Forest soils : origin, properties, relation to vegetation, and silvicultural management. 1941

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and Assistant Senior Forester,
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Madison, Wisconsin

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PREFACE

The contents of this book comprise the subject matter of a three credit course given for upper class and graduate students in soils, forestry, botany, game management and landscape architecture. This course is intended to satisfy some of the needs of professional men engaged in forestry and related branches of land utilization. In the preparation of the book, an attempt was made to eliminate detailed soil classification and techniques not adapted to forestry practice, and to avoid the repetition of elementary information already available in texts on soils and silviculture. As far as possible, generally accepted terminology and treatment of the subject matter were followed, but a number of deviations were found to be necessary. Most of the material presented has been subjected to the test of field and laboratory trial. The book is a pioneer effort in its field and hence important omissions may have occurred.

The general attitude of the writer has been influenced chiefly by the works and personal instruction of the following teachers of soils and forestry: J. Kopecky, G. F. Morozov, J. Sigmond, Julius Stoklasa, Emil Truog, G. N. Wissotzky, and A. R. Whitson.

Dr. R. J. Muckenhirn aided in the preparation of the manuscript. A portion of the field and laboratory data incorporated in this book was accumulated in collaboration with S. F. Buran, H. M. Galloway, J. G. Cady, W. E. Patzer, D. P. White, E. L. Stone, and C. J. Krumm, Assistants in Forest Soils, University of Wisconsin. Wholehearted cooperation in silvicultural investigations was rendered by C. L. Harrington, F. G. Wilson, F. B. Trenk, H. B. Wales, G. W. Jones, F. G. Kilp, W. H. Brener, and R. Wittenkamp. To all these the writer extends his most cordial thanks. Grateful acknowledgment is also made to Miss Margaret Stitgen, Secretary of the Soils Department, who arranged the manuscript in its final form and prepared the stencils.

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S. A. Wilde

Madison, Wisconsin
January, 1941

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Chapter Page

FOREST SOILS
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A BRIEF HISTORICAL REVIEW OF FOREST SOIL STUDIES

"The soil, barring the living organisms which it supports, is perhaps the most complex, the most interesting, and the most wonderful thing in nature."

John E. Weaver

The credit for the crystallization of soil science into an independent body of knowledge is divided among geologists (Fallou, Richthofen, Dokuchaev, Hilgard, Glinka), agricultural chemists (Boussingault, DeSaussure, Liebig, Lawes, Gilbert), microbiologists (Beijerinck, Winogradsky) and foresters (Grebe, Ebermayer, Müller, Morozov, Ramann, Wissotzky, Gedroiz). Since the pioneering days in soil science, foresters have been ceaselessly broadening the scope of this subject by their studies of humus, ground water, and the relation of vegetation to soils. In recent years the information accumulated by the students of forest soils has assumed the form of a separate scientific discipline.

The history of the accumulation of forest soils theory covers a period of about one hundred years. As early as 1840, Grebe, a German forester, introduced the ecological aspects of silviculture. His doctor's thesis "De conditionibus ad arborum nostrarum saltuentium vitam necessaries", submitted a t Marburg, may well be considered as the cornerstone of forest soils. The "Forstliches Cotta Album", published in 1844 includes the following statement of Grebe, remarkable for its vision: "As silvicultural horizons widen, the importance of environmental conditions becomes more sharply pronounced. It appears clearly to the foresters that the form of forest management is determined by a number of physical influences related to topography, geology, type of soil and climate." Thirty years later Grebe wrote: "In short, almost a ll of the forest characteristics depend on the soil, and, hence, intelligent silviculture can be based only upon a careful study of the site conditions."

In 1860, Pfeil, a German authority on forest management, published his text with an extensive chapter devoted specifically to the conditions of environment and entitled "Science of Forest Habitat". The variation in the results of silvicultural operations under different conditions of climate and soils led Pfeil to introduce his paradox: "The only general rule in forestry is that there are no general rules...."

The publications of Grebe and Pfeil have strongly influenced a number of texts on silviculture, particularly Gayer's notable work on "Diagnosis of Forest Stands" which appeared in 1876.

Research in forest soils by Müller, Ramann and Ebermayer had accumulated at the end of the past century, a great deal of factual knowledge. Müller's voluminous monograph on "Natural forms of humus" revealed the biological nature of forest soil development and opened a new chapter in general soil science. Ebermayer contributed numerous papers of lasting value on physical and chemical aspects of forest soils. Ramann's comprehensive text "Forstliche Bodenkunde" published in 1893 consolidated the existing knowledge and outlined the general course of the subject. The work of Ramann, Ebermayer, and Müller was continued by a number of German and Scandinavian students, particularly Albert, Lang, Krauss, Vater, Hesselman, Tamm, and Bornebusch.

About 1880, Grandeau introduced the subject of soils to French foresters. "Les sols forestiere" by Henry appeared in 1908.

A wealth of observations on the relation of tree growth to soils and climate in the Old and New Worlds was collected by Mayr. His "Silviculture on a Scientific Basis", written in 1909, considers the factors of environment in terms of concrete data. The publication of Mayr's text was followed shortly by another outstanding book, namely Wagner's "Areal Regulation of the Forest". Wagner placed foremost emphasis upon the use of environmental forces in selective logging and natural regeneration.

Toward the turn of the century, the subject of forest soils received great stimulus when the climatic-zonal principles of soil development were discovered by Dokuchaev in Russia and Hilgard in America.

The findings of Dokuchaev and his associates were enthusiastically received by Russian foresters, and the beginning of the twentieth century was marked by intensive research in forest soils, led primarily by Morozov, Wissotzky and Kruedener. Glinka observed in his widely-known text on soils: "The abundant material collected by foresters on the relation of soils and forest vegetation exceeded by far that accumulated in regard to other types of vegetation. In the reports of Morozov and his followers the problems of soils are intimately welded to those of silviculture."

Among the numerous students of soils in Russian forestry schools, Gedroiz cast an entirely new light upon the relation of soils to plant nutrition by his investigations of colloids and exchange reactions. As Marbut stated, "In the pioneer chemical work of Gedroiz...with a previously unknown method real soil chemistry was created".

The Danish text on environmental requirements of plants, published by Warming in 1898, initiated numerous studies in the field of plant ecology. The investigations of ecologists provided an important link in the chain of studies on the relation of forests to environment. Two forest ecologists, Sookachev of Russia and Cajander of Finland, devised botanical site classifications directly applicable to silvicultural practice.

During the post-war period the information accumulated by the students of soils and ecology initiated a new school of thought among the practical foresters of Central Europe and led to a revolt against the outmoded theories of Cotta and Hartig. Three facts provided particularly strong support to the movement for a "new deal" in silvicultural practice: destruction of vast areas of spruce stands on unsuitable sites by nun-moth epidemics; records from Saxony revealing an enormous decrease in the rate of growth of forests managed on the basis of abstract formulas; a doubled productivity in Bärenthoren estate and other forests of Central Europe where the old management patterns had been discarded.

Möller, Wiebecke, Eberbach, Wiedemann, and many other German writers denounced the principles of "stencil" forest management. They proclaimed the correlation of tree growth with micro-climate and soil as the road toward the solution of the "riddle of production". These ideas soon penetrated far beyond the boundaries of Germany. Most of the Swiss and French foresters adapted as a standard guide Biolley's "L'amenagement des Forets", a book advocating the "coordination of all the forces involved in wood production" as the basis of sound silviculture and picturing the forest as "a tri-phased unit of soil, atmosphere, and wood-producing community". The Russian, Scandinavian, and Finnish foresters from the early days of their silvicultural practice were inclined to recognize the importance of the environment and were thus fortunately spared the many disappointments of their continental neighbors.

Americans, like the people of northern Europe, lived in a much closer contact with virgin soils and original vegetation than the people of western Europe. The basic relationship between the environment and plant growth had been noticed in the New World ever since the early days of colonization. The knowledge accumulated by the settlers and woodsmen was inherited by foresters and developed into a foundation for silvicultural theory. A contribution of great importance to the development of American forestry, as well as the subject of forest soils, was made by Hilgard. This geologist by training, teacher of chemistry, botany and zoology, and soil scientist concerned with agronomical problems, has laid, perhaps unintentionally, the foundations of forest ecology. The chapters on the relation of native vegetation to soils in his classical text probably constitute the most valuable single document yet written on this subject.

The general outlook of foresters was also strongly influenced by a number of ecologists and physiographers, notably Merriam, Cowles, Bowman, Bray, Clements and Weaver. The general trend of contemporary American silvicultural practice was indicated by Toumey's "Foundation of Silviculture upon an Ecological Basis".

The recent expansion of the forestry program in the United States has served as a strong impulse for studies of forest soils. The last decade was characterized by extensive research in tree nutrition, maintenance of nursery soil fertility, adaptation of tree species to environment, and technique of reforestation under different soil conditions. Recent years have also seen a remarkable increase in the planting of forest vegetation for purposes other than lumber production. This country has vigorously promoted programs of extensive park systems, "broad-acre" cities, shelterbelts, roadside landscaping, erosion control, resettlement movements, and game management. All of these projects, demanding a rapid growth of planted stock, have stimulated a further expansion of knowledge in the use of fertilizers and technique of forest soils management.

The following list of references presents in chronological order some of the outstanding earlier works which mark the progress of knowledge pertinent to forest soils. This list is far from being complete and many of the publications quoted have only a historical significance. Nevertheless, it is believed that familiarity with such a record of titles will give the student a broader outlook and a better appreciation of the recent achievements in the allied fields of Silviculture and Soil Science. References to the more recent publications will be found elsewhere.

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Figure 1. Outstanding students and teachers of forest soils.

PART I

GENESIS OF FOREST SOILS

(Origin, Development, and Classification in Relation to Environmental Factors)

CHAPTER I

NATURE OF FOREST SOILS

> De même qu'il y a une pédologie agricole, il existe une pédologie forestière.
>
> E. Henry, 1907

In early writings of agronomists the soil was defined as "a mixture of sand, clay, lime, and humus." The geologists regarded soil as "product of weathering derived from minerals and containing decomposed remains of plants and animals" (Sprengel, 1837; Fallow, 1855). Pioneers in soil science recognized that "the soil is the weathered surface layer of the earth's crust which has been altered by the influence of water, air, organic matter, and living organisms" (Dokuchaev, 1886). Because the changes produced by environmental and biotic agents lead to the translocation of soluble salts and colloids and development of distinct layers, the soil was referred to as "a sequence of mutually interrelated horizons." (Zakharov). The definitions, formulated by the biologically-minded students, characterize soil as "a peculiar organism", "a lithosphere penetrated by the biosphere", or "a dynamic system" (Berthelot, Jarilloff, Stebutt).

All of these newer concepts are well founded and enlightening, but not entirely acceptable to a silviculturist interested in soil as a medium for forest growth. In many instances, forested soils are a product of weathering, composed of sand and clay particles and arranged in genetically interrelated horizons. Very often, however, forests grow on barren rocks, piles of gravelly detritus, deposits of peat, or even permanently flooded areas (Fig. 2). These substrata, disregarded in general definitions of soil, do not appear as rare exceptions, but cover vast areas in different parts of the world and often support forest stands of high commercial value. Obviously, the existence of such forest sites demands a broader concept of forest soils and a somewhat different approach to their studies and utilization.

In brief terms forest soil may be described as a <u>portion of the earth's surface which serves as a medium for the development of forest vegetation; it consists of a porous or unconsolidated layer of mineral and organic matter, permeated by varying amounts of water and air, and inhabited by organisms; it presents peculiar characteristics impressed by the physical and chemical action of the tree roots and forest debris</u>.

The depth of forest soils is determined by the penetration of tree roots and varies from a few inches to many feet. The lower limit of the forest soil is often delineated by the level of ground water, impermeable bed rock, or layer containing substances toxic to

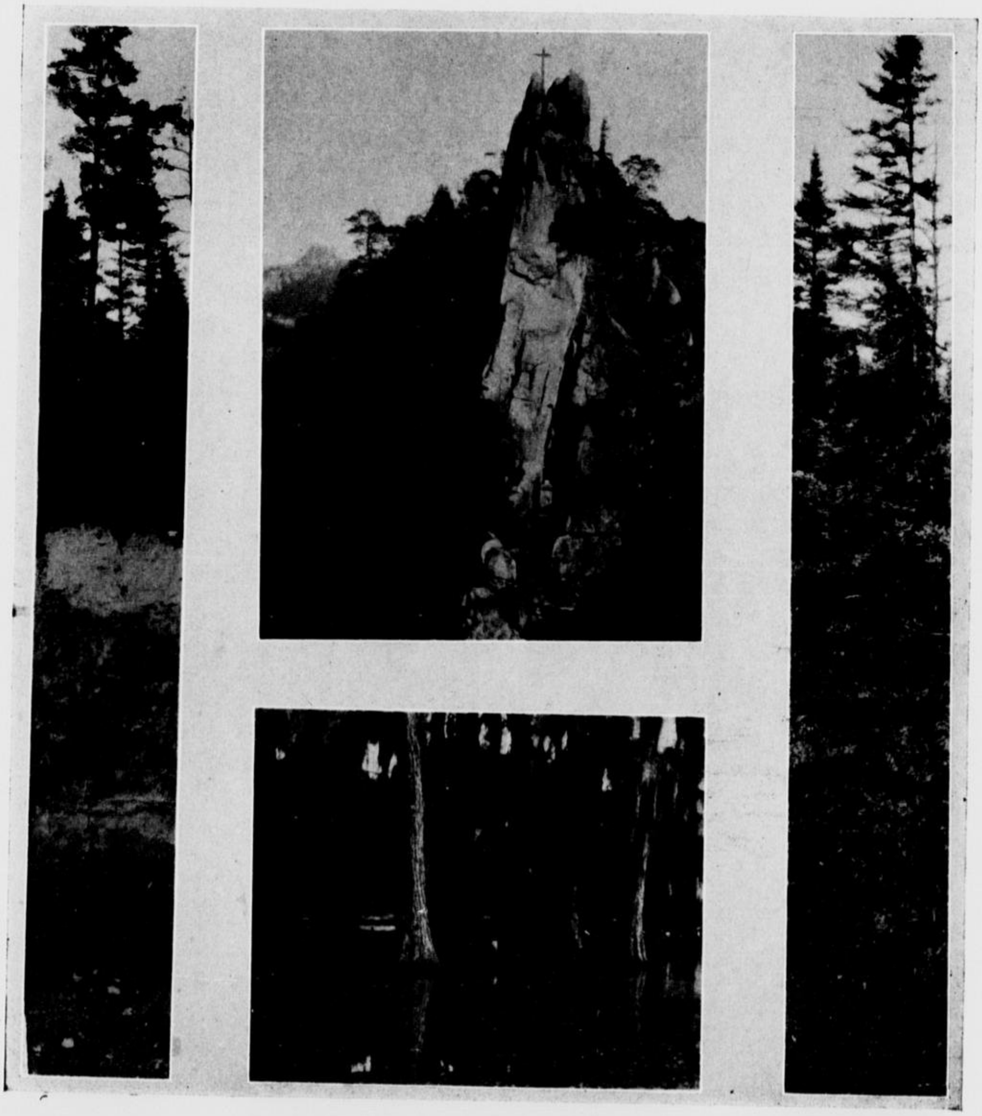

Figure 2. Rock outcrops, leached mineral soils with raw humus, deposits of peat, and flooded bottom lands are examples of forest soils.

the roots. As a rule, the essential features of forest soils can be learned by examining the soil to a depth of six or seven feet.

The mineral and organic constituents forming the body or skeleton of forest soils vary within very wide limits. In rock outcrops of forested mountains, the root systems of trees may be the chief source of organic matter, since in such situations the litter is often removed by wind and water. On the other hand, in the peat soils of swamp forests, the mineral material appears as a negligible ash fraction of plant remains. In the fine-textured soils, the content of organic matter usually varies from 3 to nearly 10 per cent by weight. Both mineral and organic fractions occur in forest soils in practically all states of division: piles of boulders, partly rotted logs, and ultra-microscopic particles of colloidal clays or humate suspensions are the extremes. With respect to the chemical composition and state of fertility, forest soils exhibit every conceivable variation: some soils are composed of nearly pure silica and support struggling stands of the least exacting species; others present a complex involving numerous mineral and organic compounds, and have a potential productivity comparable to the rich blackearths of prairie regions.

