SOIL DEVELOPMENT AND PROPERTIES

Contents

Forests and Soil Development

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Introduction

Soils are formed by the interaction of five factors: geology (parent material), landscape and topography, climate, animals and vegetation (biotic factors), and time. The interaction of biotic and abiotic factors in the development of soil beneath forest vegetation is highly complex and unique as compared to soils derived under other vegetation types. Because trees dominate forests, their multilayered canopies have a unique and complex effect on environmental conditions at the forest floor. The level of solar radiation, humidity, and effective precipitation under forest canopies vary markedly from nonforest communities. Also, trees are deeply rooted and long-lived, they can access water and nutrients from greater depths compared with other vegetation. Trees extract and cycle nutrients at different rates compared with other vegetation.

Soil genesis and its interaction with forests are complex and do not conform well to generalizations. However, three concepts are crucial to understanding the interaction between forests and soils:

1. Soils and vegetation develop together.
2. Soil includes both the largely mineral material as well as the layers of organic matter (forest floor) that form in undisturbed forests. The presence of this forest floor is a major difference between agricultural and forest soils and is a major reason for differences in characteristics.
3. Many agricultural soils are derived from soils originally developed under forest vegetation; however, removal of the forest canopy and forest floor during conversion to agriculture has such important impacts that they no longer resemble forest soils.

Soil Forming Factors and Forest Vegetation Development

Parent Material

Parent material influences weathering (the breakdown of parent bedrock) rates and, consequently, the stage of soil development and the prevailing vegetation. Although the initial mineralogical composition of the parent material matters, similarities in other soil forming factors, together with time, can result in mature soils of very similar physical and chemical properties from differing parent material. Under forest vegetation, the result is usually a clay-rich, acidic, and relatively infertile soil. These conditions result from specific pedogenic (soil forming) processes as follows:

1. Additions of organic and mineral substances as solids, liquids, or gases.
2. Losses from a portion of the soil, including movement within the profile from one horizon to another.
3. Changes in molecular form among organic and mineral compounds.

Soil physical and chemical properties that result from differences in these processes determine the development of forests. The four primary soil physical factors are texture (the relative proportions of sand, silt, and clay particles), structure (the three-dimensional arrangement of individual soil particles into aggregates such as single-grained, blocky, columnar, prismatic, or massive), size distribution of fines (particles <2 mm) versus stones (mineral solids

>2 mm), and depth available for rooting. Other soil characteristics such as soil bulk density, aeration, and hydraulic conductivity also determine the extent to which root systems and soil organisms will utilize a given soil. Together with climate, time, and parent material, knowledge of the soil physical factors helps predict the successional patterns of vegetation on a landscape. However, these soil physical factors are, in turn, influenced by vegetation dynamics.

Two classifications of soils based on the origin of parent material are generally used:

1. Residual soils result from *in situ* weathering of parent material (the underlying bedrock) on relatively stable landscapes. With time, intense weathering results in fine-textured surface soils, and coarser fragments with depth. Soil development is linked to the zone of biological and chemical weathering.
2. Transported soils tend to be more uniform in textural composition with depth than residual soils but they can vary drastically in texture. They often contain material from soils formed in place at other locations. These soils are further classified by their mode of transport. Alluvial soils are derived from materials transported by water and deposited in the floodplain associated with the watercourse. Waterborne sorting of grain sizes can lead to soils of distinctly textured layers, the finest of which are deposited near the surface. Speed of the transport waters is the greatest influence on sorting. Lacustrine deposits result from suspended sediments in lake water, and tend to be fine-textured. Colluvium is material transported downslope at varying speeds. Textural differences can be large or small with little sorting by size class. Aeolian materials are windborne deposits, usually of particles silt-sized (called loess), or smaller.

There are some general relationships between parent material and vegetation type. Under a given set of climatic conditions, limestone, shale, and similar fine-textured rocks weather into clay-rich, high base nutrient status soils. Acid crystalline rocks (those with high quartz content) such as granites generally form acidic, coarse-textured (sandy) soils of relatively low base nutrient status compared to siltstones and shales. Less moisture- and nutrient-demanding tree species, such as pines, tolerate these conditions better than most angiosperms (hardwoods).

Topography and Landscape Position

Energy from topographic relief, aspect (position of the slope relative to the radiant energy of the sun), and position in the landscape (top, mid-slope, or bottom) drive the formation of soil. Steeper slopes usually experience greater erosion from soil and water movement. These high-energy environments may be so dynamic as to preclude the development of a mature soil no matter how much time passes (see discussion of zonal model of soils, below).

