In fact, some very important early soil science research was done on forest soils. Ebermayer's work on forest litter and soil organic matter (1876) had a strong influence on soil science and agriculture. Muller's work on humus forms (1879) marked the beginning of the study of soil biology and biochemistry. Gedroiz (1912) did pioneering work on soil colloids, suggested that soils performed important exchange reactions, and laid the groundwork for modern soil chemistry. These scientists were interested not only in soil properties, but also in the processes that led to the existence of the properties. Much of the early research on forest soils in North America was similarly basic in nature.

As wood production became a pressing problem in Europe late in the nineteenth century, and the restoration of degraded forestlands abandoned after agriculture became a necessity in North America in the twentieth century, forest soils research became quite applied. Studies of species selection for reforestation, methods of site preparation for reforestation, methods for estimating the site quality of forestlands that no longer supported forest vegetation, tree nutrition and response to fertilization, and soil changes under intensive forest management dominated forest soils research for most of the twentieth century. However, this situation began to change as concern over the impact of acidic deposition and global change arose, and there is currently a broad spectrum of forest soils research. Today, applied research is still necessary, but some of our most pressing environmental problems require more thorough knowledge of the basic processes that take place in soils and their relationship to other ecosystem processes.

H. Cotta in Germany had made the importance of soils to forest production clear as early as 1809. Thus, soils education became an important part of forestry education in Europe. Portions of forestry textbooks were devoted to soil science by Grebe (1852) and by B. Cotta (1852), and in 1893 Raman published a text called *Forest Soil Science* in German. In 1908, Henry published the first forest soils text in French.

The science of forest soils was slow to develop in North America because of the lack of any compelling need for soils information during the early period of forest exploitation. Only after World War I did the ideas of managing selected forests for sustained yields, reforestation of abandoned farmlands, and the establishment of shelterbelts in the Midwest begin to take hold. Perhaps the greatest impetus to the scientific study of forest soils was the publication of textbooks on the subject by Wilde (1946; 1958) and Lutz and Chandler (1946). These books were widely used by students throughout the United States for many years, and North American forest soil scientists today are largely the "academic offspring" of these intrepid scholars.