The liquid phase of forest soils consists of a rather heterogeneous mixture of water and weak solutions of salts, acids, and gases. Most of the air volume is made up of oxygen, nitrogen, argon, and carbon dioxide. Fungi are the most common organisms in forest soils; bacteria, actinomycetes, and nematodes occur less frequently; earthworms, insects and rodents are confined to a rather small portion of soils with a well decomposed humus.

Table 1 illustrates the approximate composition of a loam soil derived from granitic rocks and supporting a stand of hardwoods.

Table 1. Approximate Composition of a Slightly Acid Hardwood Humic Loam Derived from Granitic Rocks. (V = volume; W - weight).

SOLIDS
50% by V.

Inorganic 95% by W.		Organic 5% by W.	
Sand 40% by W.	Silt and Clay 60% by W.	Humus	Organisms
Feldspar Micas Quartz and accessory minerals	Silica, Kaolin, Iron and Aluminum oxides. Secondary minerals. Clay minerals	Lignin Cellulose Sugars Resins, Waxes Proteins, Ash	Roots, Bacteria, Fungi, Actinomycetes, Algae, Protozoa, Nematodes, Earthworms, Insects, Rodents

<u>LIQUIDS</u> (20% by V.)

Dilute water solutions of salts, acids and gases.

Sulfates, Nitrates, Chlorides; Bicarbonates of Calcium, Magnesium, Potassium, and Sodium. Traces of phosphates and other inorganic and organic compounds. Concentration of salts approaches 200 p.p.m.

<u>GASES</u> (30% by V.)

Air somewhat enriched in carbon dioxide.

Oxygen.	20.0%
Nitrogen.	78.6%
Argon	0.9%
Carbon dioxide.	0.5%

Traces of Ammonia, Hydrogen, and Hydrogen Sulfide.

The composition of forest soil is subject to constant changes, caused by the growth of trees and ground cover vegetation, activity of organisms, and effects of climatic agents. Under the influence of these factors, organic remains and mineral material undergo gradual decomposition or disintegration. The released soluble salts and colloids are carried downward by percolating water and soil organisms and are redeposited in the form of definite layers or genetic horizons. Weathering and translocation of released products constitute the process of soil development. Undeveloped or very young soils are not separated into distinct layers, and are called "embryonic" soils. As the differentiation into humic, depleted, and enriched horizons becomes pronounced, the soil attains a characteristic profile which reflects the influences of environmental factors. Such soils are designated as "mature" or "genetically crystallized" soils.

Because of the intimate relationship between soils, climate, and vegetation, soils tend to be distributed on the earth's surface as continuous regions, or zones, correlated with the climatic-vegetational zones. Strongly leached, ash-like podzols found in the region of northern coniferous forests, humus-deficient red laterites of tropical forests, and nut-structured degraded chernozems supporting oak stands in the prairie-forest border, are examples of zonal soil groups. Within these zones, local conditions of parent material or drainage give rise to "intrazonal" or "azonal" soils, such as embryonic soils of recent deposits, humus-calcareous or rendzina soils of limestone outcrops, and soils influenced by ground water, viz. gley soils and organic soils.

Forest soils cover about one-half of the entire land area of the globe and are bounded by non-forest soils, namely those of tundra, marshes, meadows, prairie, and desert (Fig. 3). Approximately one-tenth of the total forest soil area is occupied by farms although as much as one-third has potential agricultural possibilities. The remainder comprises "absolute forest land", i.e. soils of the mountains, rough glacial deposits, and swamps, unsuitable for agricultural use.

The subject of forest soils is comprised of three more or less independent aspects: the genesis of soils, i.e., their origin, development, and profile characteristics acquired due to the influence of various soil-forming factors, namely, climate, topography, ground water, parent rock, and vegetation; the properties of soils, including their physical, chemical, and biological characteristics; the effect of soils upon the forest vegetation, namely, composition of the forest stands and ground cover vegetation, rate of tree growth, quality of wood, vigor of natural reproduction, resistance of stands to diseases, and other silviculturally important features.

The applied knowledge of forest soils involves two broad phases: management of forest nursery soils, viz. regulation of watering, application of fertilizers, inoculation, cultivation, and control of parasitic organisms; soils in relation to silvicultural practice, or planting of trees, management of forest stands, and silvicultural cuttings.

The following list of references includes selected works dealing specifically with forest soils, or containing information

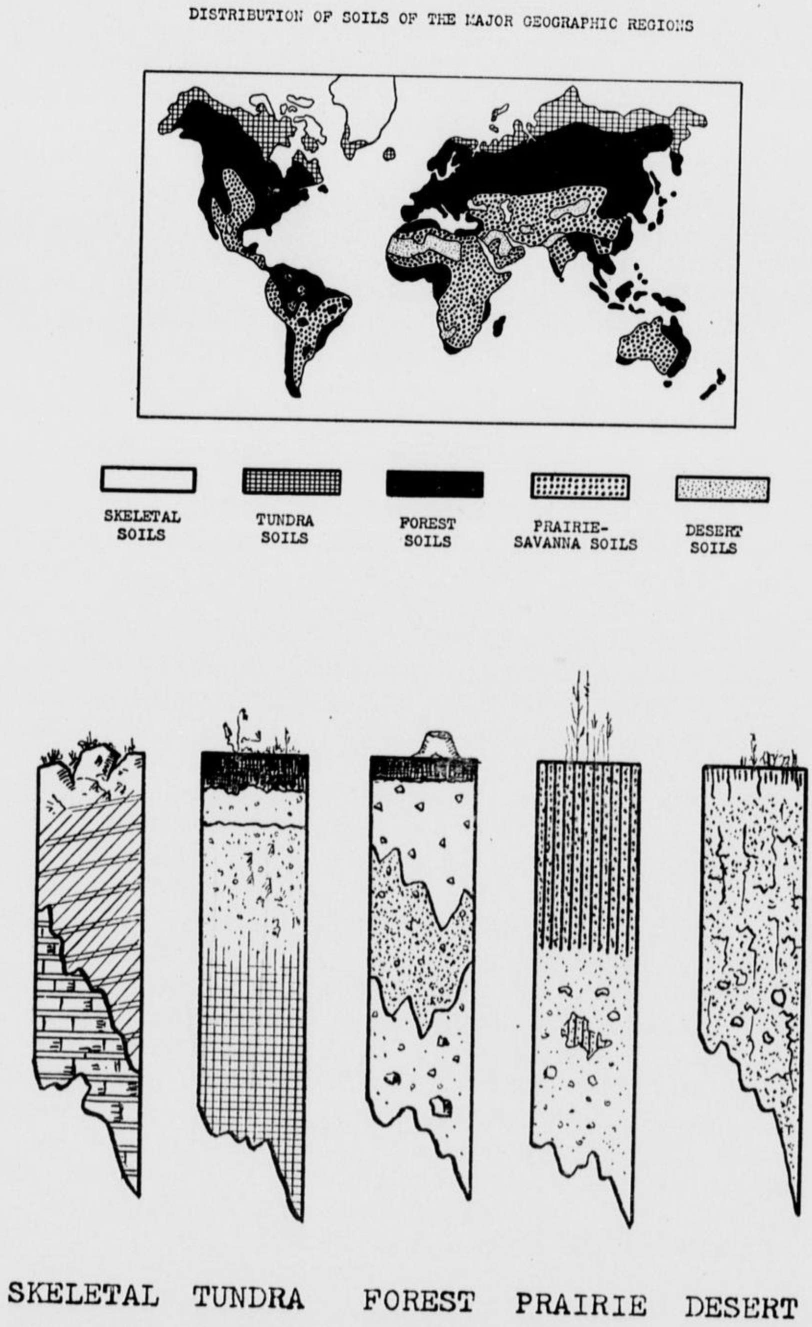

Figure 3. Soils of the Major Geographic Regions; Their Distribution and Morphological Features.

closely related to this subject. An acquaintance with these publications will provide a comprehensive background for those having a major interest in this field. The list is international in source, but is kept within the three commonly-known languages.

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CHAPTER II

PARENT MATERIAL OF SOILS

The surface of the earth presents a mosaic of rock outcrops, weathered residues, and deposits of various origin. All these formations, mineral as well as organic, serve as potential substrata for forest growth, or as parent material of forest soils. Upon the invasion of forest vegetation, the surface layer of the parent material becomes penetrated by the roots of trees, then covered with leaf-litter, and otherwise altered into a forest soil.

The study of parent material of soils coincides closely with the structural geology, and comprises the origin of the surface formations, their topographic features, textural characteristics, and mineralogical or petrographic composition. The entire subject may be conveniently reviewed under four headings: General features of the earth's surface; Soil- and rock-forming minerals; Soil-forming rocks; Soil-forming organic remains.

Surface Geological Formations

The formation of the earth's surface may be divided into three groups based upon their origin and the nature of soils produced: Residual formations, i.e., outcrops of igneous, metamorphic and sedimentary rocks, and the products of their weathering "in situ", giving rise to "residual" or "primary" soils; Transported formations or deposits of colluvial, glacial, fluvial, and aeolian origin, produced by the action of gravity, ice, water, and wind, respectively, and giving rise to "transported" or "secondary" soils; Cumulose deposits, i.e. accumulations of plant remains under conditions of excessive moisture and incomplete oxidation, giving rise to "organic" or "peat" soils.

Surface formations impart to the soils many important characteristics and constitute a convenient basis for a broad soil classification. A representative group of forest soils of different geological origin is assembled in Figure 4.

Rock outcrops and mantle rocks. Within forest regions, the occurrence of rock outcrops is confined to high mountains, steep slopes, and denuded areas of ground moraines. Root systems of trees clasp the rock surface and penetrate through the fissures, thus changing barren strata into rock outcrop soils. In accordance with the petrographic composition, granitic, sandstone, limestone, and like varieties of rock outcrop soils are recognized.

If conditions of climate and gradient permit, weathered material accumulates "in situ" as mantle rock or residuum offering forest vegetation a more favorable foothold. Residual soils vary in depth, texture, and chemical composition depending upon their age and character of their parent material.

Young residual soils consist of slightly weathered, coarse detritus which grades at a shallow depth into bed rock. The chemical composition of such soils is often the same as that of the underlying substratum.

Old residual soils are characterized by a greater depth and more finely divided particles. These soils have been subject to oxidation, hydration, and leaching for a long period and the chemical composition of their surface layers may differ essentially from that of the parent material. For instance, in the development of limestone soils, the calcium and magnesium carbonates may be entirely dissolved by water, and the upper layer of soil formed from silica, iron oxides, and other resistant impurities.

In many instances residual soils are not derived from the underlying bed rock, but from the disintegrated rock which at one time overlaid the present mantle rock. Under such conditions the soils "inherit" certain properties from the disintegrated rocks, and are called inherited soils.

Talus. The coarse-textured colluvial deposits, or talus slopes, are formed by fragments of rocks detached from the precipitous outcrops and carried down the slope by gravity. Cliff debris, rock

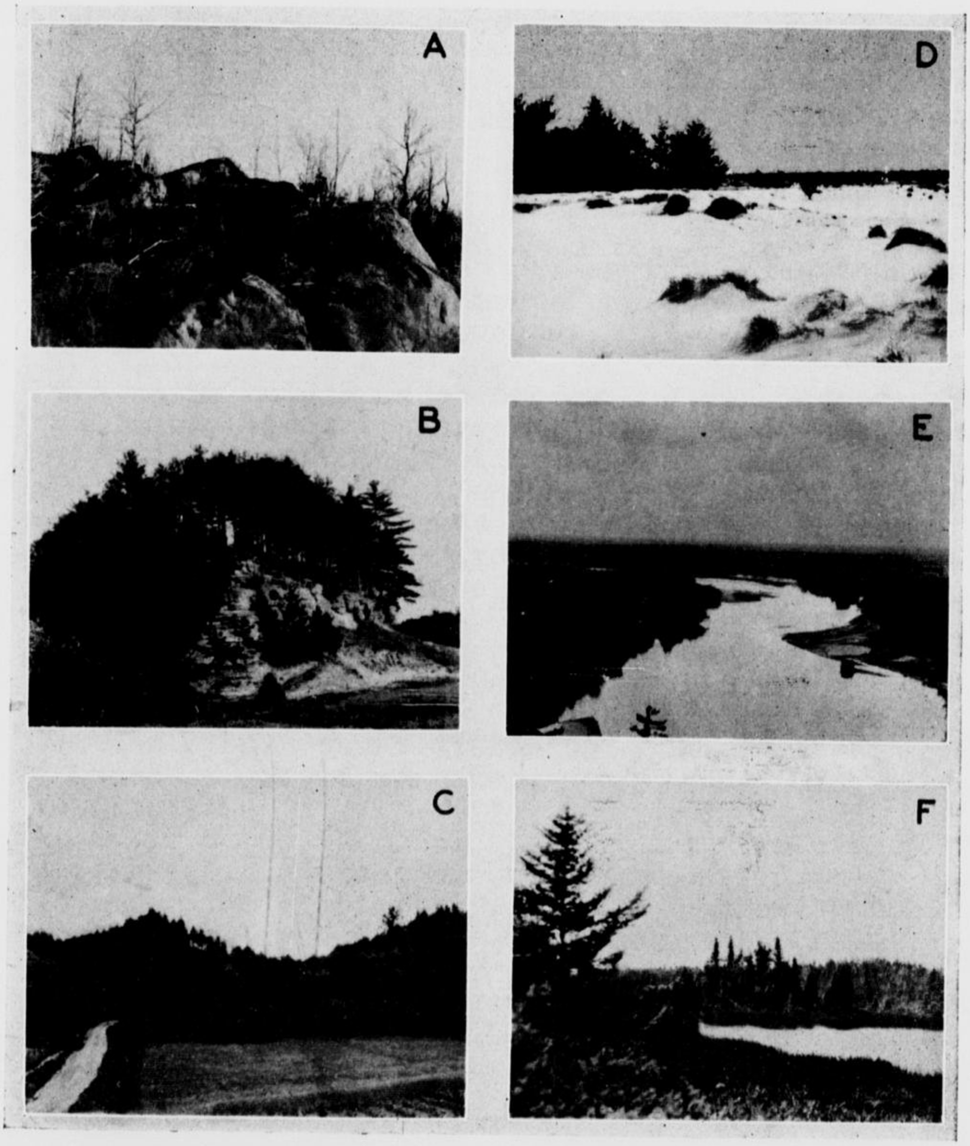

Figure 4. Forest soils of different geological origin: (a) Rock outcrops; (b) Residual soil derived from sandstone with talus at the foot of the knoll; (c) Level glacial outwash grading into terminal moraine; (d) Wind-blown sand; (e) Flood plain soils; (f) Cumulose deposits surrounding a shallow glacial lake.

falls, and avalanches are typical examples of rough and droughty talus soils. From the silvicultural standpoint such soils may differ but little from the rock outcrops.

Glacial deposits. The invasion of ice sheets during the Pleistocene period brought about fundamental changes in the surface geology of the glaciated regions. The glaciers displaced the surface soils, ground the underlying rocks, and deposited unassorted till. The water from the melting ice took up some of the deposited debris and laid it down again as stratified drift. The hummocky ridges accumulated in front of the invading ice formed end moraines or terminal moraines. Along the sides of the glacial lobes were deposited side moraines or lateral moraines. Periodic retreats of the ice produced recessional moraines similar to end moraines, but often arranged in lobes one behind the other. The ice movement compressed some material beneath it, and in melting left scattered detritus, thus forming the ground moraine. In the regions of ground moraine the action of glaciers sometimes gave rise to drumlins or "whalebacks", i.e. oval-shaped smooth unassorted knolls having their long axis parallel to the ice movement.