Local topography influences the development of soils and forests through its influence on erosion and drainage. For example, microsite differences in elevation can result in dramatically different dissolved oxygen contents in the soil, which affects soil chemistry. Under anaerobic conditions, metals such as iron, manganese, and aluminum are reduced to more soluble and mobile forms that may leach or be reoxidized to precipitates. The color of a soil, especially in the subsoil, can be used to predict drainage class. Reds and oranges signify oxidized conditions, whilst darker grays and bluish colors indicate reduced conditions typical of impeded drainage.

Climate

Climate and, in particular, the amount and seasonality of available moisture, is important in soil formation and key to the development of vegetation. Moisture and temperature drive chemical reactions. Chemical and physical weathering of parent material leads to the development of soil horizons. Climate also dictates the development of vegetation and can override the influence of parent material by precluding or enabling the establishment of specific types of vegetation, which in turn contributes to the type of soil formed.

Forest growth (biomass production) is usually proportional to available moisture. As litter falls to the forest floor, it decays and is transformed by a series of chemical reactions and biologically mediated decomposition into organic acids and humus (*see* **Soil Biology and Tree Growth**: Soil Organic Matter Forms and Functions. **Soil Development and Properties**: The Forest Floor). Soils high in organic matter are typically dark-colored by humus. Organic acids assist in the weathering of minerals in the uppermost layer of soil (A horizon), the products of which leach (a process called eluviation) into the underlying zone (B horizon). The soil directly above this zone of accumulation is sometimes so highly leached of metals (especially oxides of Al and Fe) and soluble organic matter that a distinctly light-colored horizon develops (E horizon) at the bottom of the A horizon. The products of leaching which have moved out of the E horizon give a darker color to the B horizon. Horizon development beneath a New Zealand forest is illustrated in **Figure 1**.

Organic matter dynamics is largely a function of moisture availability, temperature, and biotic

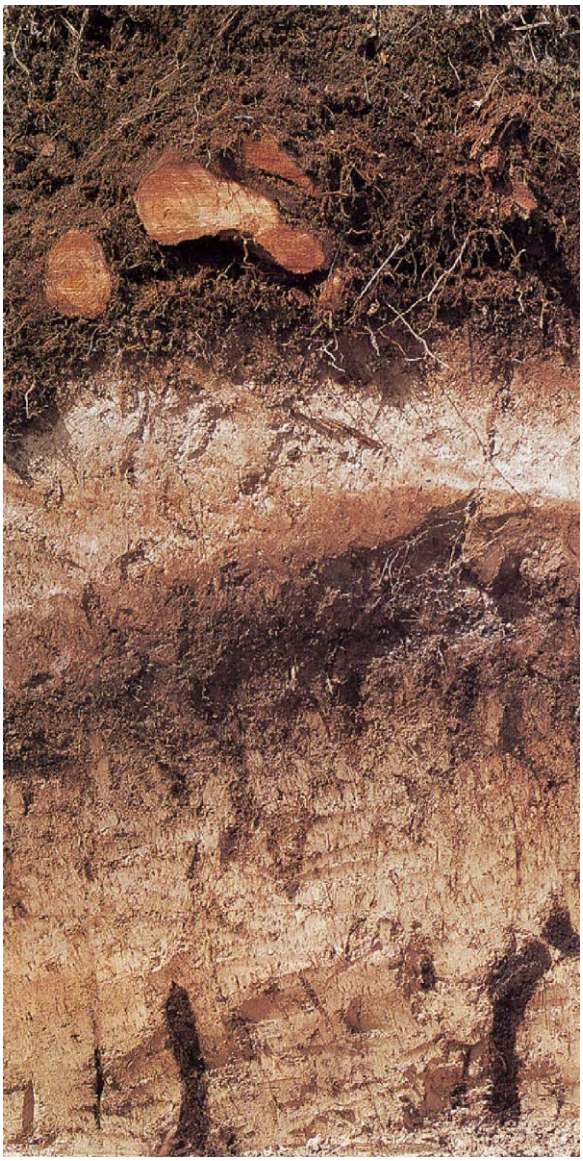

Figure 1 A soil profile beneath a kauri (*Agathis australis*) forest on old coastal sands (North Island, New Zealand). Note the dark surface horizon (A horizon) beneath the forest floor. Beneath this horizon is a 30-cm thick lighter zone (E horizon) leached by organic acids. Translocated humic and aluminum compounds have accumulated into the reddish-colored B horizon (Bhs horizon). Reproduced with permission of the New Zealand Soil Science Society.

activity. As with any chemical reaction, decomposition is fastest when rate limiting factors are at optimum levels. Low concentrations of oxygen, low temperatures, and extremes of moisture content slow decomposition of organic matter.