The soils developed on the ground moraines are characterized by a fairly level topography, presence of boulders, often shallow depth, and protruding polished rocks called "roches moutonnées" or "sheep backs". The smooth, youthful topography and the presence of impervious strata at shallow depths are often responsible for poor drainage of the ground morainic soils. The soils of terminal and recessional moraines are of rough topography, with embedded pebbles and boulders, and have widely variable proportions of sand and clay particles; they rest upon compact unassorted till, or "boulder clay". Because of the diversified topography and irregular occurrence of clay till, the drainage of these soils may show great variations within short distances. The soils of drumlins are similar to those of ground moraines.

Fluvio-glacial deposits. The streams and floods from the melting ice sheets carried in suspension eroded material which was gradually deposited forming the glacial outwash or a series of fans. The level outwash was produced by uniform sedimentation of gravel, sand, and silt over the flat areas, usually at some distance from the terminal moraine. Pitted outwash with its characteristic rolling topography and "kettle holes" resulted from the melting of ice blocks embedded in the deposits, or from the deposition of material over the rugged surface of the morainic border.

Outwash soils are predominantly of sandy or silt loam texture; other types occur in rare instances. At a depth of one or more feet, the surface layer usually grades into stratified subsoil of coarse sand and gravel. This porous substratum provides very efficient, or even excessive drainage. Freedom from stones is an important feature of outwash soils.

Fluvio-glacial deposits of limited distribution include kames and eskers. Kames are partly assorted gravelly hills or mounds accumulated at the edge of the glacier by melting waters. Eskers are winding ridges of irregularly stratified sand and gravel, deposited by sub-glacial streams. The soils of both kames and eskers are often coarse and droughty.

Lacustrine deposits. Lake-bottom sediments form level beds of silt or clay with gentle slopes of sandy material marking the previous shore line. Lacustrine clays are usually high in humus and carbonates, but deficient in both surface and vertical drainage. Most of the lacustrine soils are confined to glacial regions.

Marine deposits. These represent sea bottoms reworked by water, and left on the shore after the sea receded. The texture of sediment varies from sand to clay depending upon the depth of water at time of deposition and the force of the currents. Skeletons of animals and shells often enrich marine sands and "muds" in calcareous material.

Alluvial deposits. The action of streams in the post-glacial period produced three major types of deposits: stream bottoms, flood plains, and river terraces. Stream bottom deposits occur as narrow strips along creeks. A high content of organic matter and a ground water level near the surface, but not necessarily water stagnation, are common features of stream-bottom soils. Flood plain deposits are a result of the periodical over-flows. The soils of flood plains are often sandy in the proximity of the stream but grade into loams or clays farther from the stream. This is because the velocity of flood waters decreases from the stream to the limits of the flooded area. The drainage is likely to be adequate near the stream, but sluggish at a distance from it. The periodic inundations enrich flood plains in organic matter and soluble salts. River terraces are level or nearly level strips of land bordering flood plains. They result from the dissection of previous stream beds and are classified as "second bottom", "third bottom", etc. The soils of river terraces contain less organic matter and soluble salts and are better drained than flood plain soils.

Deluvial deposits. Overwash or deluvium is formed on the lower slopes of hills and mountains by the deposition of material eroded from the upper slopes. Soils of deluvium, as a rule, have a greater depth, a finer texture, and a higher content of humus and nutrients than the residual soils of the upper denuded areas. In places the overwash covers "relic" or buried soils, and thus deluvial soils may have two or more superimposed humus horizons.

Aeolian deposits. The action of wind produced two sharply defined types: loess and blow sands. Loess is a uniform deposit of comparatively unweathered silt of yellowish buff color. It varies in depth from a few inches to nearly a hundred feet. The soils of loessial origin have nearly ideal physical properties and very high potential fertility. Their geographic distribution, however, seldom coincides with climatic conditions favorable to forest growth. Blow sands originate due to destruction of the stabilizing vegetative cover. In places they form sand dunes which may be several hundred feet deep, and may advance over a region at a rate of nearly a hundred feet per year. Wind blown sands lack colloidal material and are deficient in both moisture and nutrients.

Cumulose deposits. The cumulose of "piled up" deposits are formed by the remains of vegetation accumulated in shallow water basins, or on uplands of the high mountains and subarctic regions. The deposits of this nature include various types of peat and muck. Lowland prairie or meadow soils, and even true blackearth soils, may also be considered as cumulose deposits. Forest soils of cumulose deposits are deficient in draina ge and often poor in nutrients.

Figure 5 illustrates schematically the outstanding topographical features of various geological formations. Figure 6 includes several representative profiles of parent soil materials.

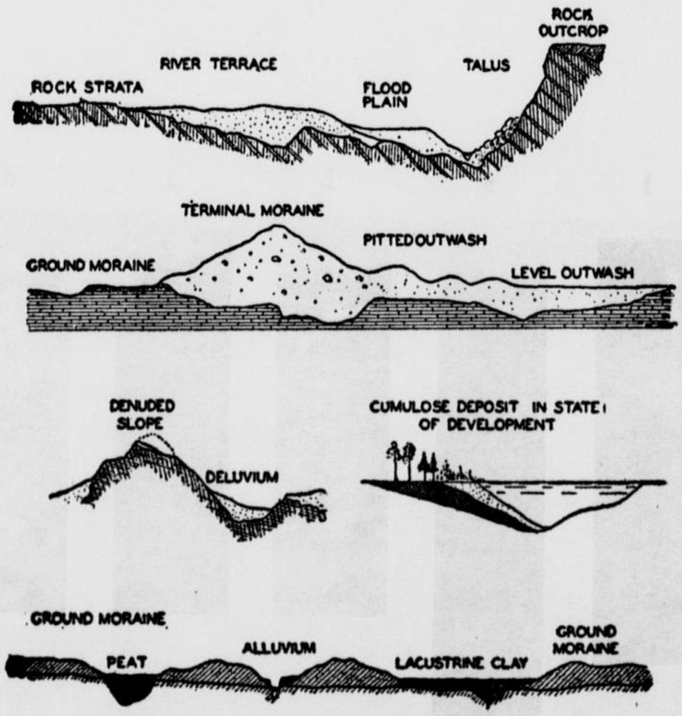

Figure 5. Topographical features of the surface geological formations

Soil-forming Minerals

The earth's crust is composed of more than ninety elements. Many of these are essential in plant nutrition but only about fifteen form the bulk of soil material. These are: oxygen (O), hydrogen (H), carbon (C), nitrogen (N), phosphorus (P), sulphur (S), chlorine (Cl), silicon (Si), aluminum (Al), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). With some exceptions these elements are combined as minerals. A discussion of the relatively few minerals that exert an important influence upon soil properties follows.

Quartz, SiO_2 (Silica). A very hard, white to drab mineral having specific gravity of 2.65; it occurs in soils as round or angular grains, often coated with red or yellow iron oxides. It is resistant to weathering, inactive, and forms the coarser fraction or "skeleton" of soil. Siliceous sandy soils may ha ve as much as 95 per cent of quartz.

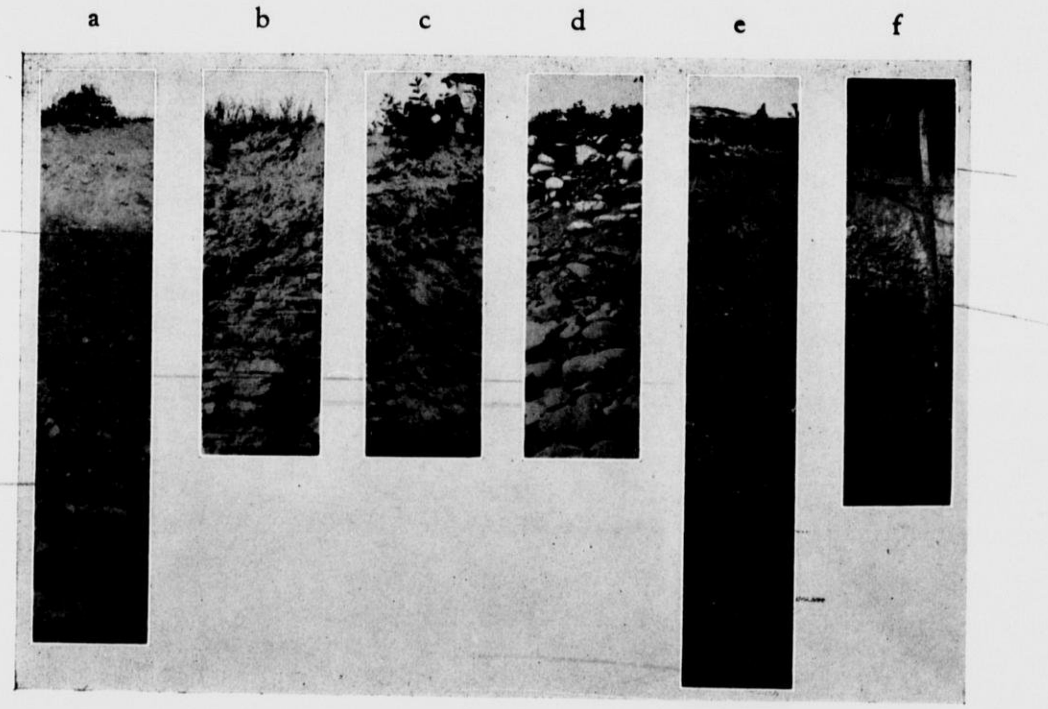

Figure 6. Soils derived from parent material of different geological origin: (a) Deep residual clay loam from schist; (b) Shallow residual silt loam from limestone; (c) Stony loam of ground moraine; (d) Stony and gravelly sandy loam of terminal moraine; (e) Assorted silt loam with stratified sand and gravel substratum of glacial outwash; (f) Clay of lacustrine deposit.

Orthoclase, KAl-silicate (Potassium feldspar). White to red, nearly as hard as quartz, with a well defined cleavage at angles of about 90 degrees and a specific gravity of 2.5. A rather easily weathered, widely distributed soil-forming mineral; an essential constituent of granitic rocks and a source of potash.

Plagioclase, CaNaAl-silicate (Calcium feldspar). White to dark-gray, with distinct cleavage, hardness approaching that of quartz and a specific gravity of 2.7. It is similar to orthoclase but weathers more easily; an essential constituent of granitic and basic rocks, and a source of calcium.

Muscovite, $AlKSiO_4$ (Potash mica). White to light-brown folia, known as "isinglass" or "white mica"; very soft and can be scratched with the finger nail. Specific gravity - 2.8. Widely distributed, and is especially abundant in schists; a source of potash, but weathers with difficulty.

Biotite, AlFeMgK-silicate (Iron-magnesium mica). A black to brown folia, known as "black mica". It is similar to muscovite but less resistant to weathering; source of magnesium, potassium, and iron.

Hornblende, Augite and Pyroxene, FeMg-silicates (Ferro-Magnesian minerals). Black to green, fairly hard and rather heavy with specific gravities of 3.0 to 3.7. Common, easily weathered soil-forming minerals; essential constituents of basic rocks and the source of many plant nutrients, particularly calcium, magnesium, potassium, and iron.

Apatite, $Ca_5F(PO_4)_3$ (Calcium phosphate). Brown, green, or black, of moderate hardness, barely scratches glass. Specific gravity - 3.2. A source of phosphorus.

Calcite, $CaCO_3$ (Calcium carbonate). Colorless, brown or red; vitreous, with distinctive rhombic cleavage. It effervesces with dilute hydrochloric acid and is scratched by copper coin, but not by fingernail. Specific gravity - 2.7. The essential constituent of limestone soils; causes alkaline reaction, and in excess is detrimental to forest vegetation.

Dolomite, $CaMg(CO_3)_2$ (Calcium-magnesium carbonate). White to brown, glassy to dull, slightly harder than calcite. It does not readily effervesce in cold dilute hydrochloric acid and has a specific gravity of 2.8. It occurs in many limestone soils, being similar to calcite, but more resistant to weathering.

Hematite, $2Fe_2O_3$ (Iron oxide). Red or brown, of an earthy nature, with a cherry red streak. It is slightly softer than glass, and has specific gravity of 4.5 to 5.3. Commonly formed in forest soils, it imparts reddish color and indicates oxidizing conditions.

Limonite, $2Fe_2O_3.3H_2O$ (Hydrated iron oxide). Yellow to brownish in color, compact or earthy, somewhat softer than hematite, with specific gravity of 3.6 to 4.0. It occurs as common "iron rust"; causes yellowish color or yellowish tints of soils and indicates oxidizing conditions.

Siderite, $FeCO_3$ (Ferrous carbonate). Green or grey to black, somewhat harder than calcite; specific gravity - 3.8. It occurs chiefly in water-logged strata of soils to which it imparts greenish color; indicates deficiency of aeration and reducing condition.

Kaolinite, HAl-silicate (Hydrated aluminum silicate). A white or yellow, very soft earthy mineral, having clay odor. Specific gravity - 2.5. A widespread constituent of clays. It is not as important in exchange reactions as had formerly been thought.

Zeolites, $R(SiO_3)_x.nH_2O$ (Hydrated silicates). Light colored, unstable minerals, which swell and lose their combined water upon slight heating. They possess capacity for cation exchange but because of their instability are rarely found in soils.

Clay Minerals. (Aluminum and iron silicates containing bases and hydrogen). These minerals are white, yellow or brown; soft and very finely divided, with specific gravities around 2.5. They possess high absorptive or base exchange capacity and are found extensively in soils of heavy texture. They were previously classed with zeolites.

Soil-forming Rocks

The consolidation of minerals into rocks took place through different geological processes, in which heat, pressure, and sedimentation were the most important factors. The rocks thus formed are classified into three groups: (a) Igneous rocks, formed by cooling of molten magma; (b) Sedimentary rocks, formed by cementation of deposited materials; (c) Metamorphic rocks formed from the above classes by the influence of heat and pressure.

The most important rocks in each of these groups are listed below:

Igneous rocks: granite, syenite, felsite, gabbro, diorite, diabase, basalt, and porphyries.

Sedimentary rocks: sandstone, conglomerates, shales, limestone, dolomitic limestone and chalk.

Metamorphic rocks: gneiss, schists, slates, quartzite.

From the standpoint of soil study the rocks may be classified into five groups based chiefly upon their mineralogical composition, namely: acidic or granitic rocks, basic or ferro-magnesian rocks, siliceous rocks, clay rocks, and calcareous rocks.

I. Acidic rocks or granitic rocks are igneous or metamorphic rocks including granite and its varieties.

Granite is a light colored, coarse and even grained rock, composed of quartz, feldspar, and micas. It also contains small quantities of apatite and hornblends. Syenite is of similar appearance and composition, but with little or no quartz. Felsites are either granites or syenites of very fine texture. Granitic porphyry is finely grained granite of mottled appearance due to coarse crystal inclusions of quartz or feldspar. Gneiss is metamorphosed granite, having a banded structure and a high content of mica.

The rate of weathering of granitic rocks depends upon their texture and composition. Coarse grained granite, syenite, and gneiss break down rather readily, but give rise to coarser soils. Finely grained or felsitic granites and porphyry break down more slowly, but produce heavier soils. The presence of magnesium mica is conducive to weathering, whereas the presence of potassium mica has the opposite effect.

Soils derived from granite are commonly of sandy loam or loam texture. The soils from syenite have heavier texture due to the high percentage of feldspar. Soils from gneisses are somewhat sandier, because of abundant foliae of undecomposed mica. Soils from porphyry are characterized by the considerable amount of coarse skeleton material. In general, forest soils derived from granitic rocks have an acid reaction, and a high potassium, fair phosphorus, and low lime content.

II. Basic or ferro-magnesian rocks include igneous and metamorphic rocks high in ferro-magnesian minerals, chiefly hornblende and pyroxene.

Diorite is a mottled, medium dark colored rock of a granitoid but fine grained texture; it is composed chiefly of hornblende and plagioclase with some quartz, orthoclase, biotite, pyroxene and apatite. Gabbro is a dark or black, coarse grained rock of a composition similar to diorite, except that it is considerably lower in silica and higher in iron, magnesium, and lime. Diabase is greenish, diorite-like rock, composed chiefly of pyroxene, hornblende, plagioclase, apatite, biotite, and sometimes with intrusions of calcite. Basalt is fine grained or felsitic gabbro. Schists are dark, finely foliated ferro-magnesian rocks, derived by metamorphic changes.

In general, ferro-magnesian rocks are fairly easily weathered and yield deep, heavy, and fertile soils. These soils are high in lime, magnesia, iron, soda, and often phosphoric acid, but rather poor in potash. Diorite weathers more slowly than other varieties and more often gives rise to shallow and gravelly soils. Schists break up easily into smaller pieces, but do not always decompose entirely and produce micaceous sandy loam soils. Soils derived from basic rocks have a tendency to maintain a neutral reaction.

III. Siliceous rocks are either sedimentary or metamorphic rocks, consisting predominantly of quartz.

Sandstone is largely quartz, cemented by varying amounts of silica, lime, iron, kaolin or clay. The character and amount of cementing material determines, to a certain extent, the rate of weathering and the productivity of the resulting soil, which may be either of sandy or of sandy loam texture with various amounts of lime, iron, and other essential nutrients. Conglomerates are gravels cemented in a way similar to sandstone. The rate of weathering and the productivity of soils depends likewise on the composition of the cementing material. Quartzite is metamorphosed sandstone or conglomerate. It is very difficultly weathered and yields shallow siliceous loams or sandy loam soils.

IV. Clay rocks are either sedimentary or metamorphic varieties of kaolin.

Shales are hardened clays, commonly stratified. They are usually dark, but may be red, brown or green. The basic mineral is kaolin, with varying amounts of accessory minerals or impurities, such as quartz, mica, iron minerals, feldspar, calcite, and ferro-magnesian minerals. Slates are hard, fine grained, easily splitting rocks of different colors. They have a similar composition to the shales from which they were derived by processes of metamorphism.

Clay rocks vary considerably as to the rate of weathering and productivity of derived soils. Shales low in quartz and high in accessory minerals and lime give rise to deep and heavy clay or clay loam soils that have a fair content of nutrients. Shales high in quartz and low in accessory minerals give rise to sandy as well as heavy soils poor in nutrients. Slates weather difficultly and give rise to loam soils with abundant flat fragments of undecomposed rock; these soils are often too shallow to produce high yields of timber.

V. Calcareous rocks include different varieties of limestone.

Limestone is calcite, mixed with different amounts of clay. Magnesium limestone is a mixture of clay with both calcite and dolomite. Cherty limestone is limestone with embedded fine grains, lenses, or strata of chert or flint. Chalk is a crumbly limestone, composed of microscopic shells.

Since calcium carbonate is soluble in water, pure limestone is easily weathered and the clay residue forms deep heavy soils. These soils tend to maintain an alkaline reaction. The admixture of other materials, such as dolomite, chert, or chalk greatly modifies the weathering properties of limestone and the productivity of the resulting soils. Dolomitic limestones are more difficultly weathered and usually form the higher portions of the topography in limestone regions. Cherty limestones weather slowly and produce stony, gravelly, or somewhat sandy soils. Chalk weathers rather rapidly, but produces unfertile forest soils. The productivity of limestone soils is in direct proportion to the amount of clay in the parent material. Soils from pure limestone are deficient in potash and phosphorus.

Soil-forming Organic Remains

Natural organic deposits are composed of the five broad groups of compounds:

Carbohydrates, or nitrogen-free compounds of the general formula $C_mH_{2n}O_n$, including starches, sugars, celluloses, hemi-celluloses, and lignin; Proteins, or nitrogenous compounds, and their derivatives, such as peptones, alkaloids, and amino-acids; Fats and related compounds, namely oils, waxes, and resins; Organic acids, such as citric, oxalic, tannic, tartaric, and numerous others; Ash, including oxides of calcium, magnesium, potassium, phosphorus, sulfur, and other elements.

The relative content of various constituents, viz. sugars, celluloses, lignin, proteins, etc. reflects not only the origin of the remains, but also the type and degree of decomposition, thus characterizing the nature of organic deposits. For example, low content of proteins is indicative of highmoor or moss peats; low content of lignin or high content of celluloses suggest slightly decomposed debris; high content of ash is a property of muck deposits, and so forth.

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CHAPTER III

WEATHERING OF ROCKS AND DECOMPOSITION OF ORGANIC REMAINS

Rocks exposed to the forces of environment undergo gradual disintegration and decomposition, referred to as "weathering". Although the action of all the environmental factors is intimately interrelated, three more or less distinct phases of weathering are recognized, namely physical, chemical and biological.

Physical Weathering

Unequal expansion and contraction resulting from changes in temperature lead to the rupture of rocks. Water, as it expands on freezing, exerts a similar effect. The erosive action of wind, rain and running water also greatly aids the process of disintegration and the formation of finer materials, particularly gravel and sand.

Chemical Weathering

Physical weathering ordinarily is only a preliminary to more profound changes in the composition of the parent material caused by chemical processes, such as solution, hydrolysis, carbonation, hydration, dehydration, oxidation, and reduction. In chemical weathering the environment supplies reagents in the form of water, oxygen, carbon dioxide, and organic as well as mineral acids. These react upon the silicate and alumino-silicate compounds of the parent material, which are composed of strong K, Na, Ca, and Mg bases and weak H_2SiO_3, H_4SiO_4, $H_4Si_3O_8$, and $H_2Al_2Si_6O_{16}$ acids.

Because of ionic dissociation, the molecules of salts, acids and bases split up in water solution into positively-charged metallic or hydrogen ions and negatively-charged acid radical or hydroxyl ions. Thus the solution of potassium nitrate or calcium chloride may be expressed in the following manner:

$$KNO_3 + HOH \rightleftharpoons K^+ + NO_3^- + H^+ + OH^-, \text{ or}$$

$$CaCl_2 \xrightarrow{H_2O} Ca^{++} + 2Cl^-$$

The dissociated salts may exchange their ions and form new compounds. For instance, calcium nitrate and potassium carbonate are likely to react:

$$Ca(NO_3)_2 + K_2CO_3 \rightleftharpoons 2KNO_3 + CaCO_3$$

The degree of dissociation is especially great when the concentration of the solution is low, and when strong bases and acids are involved. This explains the fact that water appears to be a universal solvent, dissolving to some extent a great majority of minerals.

The solvent capacity of water is considerably increased by hydrolysis; that is the ability of water to produce a small amount of free H and OH ions which attack difficultly soluble compounds.

The conversion of carbonates into bicarbonates is a typical example:

$$Na_2CO_3+HOH \rightleftharpoons NaHCO_3+NaOH$$

Hydrolysis is usually reinforced by carbonation. Carbon dioxide, upon dissolving in water, forms carbonic acid and thus increases the concentration of free or active hydrogen ions. Carbonic acid reacts with the minerals of parent material and forms bicarbonates and carbonates, which are partly removed in solution. The carbonation of calcium silicate with the formation of calcium carbonate and calcium bicarbonate proceeds as follows:

$$CaSiO_3+H_2CO_3 = CaCO_3+SiO_2+H_2O$$

$$CaCO_3+H_2CO_3 \rightleftharpoons Ca(HCO_3)_2$$

Under the combined influence of hydrolysis and carbonation, feldspar may be broken into kaolinite, potassium carbonate and silica:

$$2KAlSi_3O_8+2H_2O+CO_2 = Al_2O_3.2SiO_2.2H_2O+K_2CO_3+4SiO_2$$

The combination of the same processes is largely responsible for conversion of difficultly soluble tricalcium or rock phosphate into soluble monocalcium phosphate and calcium bicarbonate:

$$Ca_3(PO_4)_2+4H_2O+4CO_2 \rightleftharpoons CaH_4(PO_4)_2+2Ca(HCO_3)_2$$

Many minerals are subject to hydration, that is combination with one or more molecules of water of crystallization. In this way, gypsum may be formed from calcium sulfate or anhydrite:

$$CaSO_4+2H_2O = CaSO_4.2H_2O$$

In hydration the minerals tend to lose their hardness, elasticity, and luster, and to increase their volume. High temperature may lead to dehydration, by which process yellow limonite may be changed into red hematite.

$$2Fe_2O_3.3H_2O = 2Fe_2O+3H_2O$$

Incompletely oxidized minerals are converted into higher oxides by reaction with oxygen or other oxidizing agents. The process of oxidation brings about color changes and progressive disintegration of minerals and rocks. Oxidation takes place most intensively on the surfaces of rocks and minerals exposed to atmospheric oxygen. Ferrous sulfide, or pyrite, may be oxidized to ferrous sulfate and finally into ferric sulfate:

$$2FeS_2+7O_2+2H_2O = 2FeSO_4+2H_2SO_4$$

$$4FeSO_4+2H_2SO_4+O_2 = 2Fe_2(SO_4)_2+2H_2O$$

Similarly, ferrous carbonate, or siderite, may be converted into hematite:

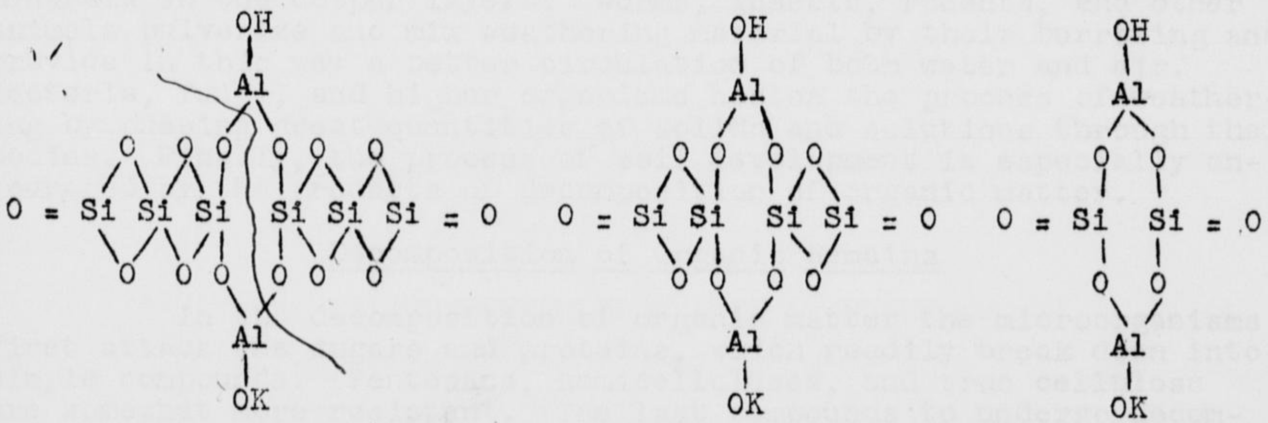
$$4FeCO_3+O_2+3H_2O = 2Fe_2O_3.2H_2O+4CO_2$$

Under conditions in which oxygen is deficient, deoxidation or <u>reduction</u> may occur. Reduction leads to the formation of less stable compounds and sometimes increases their solubility. Reduction of difficultly soluble ferric oxide by hydrogen sulfide and subsequent carbonation into readily soluble ferrous carbonate is a process particularly common in the development of forest soils:

$$Fe_2O_3 + 2H_2S = FeO + FeS_2 + 2H_2O$$

$$FeO + H_2CO_3 = FeCO_3 + H_2O$$

In many instances the chemical changes which a mineral undergoes in the process of weathering may be conveniently presented and more easily understood by the use of structural formulas. The following structural formulas illustrate the weathering of feldspar:



Orthoclase — Pyrophyllite — Kaolinite or clay

$KAlSi_3O_8$

As a general rule, the equations expressing the weathering processes have only a schematic significance, since in nature the chemical reactions are complex and interwoven with the activity of organisms. Although the weathering reactions proceed very slowly, they lead to far-reaching changes because of the length of time involved and the enormous quantity of reagents supplied by the atmosphere in the form of water, oxygen, and carbon dioxide.

The final result of all the transformations of chemical weathering is a mixture of partly decomposed fragments of original rock and new compounds, which occur either as solids, colloids or solutions. The mineral content of the weathering material may be outlined as follows:

<u>Primary minerals of the parent material</u>: quartz, orthoclase, plagioclase, muscovite, biotite, augite, amphibole, magnetite, pyrite, apatite;

<u>Secondary minerals formed in weathering</u>: hydrated aluminosilicates; clay minerals, kaolin; sericite or muscovite enriched in silica; limonite, chlorite, serpentine;

<u>Soluble products</u>: free silica, silicic acid, and salts of alkali, alkaline earth, and other metals, especially K_2CO_3, Na_2CO_3, $CaCO_3$, $MgCO_3$, $FeCO_3$, $FeSO_4$, and $Ca_3(PO_4)_2$.

Minerals precipitating from solution: Opal, chalcedony, glauconite, calcite, dolomite, siderite, limonite, gypsum, phosphorite.

Biological Weathering

The chemical processes of weathering are aided greatly by the activity of plants and animals. The first pioneers on unweathered rocks are bacteria, fungi and algae. The bacteria and fungi can utilize nitrogen from the air and supply it to green plants. Algae contain chlorophyll and are able to assimilate carbon dioxide and so provide in turn carbohydrates to organisms lacking in chlorophyll. The symbiotic action of the lower organisms gradually enriches geological material in organic matter and facilitates the invasion of higher plants and animals. The roots of trees, shrubs, and herbs secrete carbon dioxide which, in water solution, dissolves the minerals in the deeper layers. Worms, insects, rodents, and other animals pulverize and mix weathering material by their burrowing and provide in this way a better circulation of both water and air. Bacteria, fungi, and higher organisms hasten the process of weathering by passing great quantities of solids and solutions through their bodies. Finally, the process of soil development is especially encouraged by the products of decomposition of organic matter.

Decomposition of Organic Remains

In the decomposition of organic matter the microorganisms first attack the sugars and proteins, which readily break down into simple compounds. Pentosans, hemicelluloses, and true cellulose are somewhat more resistant. The last compounds to undergo decomposition are oils, fats, waxes, resins, and lignin.

Under aerobic conditions carbohydrates are transformed into soluble compounds which are oxidized to carbon dioxide and water. Under anaerobic conditions methane and hydrogen are produced in addition to water and carbon dioxide. The decomposition of carbohydrates may be represented by schematic equations:

Hydrolysis of cellulose into sugar:

$$(C_6H_{10}O_5)_n + n\,H_2O \longrightarrow nC_6H_{12}O_6$$

Complete oxidation of sugar under aerobic conditions:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

Incomplete oxidation of sugar under anaerobic conditions:

$$C_6H_{12}O_6 + 2O_2 \longrightarrow 4CO_2 + 2H_2O + 2CH_4$$

The proteins are converted into amino-acids which are hydrolyzed and oxidized with the release of ammonia. The ammonia in turn is oxidized into nitrites and finally into nitrates. Water, carbon dioxide, and nitrates are the final products of oxidation of proteins under aerobic conditions. Under anaerobic conditions the products of protein decomposition are ammonia and incompletely oxidized organic compounds.

A general scheme of the formation of simple nitrogen compounds from amino-acids may be given as follows:

$$2CH_3OHNH_2COOH + H_2O + O_2 \longrightarrow C_2H_5OH + CH_3COOH + 2CO_2 + 2NH_3$$

$$2NH_3 + 2O_2 \longrightarrow 2HNO_2 + 2H_2O$$

$$2HNO_2 + O_2 \longrightarrow 2HNO_3$$

Numerous organic acids are formed as intermediate products in the decomposition of organic remains. When unfavorable conditions of temperature, moisture, and aeration retard the decomposition, the acids accumulate in quantity. They prevent the formation of carbonates, and bring into solution, not only easily soluble bases, but also difficultly soluble sesquioxides such as those of iron and aluminum.

The decomposition of organic matter releases varying amounts of energy, which is used for the growth and activities of the soil microorganisms. At the same time the decomposition liberates the mineral fraction of organic remains including soluble salts of calcium potassium, phosphorus, and other essential elements. This liberation of mineral salts is referred to as "mineralization" of organic matter.

The most persistent part of soil organic matter, consisting of lignin and related compounds, is converted into a highly dispersed, black humus material. Humus possesses high water-holding and exchange capacity; it is saturated either with hydrogen, replaceable bases, or ammonia. These properties combined with the high mobility of organic colloids make the dispersed humus an extremely active agent in weathering and the development of soil.