Biological Factors of Soil Formation

Biological interactions are essential to pedogenesis. The diversity of life in soil, as measured by species, variety, and number, far exceeds that of aboveground communities. Forest soils are especially diverse compared with agricultural environments. Flora and fauna populate and modify the soil, especially in the rooting zone, an area known as the rhizosphere. Three major impacts of organisms are:

1. The movement of soil particles and organic matter between the surface and subsurface of the soil.
2. The mediation of some chemical reactions and resultant nutrient availability.
3. Forming a significant source of organic matter and nutrient additions to the soil.

The soil food web is a complex community ranging from predatory vertebrates like shrews and moles to tens of thousands of invertebrate species such as worms, arthropods (bugs), and decomposing fungi and bacteria, all which mediate the decomposition of soil organic matter (**Table 1**). Soil organic matter is the source of energy and nutrients used by plants and other organisms. Because they move within the soil, vertebrates, earthworms, and arthropods aerate and mix the soil as they feed. Shredders, such as millipedes, termites, sowbugs, and roaches process tens of tonnes of organic matter yearly derived from the forest floor and plant roots. Soil structure is improved through burrowing and the creation of fecal pellets, rich in readily available nutrients. In terms of biomass and overall activity in the soil, earthworms dominate the invertebrates. Earthworms dramatically enhance the porosity of soil as they burrow, thereby creating conduits for water. Moreover, they move large amounts of mineral soil and organic matter throughout the soil by providing deep cultivation. Compared with other terrestrial ecosystems, forest soil food webs are by far the most complex in the number of separate functional organismal groups.

As organisms consume food, they add to their biomass and they release wastes. Bacteria play a crucial role in mediating the chemical transformation of nutrient elements, like N and P, which are bound in the organic form (unavailable to plants), to elemental (inorganic) forms readily used by plants. This process is known as mineralization. In addition to their crucial role in decomposing organic matter, fungi also enter into a mutually beneficial relationship with tree roots. These fungal–root relationships are known as mycorrhizae (*see* **Tree Physiology: Mycorrhizae**). Roots, and their fungal and bacterial symbionts, have been found to release carbohydrates, vitamins, and amino acids into the rhizosphere, resulting in greatly increased populations of bacteria and fungi. In turn, the increased activity accelerates mineral and organic matter weathering.

Table 1 Characteristics of organisms in the forest soil food web

Class of soil organism	*Important functions*	*Biomass*[a] ($g\,m^{-2}$)
Protozoa	Bacterial feeders	2–20
Bacteria	Decomposition, conversion/release of nutrients to plant available forms	40–500
Fungi	Decomposition, binding soil, enhance root function in uptake of nutrients	100–1500
Nematodes	Feed on fungi, roots, bacteria	1–15
Arthropods	Shred litter; mix soil; feed on bacteria and fungi	2–5
Earthworms	Same as arthropods; enhance soil structure and fertility; most important macrofaunal species	10–150

[a] To a depth of 15 cm.

Perhaps the greatest impact of bacteria in forest soils is their mediation of the chemical transformations of N. Nitrogen availability limits forest productivity globally more than does any other single nutrient. Because the supply of N is so important, nature has developed means to provide that supply, yet to also preserve stocks so that they are not lost from the ecosystem. The ultimate source of N in the soil comes from the abundance of N_2 in the atmosphere. Plants cannot use N_2. In a microbially mediated process, rhizosphere bacteria (and a few other microbes) convert N_2 to ammonium. This is called biological N-fixation. However, most plants require N in the form of NO^{-3} (nitrate), so bacteria must convert ammonium to nitrate. Unused ammonium and nitrate are lost easily from the soil, so conversion back to forms (insoluble) not easily lost is essential to preserving ecosystem productivity.

Tree roots grow where soil conditions are favorable. Thus, the proliferation of fine roots (the growing root tips) is usually greatest in the surface soil, as a result of greatest resource availability. Although roots of some forest species may extend to depths of 10 m or more, 90% of the root length and surface area occurs within the first 1 m of the surface. Together with the biotic activity of other soil flora and fauna, roots occupy and modify the top zone of soil, with activity decreasing exponentially with soil depth. The most important factors are availability of oxygen and moisture, soil temperatures, amounts of available (inorganic) nutrients, and organic matter quality. Turnover (herbivory, and root death and decomposition) of roots accounts for a significant portion of the soil organic matter pool. Studies of root mortality and decomposition have found that as much as 50% of annual biomass production may be invested in root production, with 20–45% of that as annual root turnover.