The Role of Weathering in Development of the Soil

The composition of the final products of weathering depends upon the conditions of climate, and three fundamental types of weathering may be recognized within the boundaries of forest regions: physical disintegration, kaolinization, and laterization.

Disintegration is the only process active in cold as well as dry climates; it is characterized by inhibited biological and chemical processes and accumulation of coarse skeletal material. This type of weathering ultimately produces either sandy or sandy gravelly detritus deficient in clay particles and, hence, base exchange material.

Kaolinization is common in temperate regions and is characterized by oxidation, leaching, and partial desilication, but not destruction of the kaolin or, more correctly, aluminum-silicate nucleus (Zakharov). This type of weathering tends to produce parent material of loam, silt loam, or clay loam texture, high in clay minerals, and, hence, exchange properties.

Laterization is confined to hot and humid tropical climates, and is characterized by extreme leaching, desilication, and destruction of the aluminum-silicate nucleus with the release of hydrated aluminum and iron oxides. This type of weathering tends to produce material of clay texture, deficient in base exchange constituents.

Weathering is a geological process, extending to a considerable depth in the earth's strata; it plays an important, but a rather indirect part in development of the soil profile, that is, translocation of salts and colloids within a relatively shallow portion of the w eathered mantle. Regardless of the type of weathering, the mantle rock or parent soil material may undergo one of the three basic processes of profile development common to forest soils, i.e., incorporation of humus or melanization, leaching or podzolization, and deoxidation by ground water or gleization.

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CHAPTER IV

DEVELOPMENT OF THE SOIL PROFILE

Soil as a Sequence of Horizons

Young or embryonic forest soils of denuded slopes or recent deposits have only two layers: the upper, an accumulation of plant remains, called litter; the lower, more or less uniform mineral material. After the soil has supported vegetation for a longer period of time, additional layers are formed. The litter becomes partly decomposed and the humified material is gradually infiltrated by percolating water or incorporated by organisms into the upper portion of the mineral soil, giving rise to a dark, partly mineral and partly organic layer, called the humic horizon. This darkening or melanization of the soil surface constitutes the initial phase in the development of the soil profile, common to forest soils of all regions. In some instances, the conditions of climate, vegetation, or parent material prevent appreciable leaching of salts and colloids, and thus give rise to a large group of melanized soils, whose outstanding characteristic is the horizon with incorporated humus.

Under other conditions, the percolating water, reinforced with carbon dioxide and organic acids, leaches a certain fraction of humus and mineral salts from the upper soil layers. At a certain depth the mobile fractions are precipitated or flocculated due to the presence of bases or other conditions. As a result of this translocation of mineral and organic substances, or podzolization, the soils show three additional layers: a leached or eluvial horizon; an accumulative or illuvial horizon; and the parent material of soil, unaltered by the soil-forming processes.

Aside from the action of the percolating water, the character of the soil profile may be influenced by ground water. Capillary action may carry dissolved salts to the upper part of the soil profile, where they are recrystallized by evaporation. Some of these salts may be permanently fixed by oxidation into insoluble compounds. The ground water also translocates, in its periodic fluctuations, the colloidal particles and causes the hydrolysis and reduction of some chemical compounds, forming sticky and mottled "gley" horizons. These changes of soil profile, or gleization, constitute the third and the final process which may affect the development of forest soils.

Designation of Soil Horizons

The horizons of forest soil are designated according to Glinka by different letters:

A_0 - Undecomposed and partly decomposed organic debris, such as forest litter, duff, and peat. This layer is subdivided sometimes into A_{00}, i.e. undecomposed organic remains or "leaf litter", and A_0, i.e. partly decomposed organic remains or "duff".

A_1 - Humic or "melanized" horizon consisting of mineral matter and humus. This horizon is of a dark color and is usually high in nutrients.

A_2 - Leached, "podzolic" or eluvial horizon, depleted in soluble salts and organic matter. It is commonly coarser in texture than the underlying layer. If leaching is intensive enough to remove iron compounds, the horizon attains a light color; in extreme cases it becomes ashy-grey or white.

B - Enriched, "accumulative" or illuvial horizon, containing soluble salts and colloidal humus. Depending on the nature of soil-forming process, it may be structured or compacted, or cemented to form an impervious strata, referred to as "hardpan", "ortstein" or "claypan". This horizon is often subdivided into B_1, B_2, etc., depending upon its chemical and morphological composition. The color tends to be brownish or reddish.

C - Parent material of soil, consisting of either unweathered or weathered mineral matter. This layer may be subdivided into C_1 or C_2 to distinguish the strata of different geological origin, or to distinguish the weathering part from the solid bed rock.

G - Water-logged or "gley" horizon, formed by the influence of ground water and characterized by the presence of ferrous iron and other reduced compounds. It occasionally has some organic matter and may contain H_2S, NO_2 and other products of anaerobic decomposition. It is characterized by greenish, bluish and reddish mottling. In some instances the mottling is masked by infiltrated organic matter. The seasonal fluctuations of ground water may produce distinct eluvial or impoverished gley layers, and illuvial or enriched gley layers, designated as G_1 and G_2.

The original version of this system of profile designation was introduced by Dokuchaev in connection with the study of chernozem soils, i.e. soils comprised of the three A, B and C horizons. When the same method was extended to forest soils with four or more layers, the letters were sub-classified by numerical symbols and the system became somewhat cumbersome. Further complications arose when Dokuchaev's scheme was applied to soils of arid climates. As a result numerous modifications and substitutes were proposed at different times.

In the Kossovich adaptation, the leached horizon was designated by the letter B instead of A_2; the accumulative horizon and parent material were subsequently designated by the letters C and D. A careful reading of a profile description is, therefore, always necessary to determine which system of designation is followed.

Hesselman suggested the use of F-layer for the undecomposed and partially decomposed forest debris, and H-layer for humified remains. However, in many instances, the boundary between these two sub-horizons is poorly defined, and their separation is more justified in special humus studies than in general soil investigations. In some recent writings the surface litter, or L-layer, is separated from the partly humified, fermenting F-layer.

Wissotzky devised a new Latinized nomenclature for all horizons of the forest soil profile, but retained the original A, B, C letters for the well-drained mineral portion of the soil. The entire abandonment of the original scheme was advocated by Sokolovsky who proposed the designation on a phonetic basis, such as H - humus layer, E - eluvial layer, P - parent material, and so forth. Similar plans were suggested by Vilensky and other pedologists

In spite of some obvious advantages, most of these proposals are likely to find only a limited application. Long-time tradition and thousands of already published papers, using the original designation, are the chief obstacles to the introduction of a new method. Furthermore, the Dokuchaev designation, no matter how awkward at times, reflects the inherent sequence of soil development, and has a more logical foundation than purely empirical schemes. Fortunately the standard designation presents no unavoidable difficulties in application to forest soils.

Figure 7 shows the designation of horizons in a profile of a leached forest soil influenced by ground water.

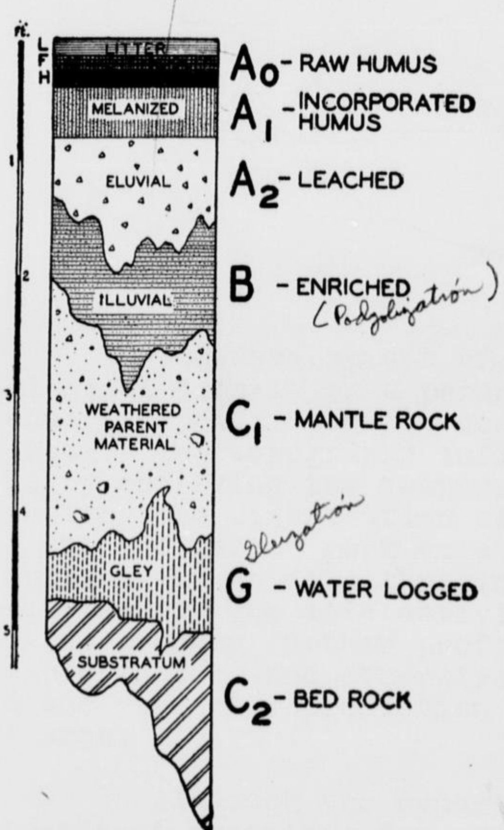


Figure 7. Designation of horizons in the profile of a leached forest soil influenced by ground water.

Sometimes the soil horizon is penetrated by the inter-layers or intrusions of other horizons, viz., spots of podzolized material in the infiltrated layer, stripes or "pseudo-fiber" of ortstein in the leached layer, or islands of gley in the accumulative layer. Such compound horizons are designated usually by the two letters, viz. A_1A_2, A_2B, and BG.

The boundaries of soil horizons seldom follow a horizontal or a straight line; rather they form an undulating or even a zigzagging contour. Therefore, in the descriptions of soil profiles or in schematic drawings it is desirable to indicate the minimum and maximum depth of both the upper and the lower boundaries of soil horizons, as well as their general outline.

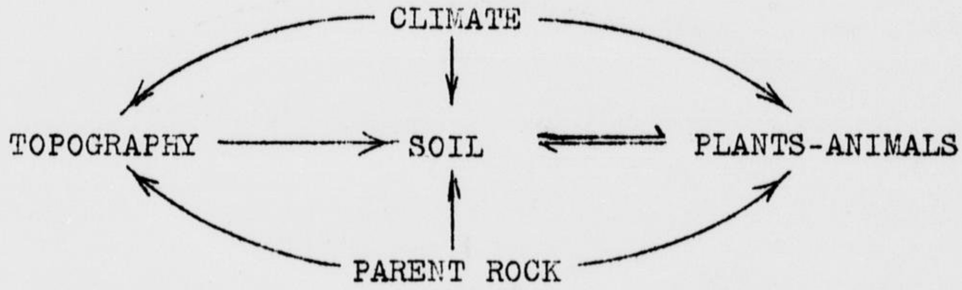
The recognition of soil horizons is important not only in the abstract genetical studies of soil "as an independent natural body", but in practical silviculture as well. The composition of forest stands, their rate of growth, possibilities of natural reproduction and silvicultural management are intimately dependent upon the amount of forest litter and other raw organic remains, depth of incorporated humus, composition of the leached and accumulative layers, and the proximity of the gley horizon. No correlation between the physical, chemical, or biological properties of soil and forest growth can be established, or comparable data obtained, if the composition of separate soil layers is disregarded in soil analyses.

Influence of Environmental Factors upon Soil Profile Development

The first basic law of soil science, formulated in the eighties of the past century by Dokuchaev states: "The soil is a result of reactions and reciprocal influences of parent rock, climate, topography, plants, animals, and age of the land." Mathematically speaking the soil (S) is a function of geological substratum (g), environmental influences (e), biological activity (b), and time (t):

$$S = \int (g.e.b.)dt$$

The reciprocal relations of soil, parent rock, climate, topography, plants, and animals may be expressed graphically by the following scheme:



The development of soil begins with weathering of a bare geological deposit or a parent rock. The nature of weathering products depends upon the conditions of climate and the composition of rock. The topography influences weathering and properties of soil by modifying the temperature and moisture conditions and by affecting the distribution of weathered or eroded material. The climate and parent rock to a large extent determine the composition of plants and animals that invade the soil in its early stage of development. The life activities of the organisms and decay of their remains produce further profound changes. The soil enriched in organic matter, and otherwise modified, influences in turn the growth and the rate of reproduction of species competing for possession of the area.

Although the dynamic processes of soil development and struggle of organisms for space proceed endlessly, after a certain period of time both soil and plant-animal community reach a state of apparent equilibrium. At this stage the make-up of the soil profile reflects distinctly the influence of the climatic conditions of the area and the soil supports a climax association, i.e. selected group of species best adapted to the given set of environmental factors.

By virtue of necessity, the discussion of soil development must be subdivided into climatic, topographic, geological, and vegetational aspects. No such division, however, exists in nature where all soil-forming factors act jointly and reciprocally. For this reason, the classification of soil on the basis of climate or any other single factor, no matter how influential, has only a general or a schematic significance. This is especially true in dealing with forest soils. The forest itself is a factor of tremendous modifying power which may bring podzolization into a region of prairie or lateritic soils; vice versa, it may arrest the leaching and promote the blackearth-like process of humus incorporation in the heart of the podzol or laterite region.

Influence of climate. Among climatic factors, the conditions of temperature and moisture exert a particularly profound and obvious influence upon the distribution of plants and the development of soils. Figure 8 outlines in schematic form the distribution of the World's geographic regions and great groups of soils in relation to temperature and moisture.

In a suitable climate a permanently high water level is about the only condition that can arrest the natural distribution of forest vegetation. In many instances even this obstacle is overcome by trees, and lakes or marshes are gradually converted into forest swamps or gley soils.

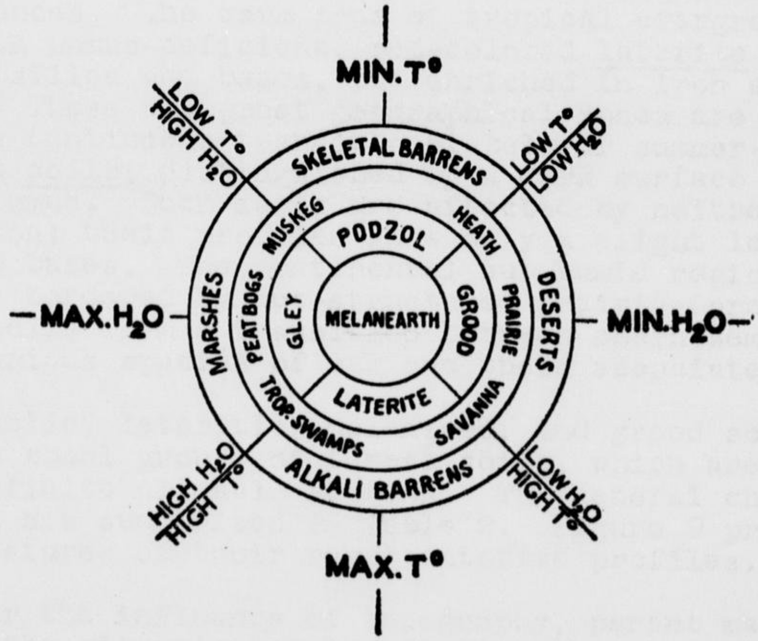


Figure 8. Distribution of the great soil groups of the World in relation to temperature and moisture.

A certain minimum amount of total heat is one of the prerequisites determining the existence of forest, and, hence, the occurrence of forest soils. In arctic regions and in high mountains, the forest is replaced by heath shrubs, mosses, and lichens, as soon as the average temperature of the growing season drops below 50° F. (Mayr). The soils of such microthermal conditions include skeletal barrens, wet tundra or muskeg soils, dry tundra or heath soils, and alpine meadow soils.

Of equal importance to the forest distribution is the humidity of the climate, i.e. certain excess of precipitation over evaporation (Hilgard). In arid or semi-arid climates, deficient in available moisture, the vegetative cover is formed by grasses, xerophytic shrubs, cacti, or halophytic plants; these inhabit chernozems or prairie soils, savanna soils, desert soils, and alkali soils. The general tendency of these non-forest soils is to accumulate salts in their surface layers through either the action of plants or the evaporation and recrystallization from solution.

On the other hand, the humid climates, resulting from either abundant precipitation or low evaporating temperatures, are conducive to the development of forest vegetation. Such conditions generally promote the translocation of mineral and organic matter in solution or in colloidal form from the upper soil layers to the lower strata, and, in some instances, cause complete leaching of soluble salts from the soil profile into drainage waters. The nature and degree of soil leaching is to a great extent determined by the state of temperature, particularly its seasonal fluctuations.

The cold conditions, prevalent in the region of boreal coniferous forests, give rise to podzol soils, characterized by the accumulation of raw organic remains and an ashy-grey, siliceous surface layer, depleted in iron and aluminum sesquioxides and other soluble substances. The warm zone of tropical evergreen forests is correlated with humus-deficient, red-colored laterite soils, impoverished in silica and bases, but enriched in iron and aluminum sesquioxides. These two great geographical zones are separated by a more or less continuous transitional belt of summer-green hardwoods with melanized soils, distinguished by a dark surface layer with incorporated humus. Such soils are affected by neither podzolization nor laterization; their profiles show only a slight leaching of the easily soluble bases. The continental sub-humid region of steppes or prairies is bordered by nut-structured prairie-forest or grood soils; these soils form a transition between chernozems and podzols, and support various species of oak and their associates.