Observations of changes in a soil following deforestation and afforestation, and the resulting morphological soil traits, indicate that the relationship between forest vegetation and soil is interactive. Students are often introduced to this relationship by considering the influence of forest vegetation on the genesis of podzols (spodosols). The litter from certain tree and shrub species decomposes to an especially acidic form of humus, which results in a lowering of soil pH, especially if the soil is not well buffered (*see* **Soil Biology and Tree Growth**: Soil Organic Matter Forms and Functions). The acidic, nutrient-poor status of these soils results in an edaphic climax. For example, certain conifers, such as the Pinaceae, *Picea*, and *Tsuga* (northern hemisphere), and the broadleaved evergreen *Agathis* (southern hemisphere), commonly form on Spodosols, and under certain conditions, result in a site-specific soil climax. Experts question whether the formation of these morphological features is merely accelerated by certain vegetation or if they are most likely examples of forest vegetation adapting to pre-existing edaphic constraints. Podzolization can occur on pure, relatively sterile sands after a few hundred years under conifer forest, although well over 1000 years is considered usual. It has been noted that successional change to hardwoods can result in changes in nutrient cycling and soil chemistry, leading to a reversal of the podzolization process.

An especially illustrative example of the relationship between forests and soil development are the 'egg-cup' podzols formed under some New Zealand podocarps (in particular old-growth forests of kauri (*Agathis australis*). In this case, moisture, parent material, and vegetation combine to form a unique soil morphology consisting of well-developed E and B horizons. Years of litter fall, and the concomitant leaching from the products of litter decomposition result in a distinct, bleached, egg-cup shaped E horizon beneath the roots of giant, old-growth kauri, underlain by a zone (spodic horizon or Bhs horizon) of accumulated sesquioxides, soluble bases, clays, and colloidal organic compounds, largely from the E horizon beneath the stems of individual trees (**Figure 2**). This process is aided by soil textures dominated by sands of acid crystalline minerals, such as quartz.

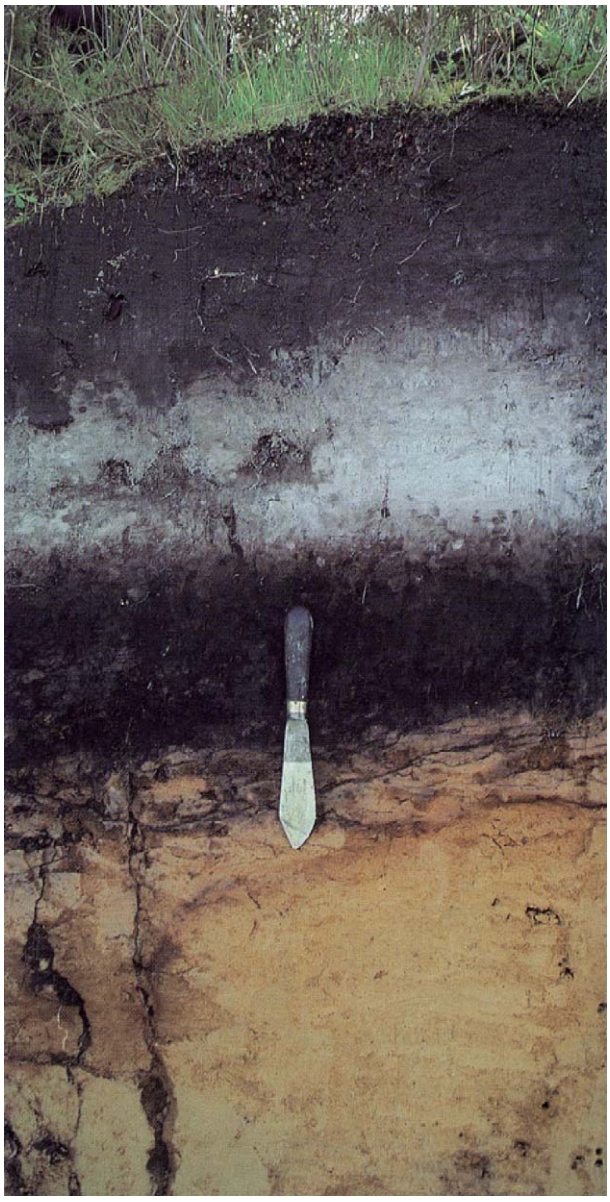

Figure 2 An 'egg-cup' podzol formed under the stems of long-lived trees in New Zealand, where extra leaching of water down the stems of Kauri trees results in distinct zones of leaching and accumulation. Reproduced with permission of the New Zealand Soil Science Society.

Another important forest-mediated soil process is known as desilication, wherein high uniform temperatures and rainfall along with the acidic products of litter decomposition favor loss of silica from the upper soil profile. Simultaneously, iron- and aluminum-rich oxides concentrate and form an oxic horizon. Typically, this is a clay-rich, but lacking in any mineralizable primary minerals (those containing calcium, magnesium, and potassium). This process is characteristic of the intensely red tropical soils known as Oxisols.

Figure 3 Example of a fallen tree and the development of pit and mound topography in a hardwood forest in the USA.

The ecology of soil change as forests are cleared and grow back has been studied around the world. The magnitude of change depends on management practices and the differences among sites. It is important to remember that farmed soils are a result of constant human inputs and harvests as opposed to forested soils which, depending on harvest intensity, are largely a product of natural soil-forming factors. Our knowledge of these changes have been aided by research which quantifies the change in soil properties as forests are cleared to make way for farming, followed by reversion to forest.

Another example of the interaction between forest and soil development can be observed in the 'pit and mound' microtopography created by tree falls. Windthrow and uprooting results in a pit at the former root collar and a mound nearby where the displaced surface soil clings to the remaining roots and tree stem (**Figure 3**). Tree falls increase in mature and old-growth forests, and where predisposing environmental conditions such as restricted rooting depth and meteorological conditions exist. The resulting effects on soil formation include: litter accumulation and decomposition, respiration, soil climate (humidity, moisture content, temperature, solar radiation), sequence and thickness of soil horizons, and biotic diversity/activity. Forest floor tends to accumulate in pits due to increased trapping of litter, and reduced decomposition rates resulting from higher moisture contents. Greater moisture in surface soil may facilitate the weathering process unless oxygen is limiting. Horizon differentiation is slowed on mounds due to attenuation of weathering from a decrease in moisture levels and organic matter inputs from litter fall. Pits have the highest amounts of organic matter, nitrogen, and carbon, while mounds have the least, and the surrounding

undisturbed (flat) areas are intermediate. Calcium and other soluble bases are often higher in pits, resulting in higher soil pH. The occurrence of pit and mound microtopography varies from as little as 1–2% to as much as 30–40% of the forest floor in especially prone areas.

Pits, when associated with high water tables, can lead to the formation of vernal (ephemeral) pools. These pools remain as long as the water table remains high, or longer when sediments coat and seal the edges of the depression. Microtopography, and the resulting creation of soil microsites, has been found to influence the distribution of understory plants. Animal activity is also tied to the availability of favorable microsites. Variation in earthworm and other invertebrate activity contributes to the fine-scale heterogeneity in forest soils characteristic of pit and mound landscapes.

Time

Changes occur constantly in soils as a result of parent material weathering and vegetation dynamics. Given enough time and a particular set of climatic and vegetative factors, most soils will stratify, developing the characteristic horizons and other features we use to distinguish among them. The concept of soil maturity, or that a predictable type of soil will develop over time, is referred to as the zonal model of soils. Although this concept is manifest under certain conditions, it does not adequately explain the variation in soils under all conditions and the concept does not have universal acceptance. Similarly, the idea of climax vegetation communities in equilibrium with the soil is a largely misleading one based on studies of limited time scales, within relatively few old-growth forests. Thus, it is difficult to predict how long it will take for soil to develop. It may take 100 years to add 1–2 cm of topsoil in residuum under harsh climatic conditions. In contrast, well over 10–20 cm of soil may form on volcanically derived parent material under tropically moist conditions in that same 100 years. Because soil is constantly being lost by erosion on some landscapes, it is probably best to discuss time and forest soil formation in terms of soil profiles and horizons.

Under temperate climatic conditions, such as those found in the continental USA and Western Europe, a well developed A horizon can form in as little as 150–400 years, with full profiles averaging 1500–12 000 years. Extremes in environment such as high moisture content, arid conditions, or dynamic landscapes due to slope or depositional intensity, can slow development dramatically. Ultisols (red–yellow podzolic soils) and Oxisols (Latosols, Ferralsols) are commonly the most ancient of soils ranging in age from 50 000 to well over 500 000 years. Some clayey soils, especially those rich in aluminum or iron, are particularly resistant to change.

Soil Classification Systems

The most widely used classification systems are the US Department of Agriculture (USDA) *Soil Taxonomy* and the United Nations Food and Agriculture Organization (FAO) *Legend*. *Soil Taxonomy* is an hierarchical system based on morphological variables that are quantitative, and thus easily interpreted. The system groups all soils into 12 soil orders based on their current properties (color, clay content, etc.), similarities in pedogenic factors (climate, presence or absence of diagnostic horizons) and overall profile development (**Figure 4**).

Table 2 provides a comparison of the world distribution of soil, by percentage of land area, for the FAO Legend, and Soil Taxonomy. Entisols and shifting sand or rock constitute the largest categories.

Distribution of Soil among and within Forest Biomes

Past and present differences in climate and landscapes have created the forests we view today. Discounting the role of humans, the species composition of the worlds forests correspond to areas of distinctive landscapes, climates, and biota referred to as biomes. Because the extent of biomes can extend across continents, large differences can occur in the types of soils encountered. Describing this variation is really a matter of the scale chosen. However, three major points are:

1. soils commonly differ as much within regions as around the globe
2. soil types are distributed unevenly around the globe
3. a particular forest biome can occur on a variety of soils.