Podzolic, lateritic, melanized, and grood soils constitute the four large zonal groups of forest soils, which are more or less confined to definite climatic regions. The general characteristics of these soils are summarized in Table 2. Figure 9 presents the outstanding features of their representative profiles.

Under the influence of topography, parent material, and forest cover, the climatic-zonal soil types break down into a number of morphological varieties and are interspersed with immature and intrazonal soils, viz., rendzinas, gley soils, and organic soils.

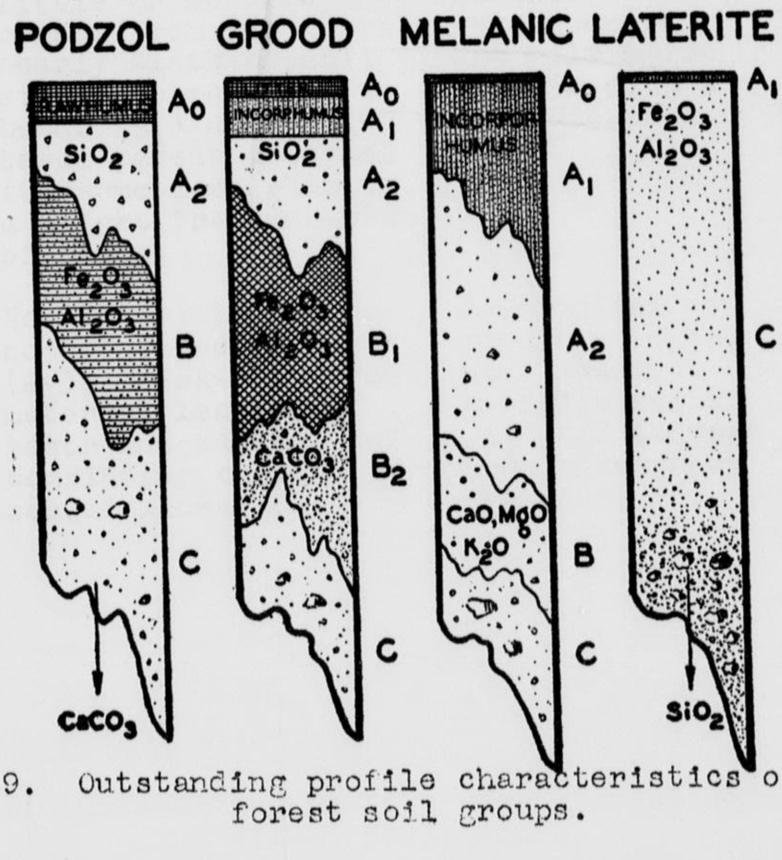


Figure 9. Outstanding profile characteristics of zonal forest soil groups.

Table 2. General Characteristics of the Climatic-Zonal Groups of Forest Soils

Soil Groups	Profile Characteristics	Climate	Vegetation
PODZOL	Raw humus (A_0); white or ashy-grey topsoil, leached of bases and sesquioxides (A_2); compacted or cemented layer containing precipitated salts and flocculated colloids (B).	Boreal: moist, mild summers with equally distributed rains; cold winters with abundant snowfall.	Taiga forest; heath, conifers and northern hardwoods.
GROOD	Partly decomposed litter (A_0) and humus incorporated with the soil (A_1); dark or light grey layer leached of bases and some sesquioxides (A_2); nut-structured horizon (B) grading into substratum containing carbonates.	Continental: hot and often dry summers with unequally distributed rains; cold winters with lasting snow cover.	Prairie forest; predominance of oak species.
MELANEARTH	Little or no free organic remains; dark, nearly black topsoil with incorporated humus (A_1) and unaltered parent material (C) sometimes showing a slight translocation of bases.	Oceanic: moist, warm summers and mild moist winters with a sporadic snow cover.	Deciduous forest; predominance of beech, maple, tulip, and chestnut.
LATERITE	No litter; little or no incorporated humus (A_1); brick-red parent material leached of bases and silica, and consisting chiefly of sesquioxides (C).	Subtropical or tropical: moist with abundant periodic rains and high temperature throughout the year.	Evergreen forest; palms, laurels, magnolia and numerous other genera.

Influence of topography. Topography serves as a multi-faceted prism dispersing or concentrating the effect of climatic factors. It directs the course of runoff water and determines the content of soil moisture, the depth of the ground water table, and the amount of soluble salts, fine-earth particles, and organic matter deposited by erosive processes. All of these "micro-climatic" and "micro-relief" modifications exert a profound influence upon the distribution of vegetation and the development of soil. As a result, in the regions of diversified topography there may be encountered a wide variation in the composition of soil profile. Two examples should suffice to illustrate this so-called "micro-zonality" in distribution of soils (Fig. 10).

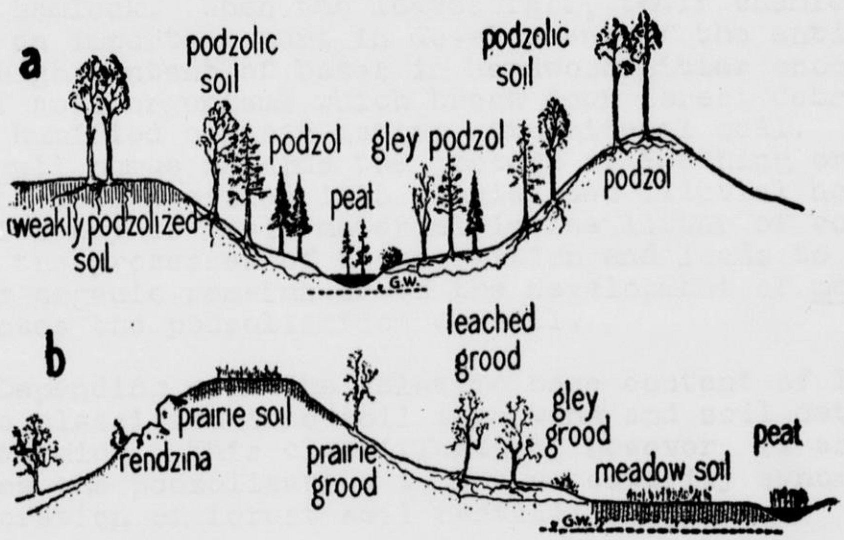


Figure 10. Influence of topography upon soil development: (a) glacial deposits in podzol region; (b) unglaciated limestone in prairie-forest transition.

Morainic landscape in the podzol region is characterized by the presence of peat soils in depressions. Gley soils are confined to the borders of swamps influenced by ground water. Strongly leached podzols occupy the lower slopes, where the rate of water percolation and leaching are intensive. Slightly podzolized soils commonly occur on the elevated uplands. However, in many cases fully developed podzols are found on the light-textured, gravelly morainic ridges, predisposed to the invasion of podzol-forming conifers (Fig. 10, a).

The rough calcareous deposits in a transitional prairie-forest zone may show even greater variety of soil conditions within a comparatively small area. The elevated plateaus are, as a rule, occupied by prairie soils overlying a limestone substratum. The nut-structured grood soils are confined chiefly to the lower slopes. On the northern slopes with their deep snow cover, groods may be replaced by podzolic soils. The dry, and often barren southern exposures are limestone outcrops or the shallow immature rendzinas. Lowland prairie or wet meadow soils are found in the valleys and lower plains, accumulating eroded calcareous material (Fig. 10, b).

Influence of vegetation. Forest stands modify the temperature as w ell as the moisture content of the soil. The roots of trees and ground cover vegetation increase the soil porosity and aeration. Plant roots produce carbon dioxide, which in water solution increases the solubility of carbonates, phosphates, and silicates. The solutions of these salts contribute to the formation of the illuvial soil layers.

During the growing season leaves accumulate calcium, magnesium, potassium, phosphorus, sulfur, iron, and other elements. The content of accumulated salts varies greatly with the species. Hardwood trees, such as ash, maple, and basswood, accumulate, as a rule, considerably higher amounts of bases than do conifers, particularly spruce and hemlock. When the leaves fall, their chemical composition plays an important part in development of the entire soil profile. High content of bases in hardwood litter encourages the activity of soil organisms which break down forest debris and incorporate the humified organic matter with mineral soil. Such base-saturated mull humus retards the process of leaching or the differentiation of soil profiles into eluvial and illuvial horizons. Vice-versa, deficiency of basic material in the litter of conifers tends to inhibit the processes of decomposition and leads to the accumulation of raw organic remains or to the development of mor humus, which promotes the podzolization of soil.

Depending upon the relative base content of litter, tree species are classified into soil improving and soil deteriorating or podzol forming. This classification, however, is somewhat ambiguous as the podzolization is not necessarily synonymous with the deterioration of forest soil fertility.

The soil-forming effects of vegetation may be offset by the more powerful influences of climate and parent rock. In numerous cases mull humus and unleached soils are found under coniferous stands, whereas raw humus and strongly leached soils are found under hardwoods.

Influence of parent material. The soils which develop under extreme climatic conditions are influenced by the parent material only to a limited extent. The upper mineral layers of mature podzols are composed of nearly pure silica regardless of the nature of parent material. Similarly, on all substrata the upper layers of the chernozems and alkali soils accumulate humus and soluble salts, respectively. On the other hand, the soils adapted to regions with a mild climate, viz. melanized or weakly podzolized soils, preserve many important properties acquired from their parent rocks.

Calcareous rocks and deposits exert a profound and long-lasting influence upon the soil. Their high content of carbonates tends to maintain the original alkaline reaction, and counteracts the leaching of salts and colloids. The alkaline reaction of calcareous deposits is apt to favor the growth of grasses rather than forest vegetation. Because of this, calcareous deposits often give rise to "intrazonal" prairie soils occurring throughout forest region and referred to as rendzina soils. In time such soils may be leached or "degraded" into grood soils, podzolic soils of calcareous substratum, or calcareous podzols. The basic or ferro-magnesian rocks react similarly to calcareous material, but their resistance to leaching is considerably lower. The siliceous rocks, especially sandstones, are affected but slightly by environmental conditions because of the inert nature of silica. The granitic rocks produce, in different climatic regions, soils having a very wide range of profile variations.

The influence of parent material in different climates can be clearly seen by comparing mature soils which have developed on limestone, sandstone, and granitic rocks in the podzol, chernozem, and transitional prairie-forest regions (Fig. 11).

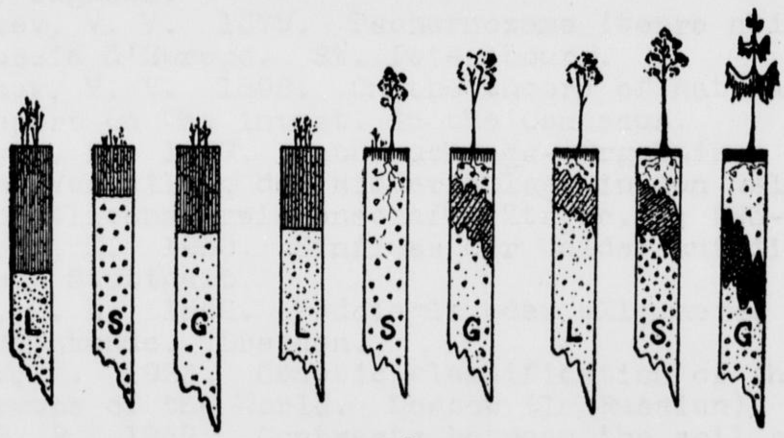


Figure 11. Influence of parent material upon soil development. L - limestone; S - sandstone; G - granite.

In the semi-arid region of prairie, black earth or chernozem soils develop on all of the three types of rocks. The black earths derived from limestone rocks (L) have more bases and a higher content of humus than the soils derived from granitic (G) and especially from sandstone (S) rocks. In the podzol regions, with its pronounced leaching, podzols or podzolic soils develop on all of the three types of rocks. The soils from granitic rocks show the leaching and other features of podzolization most pronouncedly. The soils from sandstone manifest podzolization to a lesser extent. The soils derived from limestone resist leaching and usually retain bases in the lower part of the soil profile. Along the prairie-forest boundary, calcareous rocks are likely to produce chernozem-like prairie soils, whereas granitic rocks give rise to podzolic forest soils. The sandstone soils, owing to their coarse texture and deficiency of nutrients, support struggling forest stands which alternate with an inferior cover of prairie grasses. In either case, these soils develop a thin humic layer, but no other profile characteristics and are classified as <u>bor sands</u> when they support forest and <u>prairie sands</u> when they support grass vegetation.

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PART II

GREAT GROUPS OF FOREST SOILS

> "The eternal genetical relationships that exist between the forces of environment and physical matter, living and non-living nature, plants and animals and man, his habits and even his psychology--these relationships comprise the very nucleus of natural science."
>
> V. V. Dokuchaev

Since the early days of scientific forestry, numerous attempts have been made to establish natural, physiographically homogeneous regions in which the same silvicultural policies and methods could be applied. None of these, however, approached in simplicity and ecological importance the classification of soils on a genetical basis. The great soil groups of the world are natural land types determined by conditions of climate, composition of native vegetation, and general trend in the development of soil profiles. Such land types, if properly delineated, provide a reliable broad foundation for establishing the type of forest management, acclimatization or translocation of tree species, and selection of logging and planting methods.

CHAPTER V

ZONAL FOREST SOILS

A. PODZOLS: SESQUIOXIDE-LEACHED SOILS

Podzol is a Russian word meaning ash-like soils; it pertains to the light grey, ashy color of the siliceous eluvial layer (Sibirtzev). The term "sesquioxide-leached soils" equally well expresses the nature of podzolized soils. In the out-moded, but entirely justifiable terminology of the old-time foresters, podzols were known as "raw humus soils"(Sigmond). Raw humus, with all its complex chemical and biological influences, is the chief factor directly responsible for the translocation of sesquioxides and colloids, i.e., the essential characteristic of the podzolization process (Müller, Emeis).

The cold and humid climate of the podzol region promotes the downward movement of water, removing bases and other easily soluble compounds from the surface soil layers. The impoverishment in electrolytes and winter freezing inhibit the activity of microorganisms, and plant remains tend to accumulate on the surface. Organic acids, hydrogen sulfide, and other reducing agents are formed as by-products of the retarded decomposition. These agents cause reduction and other transformations enabling the translocation of difficultly soluble compounds, particularly iron and aluminum sesquioxides (Aaltonen, Albert, Drosdoff and Truog, Joffe, Wityn). As a result, the profile of a fully developed podzol consists of a raw humus layer, ash-like siliceous residue, and reddish-brown horizon with precipitated sesquioxides.

The podzol region extends as a wide circumpolar belt throughout the northern parts of America and Eurasia (Glinka). It is bounded by tundra on the north and grades into melanic and prairie-forest soils on the south. Under special conditions the process of podzolization penetrates in a southerly direction far beyond the podzol region proper, and may affect the soils of other groups. Podzolized laterites present an outstanding example of such an "ultra-zonal" occurrence of podzolization (Lang, Giesecke).

Podzolized soils support heather plants and numerous species of conifers and northern hardwoods. The stands on these soils, sometimes referred to as "Taiga" (Thornthwaite), constitute the largest portion of the world's forests.

The extent of podzolization depends upon the local conditions and the age of the soil, and gives rise to a number of morphological varieties or types, such as slightly leached or "weakly podzolized" soils, moderately leached or "podzolic" soils, and strongly leached soils or "podzols" (Neustruev). These types are readily discernible in nature and have a paramount silvicultural importance.

Representative profiles of zonal forest soils are assembled in Figure 12.