Patterns of soil properties vary in relation to the five soil-forming factors. However, variation in a given parameter can be as great within a forest stand as among biomes. Variation across a landscape can be as great as among soil types on a continent. Therefore, a given forest type can occur across a range of soils, and a particular soil type can occur in multiple forest regions.

Within the temperate regions, Entisols, Alfisols, Inceptisols, and Ultisols support the majority of forest (**Figure 5**). Other orders, excepting Aridisols and

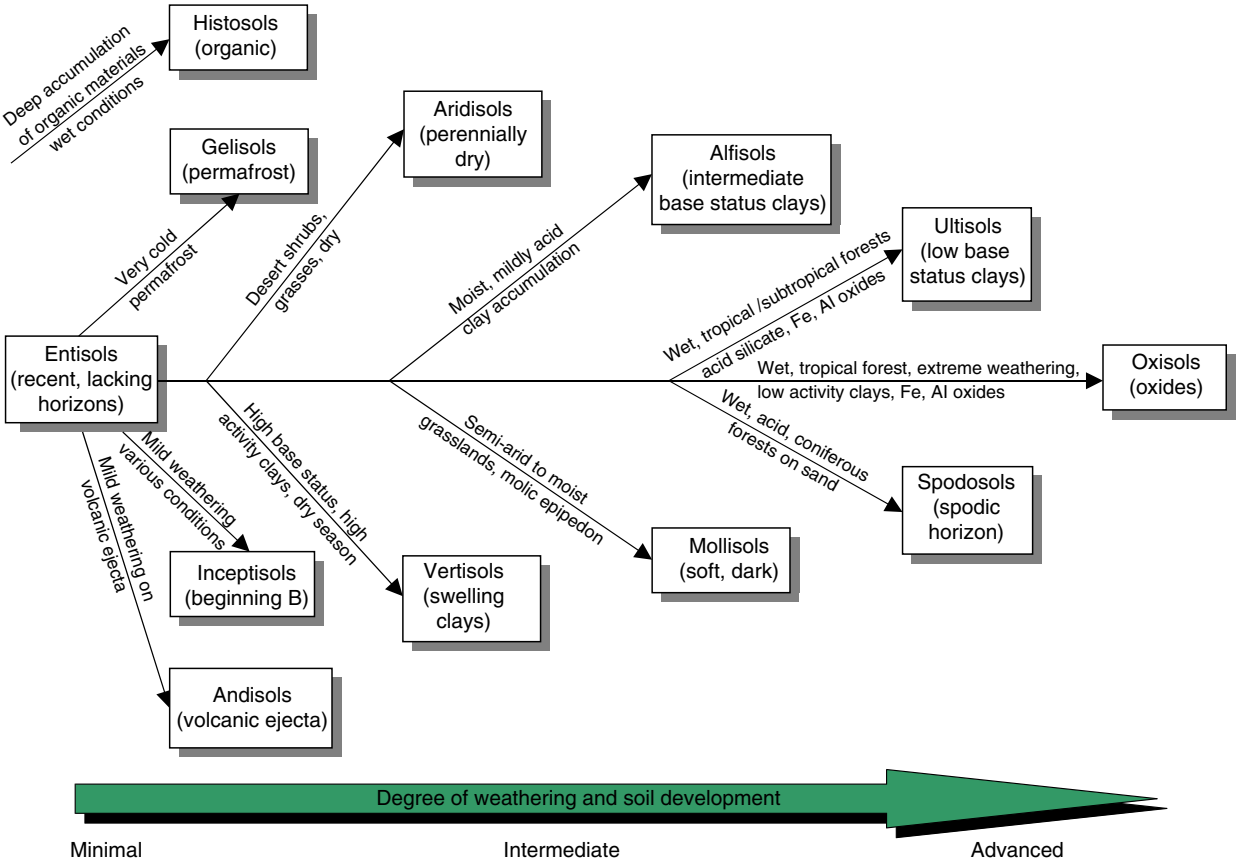

Figure 4 Diagram showing general degree of weathering and soil development in the soil orders within the US Department of Agriculture *Soil Taxonomy*, including the general climatic and vegetative conditions under which the orders are formed. Modified from Brady NC and Weil RR (2002) *The Nature and Properties of Soil*, 13th edn. Upper Saddle River, NJ: Prentice-Hall.

Table 2 World distribution of soil orders by percentage of land area

US Taxonomy Soil Order	*Analogous categories in FAO and other widely used classification systems*	*Percentage of ice-free land*
Entisol	Regosols, lithosols, arenosols	16.2
Inceptisol	Acid brown soils, gleysols, cambisols	9.8
Mollisol	Prairie soils, chernozems, rendzinas,	6.9
Histosol	Bog soils, histosols	1.2
Gelisol	Gelic members of gleysols, cambiosols, and others	8.6
Spodosol	Podzols	2.6
Alfisol	Grey wooded soils, luvisols, planosols	9.7
Vertisol	Grumusols, vertisols	2.4
Ultisol	Red–yellow podzols	8.5
Oxisol	Latosols, ferralsols	7.5
Aridisol	Xerosols, solonetz, solochaks, yermosols	12.0
Andisol	Andosols	0.7
Shifting sand or rock		14.0

Source: Modified from US Department of Agriculture Natural Resources Conservation Service.

Gelisols, are also capable of supporting forests, but large portions have been reserved for nonforest uses, particularly agriculture. Aridisols are too dry to support forests, and Gelisols are too cold. Boreal forests occur mostly on Spodosols, Entisols, Inceptisols, and Histosols. In most of the world, Alfisols indicate the potential for broadleaved forests. Because of their volcanic origins, Andisols are limited in occurrence, usually near the edges of continental plates, but can support some of the world's most

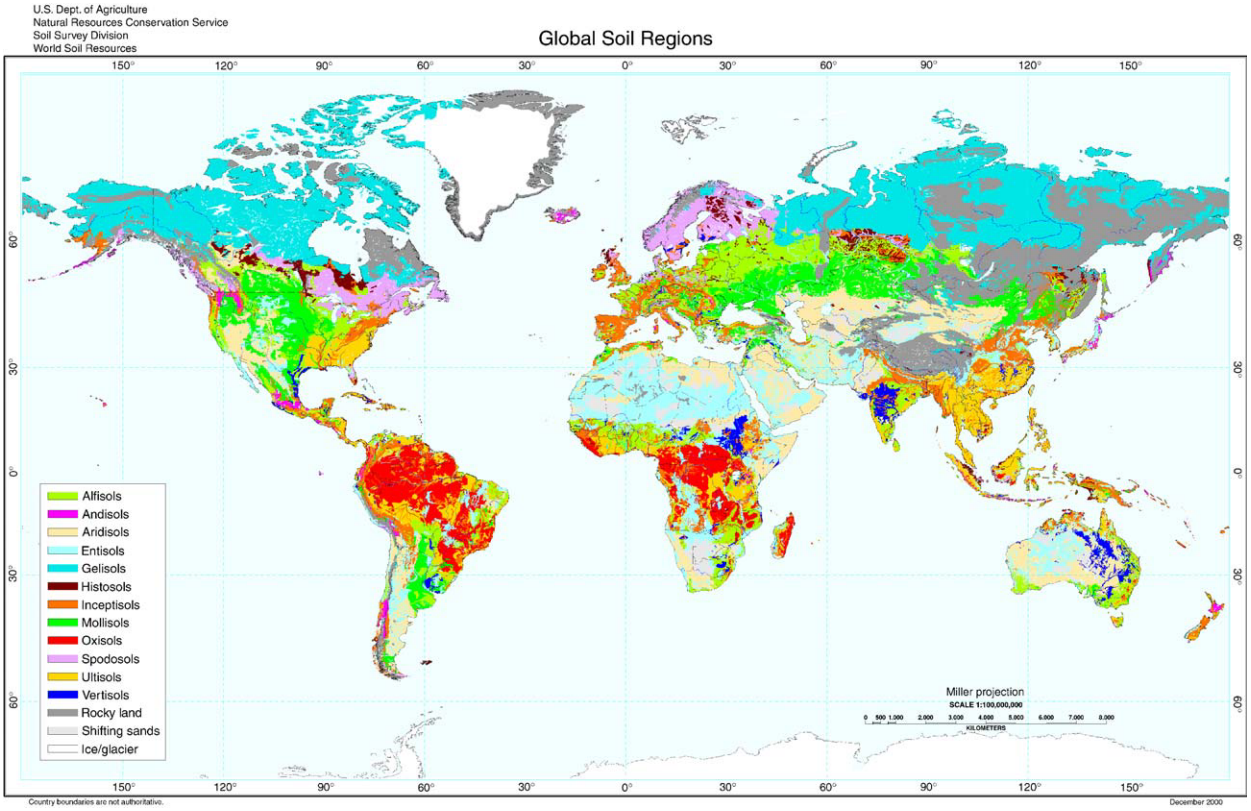

Figure 5 Map of global soil regions using the US Department of Agriculture *Soil Taxonomy's* Soil Orders. From US Department of Agriculture Natural Resources Conservation Service.

productive forests. Ultisols are most common in tropical and near tropical latitudes, and the warmest, moistest regions where soils have been permitted to weather in place for long periods of time. Both broadleaved and conifer species are common, with the broadleaves dominating on the moister and more fertile Ultisols. Oxisols are the worlds most weathered and mature soils, occurring in the tropics. A synopsis of the world's forested communities follows.