Weakly podzolized soils. These soils represent the embryonic stage of podzolization. In some instances, the absence of a pronounced leaching is a result of the soil "youthfulness". As a rule,

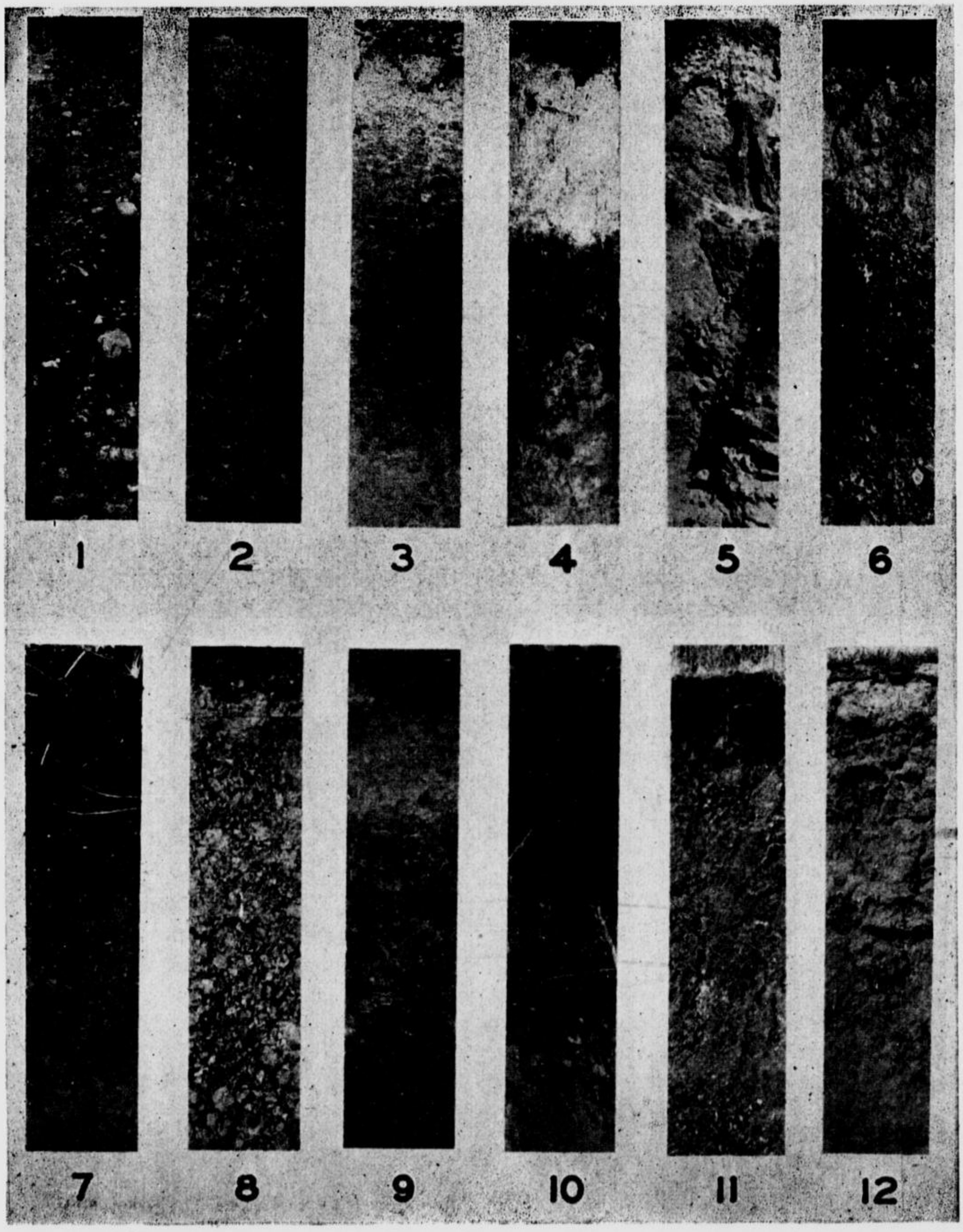


Figure 12. Representative profiles of zonal forest soils: (1) Weakly podzolized gravelly sand; (2) Weakly dzolized loam, (3) Podzolic sand; (4) Podzol loam; (5) Ortstein podzols of a sandy texture; (6) Calcareous dzol clay; (7) Dark or prairie grood loam; (8) Light or leached grood loam. (9) Strongly leached grood **loam,** ap- paching podzolic soil; (10) Melanearth of loam texture; (11) Melanized lateritic clay. (12) Podzolized lateritic y.

however, weakly podzolized soils are a more or less stable type, formed in localities where podzolization is inhibited by the high base content of the parent rock or by the litter of deciduous species (Morozov).

In the weakly podzolized soils the layer of free organic remains (A_0), i.e., litter and duff, seldom exceed a thickness of 2 inches. The humic horizon (A_1) is well developed and imparts a dark color to the surface soil. The leaching is noticeable only upon a careful examination, and hence the A_2 and B horizons may not be apparent. A slightly acid or neutral reaction and a high biological activity are characteristic of these soils.

The morphology of weakly podzolized soils may be exemplified by the following description of a profile formed under a stand of maple, basswood and elm in northern Wisconsin:

A_0 1.5 inches. Thin layer of undecomposed maple leaves underlain by a dark-brown nearly neutral friable duff having a pleasant odor of a good garden soil.

A_1 1.5-6 inches. Mull layer consisting of a slightly acid (pH 6.3) dark-grey crumbly loam infiltrated with humus. A few earthworms and a chipmunk burrow are present.

A_2 Not present as a continuous horizon but small greyish spots reveal podzolization in the zone from 6 to 12 inches.

B Not discernible.

C Dark brownish-grey gravelly loam of a moderately acid reaction (pH 5.7), grading at a depth of 4 feet into unassorted glacial till. The roots penetrate throughout the entire profile to a depth of 7 feet.

Weakly podzolized soils are sometimes referred to as "mull soils", "dark forest soils" or "diorn soils". They may be regarded as the melanized soils of the north. However, weakly podzolized soils and zonal melanearths often develop in essentially different climatic regions and support ecologically unrelated associations.

The forest cover of weakly podzolized soils consists predominantly of northern hardwoods, such as maple, basswood, elm, hornbeam, and oak; or mixtures of hardwoods with pine, spruce, and fir species. Forest cover composed entirely of conifers occurs rather as an exception. The stands on these soils are apt to produce high yields of timber and regenerate readily by seeds and sprouts (Wilde and Scholz).

Weakly podzolized soils are the most productive agricultural soils in the podzol region, and their use for forestry purposes is largely limited to the rougher and stony areas of glacial deposits.

<u>Moderately leached or podzolic soils</u>. These soils exhibit a well-pronounced grey leached layer and a more or less distinct

accumulative layer. The latter sometimes occurs in the form of concretions, pseudomycelium, or slightly cemented "ortsand" (Filatov). Being a transitional form, podzolic soils have intermediate characteristics, partly derived from weakly podzolized soils and partly from true podzols. As a general rule, podzolic soils are productive forest soils, supporting both conifers and hardwoods.

Strongly leached soils or podzols. True podzols are characterized by a thick layer of undecomposed organic matter or raw humus (A_0), the entire absence or only slight development of the humic layer (A_1), an ashy-grey or white leached layer (A_2), and a sharply defined reddish-brown cemented or compacted accumulative layer (B). The amount of salts extracted with 10 per cent HCl is two to three times as large in the B layer as in the A_2 layer. The A_2 layer in some cases contains as much as 92 per cent of silica. The available nutrients are concentrated in the raw humus layer. The exchange material is saturated chiefly with hydrogen ions and is subject to destruction in the entire soil profile (Gedroiz). Insect life is often absent. The bacteria and other micro-population are largely replaced by the acid-loving fungi (Waksman).

The following is a description of a typical podzol profile, developed under a stand of hemlock, balsam fir and yellow birch in northern Wisconsin:

A_0 4 inches. Layer of raw humus, or mor, consisting of strongly acid (pH 4.0), matted, dark-brown organic remains penetrated by the fungous mycelia, and giving off a peculiar "sour" odor. Line of demarkation between organic matter (A_0) and mineral soil (A_2) is sharply defined.

A_1 Not present.

A_2 4-16 inches. Light grey nearly white sand with irregular tongue-like lower limits of a strongly acid reaction (pH 3.8).

B_1 16-27 inches. Slightly cemented sandy loam of a coffee-brown, somewhat reddish color (Ortsand).

B_2 27-45 inches. Firmly cemented, rock-like hardpan layer of a dark coffee-brown color, a strongly acid reaction (pH 4.0), and free of tree roots (Ortstein).

C Stratified sand.

The hardpan layers of mature podzols sometimes attain a thickness as great as 4 feet. Depending upon the proportion of iron and humus in the B horizon, podzols are classified into "Iron podzols" and "Humus podzols" (Ramann, Frosterus). The development of the latter type is correlated with the occurrence of highly acidophilous vegetation, impeded drainage, and a particularly thick layer of raw humus (Tamm).

In heavy soils podzolization develops sticky and mottled "claypan" layers similar to gley horizons formed by ground water. The soils of this nature do not differ greatly in their ecological effects from poorly drained soils, and are sometimes classified as "gley podzols." In this way podzolization may produce poorly drained soils on uplands far above the real water table (Wilde).

Podzols support chiefly conifers, viz. spruce, fir, hemlock and pine. Light-demanding deciduous species, such as birch, aspen, alder and red ma ple, usually form pioneer stands or occur in mixture with conifers. Under natural conditions, the stands on podzol soils attain a fair and even a high productivity. However, in reforestation the growth of planted trees may be hindered by a strongly acid reaction, lack of plant food in the leached layer, toxicity of the accumulative layer and its unfavorable effect on the distribution of moisture during w et and dry seasons. The cementation or the toxicity of the accumulative layer leads to the development of a superficial root system and trees on podzol soils are subject to windfall (Burger, Nemec, Maran, Lutz, Stickel).

Areas of true podzols are primarily forest lands, as their fertility is rapidly depleted by clearing and decomposition of the raw humus layer.

Table 3 includes the results of total analysis of a weakly podzoliz ed soil and a fully developed podzol. Table 4 illustrates the composition of the surface layers of weakly podzolized and podzol soils.

The podzols and podzolic soils of old cut-over areas and forest meadows may be "masked" by the infiltrated grass humus which imparts a dark color to the whole soil profile. Although the leached layer is not readily discernible in such soils, the podzolization is often manifested by the cementation of the B horizon, or it may be revealed by chemical analysis. Soils of this kind are called <u>latent podzols</u>. On superficial examination they resemble the weakly podzolized soils. In the proximity of tundra, latent podzols occupy extensive areas. The sod soils of high mountains may be considered as a variety of latent podzols.

B. GROODS: NUT-STRUCTURED PRAIRIE-FOREST SOILS

Near the humid boundary of the prairie, podzolization is replaced by the somewhat milder process of "degradation" leading to the development of transitional <u>prairie-forest</u> or <u>grood soils</u>.

"Grood" is a folk's term that has been adopted by forest pedologists (Morozov, Kruedener) as a substitute for the earlier synonyms, such as "nut-structured soils" (Dokuchaev), "grey forest soils" (Sibirtzev, Korzhinski), and "degraded soils" (Glinka). It refers to the structural aggregates characterizing the profile of prairie-forest soils, as well as the type of forest cover which these soils support, i.e. a type distinctly different from the associations of podzolic soils (Pogrebniak). Kruedener makes the following statement in his "Waldtypen": "Rural people in their efforts to enlarge the agricultural area, very well appraised the differences in productivity of the grood and podzol types." (p. 82). In American literature, grood soils were described under the names of "grey-brown podzolic soils" (Marbut, Baldwin), "grey forest soils" (Joffe), and "degraded chernozems" (U.S.D.A.).

Grood soils generally originate through degradation of chernozems or prairie soils, although in some cases they are formed as primary soils (Zakharov). These soils support a rather limited number of tree genera, chiefly those of oak, hickory, walnut, a nd ash, and are known also as "oak-hickory soils."

Table 3. Total analysis of a weakly podzolized loam supporting a stand of hard maple, basswood and associated hardwoods, and of a sandy loam hardpan podzol supporting hemlock, yellow birch and balsam fir. Terminal moraine in Langlade County, Wisconsin. (S. A. Wilde and S. F. Buran).

Soil constituents	Weakly podzolized soil			Hardpan podzol		
	A_1 0-6"	A_2B 12-24"	C 36-48"	A_2 4-12"	B 24-36"	C 44-52"
	percent	percent	percent	percent	percent	percent
O. M.	8.73	1.96	0.20	0.56	2.24	0.10
SiO_2	64.52	71.93	73.46	79.03	69.02	75.47
Fe_2O_3	2.82	2.35	2.02	1.31	4.10	2.98
Al_2O_3	11.24	12.71	11.97	9.77	14.05	11.12
TiO_2	1.02	1.63	1.34	0.71	2.07	0.98
CaO	2.83	1.78	2.94	0.44	1.79	1.73
MgO	1.53	0.63	0.91	0.48	0.74	0.64
K_2O	2.10	1.02	2.93	1.71	2.40	2.43
P_2O_5	0.29	0.14	0.32	0.01	0.64	0.20
Total accounted for	95.08	94.15	96.09	94.02	97.05	95.65

Table 4. Composition of the surface 7-inch layers in podzol and weakly podzolized loams. Forest county, Wisconsin. (S. A. Wilde, S. F. Buran, and H. M. Galloway).

Soil horizons	Rea. pH	Base Exchange m.e./100g	Total N percent	Avail. K_2O p.p.m.	Avail. P_2O_5 p.p.m.	Repl. Ca m.e./100 g.	Repl. Mg m.e./100 g.
Podzol loam: raw humus layer (A_o)	4.2	67.7	1.53	423	49	27.7	6.2
Podzol loam: leached layer (A_2)	4.7	2.1	T	17	3	0.7	0.2
Weakly podzolized loam: infiltrated layer (A_1)	6.1	17.2	0.22	211	49	12.6	3.9

The chernozem soils near the margin of forest regions are subject to some leaching of bases. In time the concentration of carbonates and soluble salts in the upper soil layer decreases to such an extent that the invasion of forest vegetation becomes possible (Wissotzky). As soon as forest shrubs and trees occupy the area, the rate of leaching or "degradation" of the chernozem progresses rapidly (Tkachenko). The forest raises the humidity, moderates evaporation, and retards the melting of the snow, thus increasing the amount of water which percolates through the soil profile. The accumulated forest litter promotes the formation of reducing agents and organic a cids which break down both the humate and iron-aluminosilicate fractions of the base exchange compound. In consequence, the humus is gradually removed from the upper layer, which attains a lighter color (Kostichev, Kravkov). As Russian farmers say, "The forest devours the chernozem." The released silica appears in the profile as white dust or "frosting." The iron and aluminum sesquioxides accumulate as a brownish precipitate in the lower layer and give the degraded chernozem an appearance of a true forest soil with distinct humic, leached, and accumulative horizons (Gorshenin, Tumin).

The peculiar characteristics of the continental climate of the prairie-forest belt, i.e. cold winters, but hot and dry summers, appear to be of major importance in the development of grood soils. Cold winters with lasting snow cover periodically inhibit the activity of microorganisms and promote the accumulation of organic remains in quantity sufficient to effect the translocation of sesquioxides, i.e., a process nearly as intensive a s true podzolization. At the same time the percolation of water is not sufficiently deep and intensive to remove carbonates from the lower strata (Wissotzky).

The influence of winter temperatures explains a rather puzzling paradox, namely, leaching of grood soils in a prairie-border region somewhat deficient in rainfall, and the absence of leaching in melanized soils, formed under conditions of more abundant rainfall and reduced evaporation, but mild winters.

In the initial stages of development, grood soils are designated as "degraded chernozems", "degraded prairie soils" or <u>dark groods</u>. Such soils, as a rule, are found in the proximity of the prairie and have a high content of humus, exceeding 5 per cent. Their morphology and chemical composition resemble those of the blackearth soils (Zakharov).

<u>Leached</u> or <u>light</u> <u>groods</u> contain from 2.5 to 5.0 per cent of incorporated humus. Their eluvial layer is of a grey or greyish-tan color and has a platy structure, typical of podzolic soils. It grades into a brown accumulative horizon which in fine textured soils attains peculiar nut-structure. The structural aggregates are covered with siliceous dust. The accumulative horizon is underlain by a structureless zone containing carbonates of calcium and magnesium. The reaction of the upper soil layers is acid, the reaction of the lower part of the B horizon and of the substratum is commonly alkaline.