Tropical Forests

Tropical forests begin at the equator, and span north to the Tropic of Cancer, south to the Tropic of Capricorn. Approximately 33% of the world's forests occur here amidst considerable variation in climate, elevation, and geology. The major soil orders are Inceptisols, Andisols, Ultisols, and Oxisols.

Tropical rainforest These moist tropical forests comprise about 30% of the tropics. The nutrient cycle between the vegetation and the soil is essentially closed. Rainfall is generally between 2000 and 4000 mm year^{-1}. Constant litter fall and decomposition throughout the year (udic environments) and the virtual absence of leaching permit the development of luxuriant forest with no nutrient deficiency symptoms in soils of low native fertility. The only marked vegetation differences outside of swamps that can be correlated with soils are the reduced stature of rainforests growing on very sandy Spodosols.

Seasonally dry deciduous and semideciduous tropical forest Deciduous and semideciduous forests occur where the dry season is sufficiently strong to exclude rainforests but grasses are not dominant. Rainfall is between 1200 to 2000 mm year^{-1}. About 15% of the tropics are covered by semideciduous, deciduous, and thorn forests. The nutrient cycle, however, is markedly different from that of the rainforest. With substantial litter fall during the dry season, the solar radiation reaching the soil surface increases drastically, and the litter layer does not decompose during the dry season.

Savanna These are transitional areas between the tropical forests and deserts. Rainfall is in the range of 900 to 1500 mm year^{-1}. Also known as tropical grasslands, savannas have widely scattered trees that are generally deciduous. Fire frequency is important in maintaining these communities as trees are

normally excluded when burn frequency and intensity increases.

Temperate Deciduous Forests

These forests reach maximum abundance between the tropics and 45° N latitude. The climate is characterized by relatively cold winters and warm summers with reasonably evenly distributed rainfall (averaging 750 to 2500 mm $year^{-1}$) throughout the year. Leaf fall corresponds to a period of cold and unavailability of water. Conifers become more prevalent at the drier and colder, and mountainous margins of this biome. Entisols, Inceptisols, Alfisols, Spodosols, and Ultisols are the most common soil orders.

Boreal Forest

The boreal regions of the world are characterized by long, cold, snowy winters. These biomes are the result of a climate found only in the interior of large continental landmasses in the northern hemisphere. Conifers are the most abundant tree species with some cold-tolerant, deciduous broadleaved vegetation occurring at the southern and milder margins. Entisols, Inceptisols, Spodosols, and Histosols are the most common soil orders.

Further detail on the extent and development of the world's forest biomes can be found in the section on Further Reading.

Summary

Forests provide a unique set of environmental factors influencing soil formation. The most important of these is the microclimate at the earth's surface engendered by the canopy of trees and understory vegetation, the role of tree roots in cycling nutrients from great depths, and the large additions to soil organic matter made by tree roots and foliage. Fully one-third of the earth's soils developed under a original cover of forest. Although forests can occupy very fertile soils, much of the world's remaining forest exists on landscapes marginally suited for other human uses.

The two dominant soil-forming processes in forests are podzolization and desilication. These two processes occur in the two forest biomes least influenced by humans, the boreal and tropical forests, respectively.

Some tree genera and species assemblages will thrive on most of the soil orders making it difficult to predict forest composition based solely on soil. Forest composition and productivity depend more on local-scale factors such as topography, soil physical properties, and inherent differences in local climate, than to soil categories.

See also: **Soil Biology and Tree Growth**: Soil and its Relationship to Forest Productivity and Health; Soil Biology; Soil Organic Matter Forms and Functions; Tree Roots and their Interaction with Soil. **Soil Development and Properties**: Landscape and Soil Classification for Forest Management; Nutrient Cycling; Nutrient Limitations and Fertilization; The Forest Floor. **Tree Physiology**: Nutritional Physiology of Trees; Root System Physiology.

Further Reading

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Landscape and Soil Classification for Forest Management

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Soil Classification

Soils vary across the earth's surface, and understanding and managing this variation is key to understanding, managing, and sustaining both natural and anthropogenic ecosystems. Properties of the soil at any point in the landscape are the product of an array of complex processes, tempered by the environmental factors climate, biota, and topography, acting on a parent material over time. Because of the vast numbers of combinations and intensities of these five state factors, the number of different soils is seemingly endless. It is generally agreed, however, that it is possible to group soils into classes having many properties that are similar which is the basis for soil classification.