The following description outlines the morphological features of a representative profile of grood soils, developed under an oak-hickory stand in northeastern Iowa:

A_0 Undecomposed oak leaves, acorns, twigs and other forest litter varying in thickness from 1 to 2 inches.

A_1 0-6". Dark grey silt loam high in organic matter and of a slightly acid reaction (pH 6.5); mellow and smooth to the touch, breaking into fine aggregates. It contains a considerable number of small earthworms (Helodrillus) and is penetrated by a network of roots. Lower limit of horizon is irregular with tongues and root channels extending into the lower portion of the profile.

A_2 6-14". Light grey to tan, brittle silt loam showing a distinct platy structure with strata of 1/16 to 1/32 of an inch in thickness. Plates are "frosted" with siliceous dust. The reaction is acid (pH 5.6). Roots are numerous and some earthworms are present.

A_2B 14-20". Light chocolate brown porous silt loam breaking into small nut-like aggregates about the size of a pea, showing a gray or white speckled coating. Nuts are honeycombed by a number of very fine channels.

B_1 20-32". Chocolate brown silty clay loam breaking into larger aggregates about the size of a small acorn and exhibiting porous structure and greyish siliceous powder when dry. Penetrated by tree roots and with some large earthworms (Lumbricus) in root channels. Acid in reaction (pH 5.8).

B_2 32-48". Reddish-brown clay loam with rusty streaks. Contains some carbonates and exhibits a tendency to break into large cloddy aggregates in the upper portion of the horizon. Reaction is alkaline (pH 7.8). Some fine roots are present.

C 48" plus. Calcareous detritus terminating the distribution of roots.

This description is fully applicable to the profiles of the prairie-forest soils reported by European authors (Georgievsky, Levchenko, Turin, Kassatkin and Krasiuk).

Table 5 reports results of total analysis of a grood silt loam.

In time the leaching may remove most of the basic material from the B horizon, destroy structural aggregates, and thus convert a grood soil into a podzolic soil.

In some instances grood soils are invaded by the prairie grasses and undergo melanization or "regradation", i.e. a process opposite to leaching, and resulting in the transformation of groods into chernozems or prairie soils (Williams).

Grood soils support stands of oak, hickory, butternut and walnut with some ash, elm, maple and other hardwoods occurring incidentally. In the proximity of prairie, hardwoods are sometimes replaced by the so-called "poplar savanna" and other pioneer stands.

Table 5. Profile Analysis of a Nut-structured Grood Loam Formed Under a Stand of Oak and Hickory in Southern Wisconsin (After S. A. Wilde and D. P. White)

	A_1 (0-4")	A_2 (4-12")	B_1 (16-24")	B_2 (36-48")	C (56-60")
Reaction: pH	6.3	5.4	5.7	5.5	7.8
Base Exchange Capacity: m.e./100 g.	20.6	6.9	14.6	12.1	9.7
Total N, Per cent	.30	.04	.03	.015	.003
SiO_2 "	73.03	78.74	71.40	64.98	76.12
Fe_2O_3 "	2.23	2.47	4.27	4.71	2.17
Al_2O_3 "	8.34	8.94	10.12	11.90	8.28
TiO_2 "	.401	.367	.474	.495	.393
MnO "	.143	..077	.087	.164	.231
CaO "	.981	.692	.930	1.472	1.850
MgO "	.624	.127	.632	.953	1.245

With the exception of cedars, the conifers are not native to grood soils. They have been introduced artificially in both Russia and the United States with only moderate success. The promising early growth of coniferous plantations, as a rule, ceases at the age of 30 to 40 years and trees undergo rapid deterioration. The forest stands on these soils have short boles, poorly shaped stems, high percentage of cull, and often inferior stocking. The yields seldom exceed 7,000 board feet per acre. The productivity of stands is especially low near the border of the blackearth, but it increases toward the podzol region where leaching of the soil is greater and carbonates are removed to a greater depth in the soil profile. As recent studies have shown grood soils exhibit inherent adverse effects upon the growth of forest stands similar to prairie soils (White). By and large groods a re highly productive agricultural soils and intensively managed woodlots are about their only justifiable silvicultural use.

C. MELANEARTHS: HUMUS-INCORPORATED SOILS

Melanized soils are the chernozems or blackearths of the forest (Schlich). Their name is derived from the Greek "Melas", "melanos" meaning black or dark. The profile of these soils is composed of a dark surface layer with incorporated "mull" humus and apparently undifferentiated or unaltered substratum. The common expression "black top soils" well points out the general appearance of melanized soils.

This soil group is confined to a transitional climatic zone where neither podzolization nor laterization are manifested in the soil profile, i.e. where there is no translocation of either sesquioxides or silica. Thus, the leaching of these soils is limited to the removal of easily soluble sulfates and carbonates which accumulate in varying amounts in the deeper part of the substratum. A considerable portion of these compounds is returned to the surface layer by vegetation and soil organisms. As a consequence, melanized soils or melanearths present a unique example of a profile in which nearly all of the constituents are more or less fixed "in situ". This morphological equilibrium of soil is sponsored by both mild climate and native vegetation of hardwood species (Stebutt).

In some instances the state of "neutralized" environment exists over considerable area. However, the combined influences of climate, topography, parent rock, and vegetation may bring the podzolization to the immediate proximity of laterization, so that the dividing belt of melanized soils is broken into sporadic islands.

The dark humus horizon (A_1) of a melanearth gradually becomes lighter in color and merges without a definite boundary into the parent material (C), which may be light brow n, grayish-brown, yellow, or even white, depending on the soil-forming rock. Therefore, the differentiation of these soils into A, B, and C horizons is difficult. Such a differentiation may be justified, however, because of the translocation of bases (CaO, MgO, K_2O and Na_2O) as detected by chemical analysis.

Melanized soils sometimes ha ve a granular structure, distinctly different from the nut-structure of grood soils (Murgoci). The reaction of the surface horizon may be either neutral or acid, depending upon the amount of removed bases; the reaction of the deeper portion of profile is usually slightly acid or alkaline. The content of humus ranges from 3 to 6 per cent. Soils approaching the podzol boundary are likely to have a higher content of organic matter than those approaching the lateritic boundary.

The following description gives an example of a characteristic soil profile:

A_0 Sparse interrupted remains of the last year's leaf fall.

A_1 0-16 inches: Dark brown crumby humic loam growing lighter with the depth; somewhat compacted and penetrated by light colored veins and threads in the lower portion. Nearly neutral in reaction.

A_2 Not discernible.

B 16-42 inches: Reddish brown compacted clay loam of a slightly alkaline reaction, penetrated by the roots of trees and root channels.

C Disintegrated shale.

Table 6 presents data of profile analysis of a melanized soil from southern Indiana.

Table 6. Total Analysis of a Melanized Loam Supporting a Stand of Hardwoods in Southern Indiana (S. A. Wilde and W. E. Patzer)

Horizon and depth	N	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	CaO	MgO	K_2O	P_2O_5
	Per cent									
A_1: 0-8"	.221	73.51	3.28	8.27	.32	.59	1.61	.59	1.04	.11
A_1-A_2: 8-16"	.073	77.80	3.47	8.15	.35	.47	.96	.47	.87	.09
A_2B: 16-30"	.041	82.05	3.46	8.29	.33	.45	.88	.46	.75	.12
C: 30-40"	.006	82.20	4.01	7.49	.33	1.06	1.73	1.06	1.18	.08

Melanized soils are closely related to "brownearth", described by Ramann, but not identical with that type. According to recent investigations (Ballenegger, Smolik, Lundblad, Aarnio, Stebutt) the concept of "Braunerde" or "brown forest soils" is applicable to a number of soil groups, viz. weakly podzolized soils, brown podzolic soils, latent podzols, melanized lateritic soils, and even degraded chernozems (Glinka, Afanasiev, Vilensky). This confusion arose chiefly because Ramann gave only vague descriptions of the soil type introduced and failed to supplement such with representative profile analyses (Stremme). To some extent, the matter was complicated by the unfortunate terminology: the "brownearth" includes soils of various colors other than brown, and, conversely, many brown soils are not related to the brownearth. All things considered, the term brownearth has become more a liability than an asset and the revision of its concept, as well as the change in designation, is highly desirable. The terms "humus-incorporated" or "melanized" soils appear to imply best the original, basically correct ideas of Ramann on the genesis of hardwood soils formed in temperate climate and characterized by the dark humic layer of "vegetable mould" (Darwin).

Some scientists were inclined to classify humus-incorporated soils as immature soils with "imperfectly developed profiles" (Marbut), that is, soils in which the differentiation into horizons is not pronounced because of the youthful age of the parent material. Such a condition, however, is likely to persist for any pedologically appreciable length of time only on the outskirts of the podzol region where the invasion of podzol-forming vegetation is hindered by the state of climate and the composition of parent rock. The results of analysis of a soil from Massachusetts, reported by Marbut, provide an excellent illustration of the connecting link between melanized and podzolic soils (Table 7). Nearly ideal uniformity in the distribution of practically all constituents in this profile strongly suggests a state of stable equilibrium of the soil.

Near the lateritic boundary the profile of melanearth is somewhat enriched in iron and aluminum sesquioxides, and attains an intensive brown color.

Table 7. Total Analysis of a Merrimac Fine Sandy Loam from Foxboro, Massachusetts (C. F. Marbut and F. A. Baker)

Horizon and depth	N	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	CaO	MgO	K_2O	P_2O_5
	Per cent									
A_1: 0-2.5"	.35	64.78	4.31	11.41	.99	.06	1.33	.66	1.16	.24
A_2: 2.5-3.5"	.43	64.15	3.83	9.93	.97	.06	1.02	.71	1.14	.31
B: 3.5-18.0"	.15	69.17	4.41	12.85	.89	.06	1.40	.77	1.11	.39
C: 18.0-28.0"	.09	72.89	4.25	11.60	1.05	.07	1.57	.91	1.22	.15

Because humus-incorporated soils do not exhibit conspicuous profile characteristics, as are found in podzols, laterites, or chernozems, the soil scientists and foresters of central Europe failed for a long time to recognize the role of climate in soil development. Instead they emphasized the importance of the parent material (Fallou, Grebe), which indeed greatly influences the properties of melanized soils.

Melanized soils of central Europe, eastern portions of the United States, and numerous belts of the lower mountain slopes throughout the world constitute approximately one-tenth of the total area of forest soils. In general, these soils have a high content of base exchange material and available nutrients. They support productive stands composed primarily of hardwoods, among which tulip poplar, beech, chestnut, and species of oak are prominent. The occurrence of native conifers is limited to the species of cedar, fir, and Douglas fir. The "Central hardwoods" of eastern America (Shantz and Zon), Douglas fir of the Rocky Mountains, and the "Fagetum-Castanetum" associations of Europe (Mayr) constitute the principal forest types on these soils. During the past century, a number of microthermic conifers, such as Norway spruce and European larch, were introduced on a large scale in European countries. However, neither climatic conditions nor the properties of soil proved to be satisfactory for these species. The introduction of these conifers produced, in numerous cases, a rapid leaching of soils and their conversion into podzolized soils or even true podzols (Wiedemann). The silvicultural significance of such a transformation is not well established; one group of foresters is inclined to see in podzolization the beneficial modification of environment, favoring the growth of planted conifers, while another group identifies podzolization with the deterioration of soil fertility (Albert, Erdmann, Volk, Leiningen, Sigmond, Kvapil and Nemec).

D. LATERITES: SESQUIOXIDE-ENRICHED SOILS

Laterite is a product of tropical weathering; it is a material depleted in bases and silica and composed chiefly of aluminum and iron oxides. The name was derived from the Latin, Later or brick, because hardened lateritic clays were used in India as building stone. Incidentally the term implies the typical red color of the lateritic soils (Buchanan). "Terra rossa" or red earth is a designation of some soils of a lateritic nature (Blanck).

High temperature throughout the year and abundant periodic rainfall of tropical regions promote a rapid and nearly complete decomposition of organic matter, and lead to disintegration of the aluminum-silicate nucleus with the release of silica and hydrated iron and aluminum oxides. The silica is gradually washed out in colloidal form by the drainage waters, whereas iron and aluminum sesquioxides accumulate as residue.

Because of the advanced stage of chemical weathering, lateritic soils usually have a clay texture. However, the decomposition of organic matter and alumino-silicates greatly decreases their absorbing properties. Lateritic soils, in spite of their high colloidal content, are porous and low in base exchange material. The latter is largely of a mineral nature and is saturated with H ions. The entire soil has a very low base status.

The profile of a true laterite is the direct opposite of the podzol profile. The upper layer of the podzol is rich in raw organic matter and silica, but low in iron and aluminum, the SiO_2/R_2O_3 ratio being greater than 2. The upper layer of a laterite is poor in organic matter and silica, but high in iron and aluminum, the SiO_2/R_2O_3 ratio being considerably less than 2 (Bennett). On the other hand, laterites and podzols have very much in common: both are leached, deficient in exchange material, depleted in bases, and often strongly acid. They are two extreme members of the same family of "pedalfers" (Marbut) or "unsaturated soils" (Gedroiz) with a "disintegrating exchange compound" (Stebutt).

A distinct line is drawn between true laterites and lateritic soils, i.e. soils either enriched in humus (melanized laterites), or somewhat impoverished in sesquioxides (podzolized laterites).

True laterites are of rare occurrence. They show a very low silica-sesquioxide ratio and represent the end product of tropical weathering. A high content of hydrated aluminum oxide, as well as the presence of crusts and concretions of iron, are the other outstanding features. The plant life exerts but a negligible influence upon the development of true laterites, and they are considered as "geological ma terial" rather than "soil" proper (I.A.B.).

Melanized laterites. The melanization or darkening of the surface layer by the infiltrated or incorporated humus is the initial stage in the development of a true soil from a lateritic parent material (Harrassowitz). In numerous instances lateritic soils do not undergo any other profile alterations, and, hence, melanized laterites present a stable type. Under favorable conditions, the humus layer (A_1) attains a depth of several inches and the content of soil organic matter may reach as high a figure as 6 per cent (Bennett and Allison).

The profile of a melanized lateritic soil may be exemplified by the following description:

A_0 Uneven and sparse cover of the remains of vegetation.

A_1 6 inches: red brown clay with incorporated humus.

C_1 6-90 inches: red gravelly clay with ferruginous incrustations and concretions, pieces of iron-stone and some quartz fragments.

C_2 90-120 inches: the horizon of non-lateritic weathering material grading into unweathered ferro-magnesian rock.

An analysis of a clay from Alabama, reported by Marbut, provides an illustration of melanized lateritic soil in this country (Table 8).

Table 8. Total Analysis of a Melanized Lateritic Soil (Cecil clay loam) from Chambers county, Alabama.
(After Mark Baldwin, E. D. Fowler, G. J. Hugh, and J. B. Spencer)

Horizon and depth	Ign. loss	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5
	Per cent							
A: 0-7"	13.24	35.18	12.84	35.80	0.29	0.45	0.30	0.25
B_1: 8-24"	13.84	34.25	15.20	34.47	0.08	0.18	0.30	0.04
B_2: 25-59"	12.57	36.09	14.85	34.12	0.02	0.07	0.37	0.04

This profile shows a rather uniform distribution of iron and especially aluminum sesquioxides and a pronounced enrichment of the surface layer in bases and phosphates. The high contents of iron and aluminum should be attributed to both laterization and heavy texture of the soil.

Lateritic soils support numerous species of the equatorial and tropical forests. In the transitional belt of temperate climate they are associated with hardwoods, particularly oaks, beech, red gum and magnolia.

<u>Podzolized</u> <u>laterites</u> are confined chiefly to the cooler margin of the lateritic region, although they occur in patches in the other parts of the region wherever conditions retard the decomposition of organic matter (Lang). Under the influence of organic remains and heavy rainfall, a considerable portion of the iron and aluminum is translocated into the lower layer, leaving a reddish-grey or yellowish-grey quartzose top soil (A_2). In some instances, a bleached horizon more than three feet deep was found under raw humus layer (Vageler). The accumulative horizon is of a rather intense reddish color (B). In some soils it stands out as in true podzols, and in some it merges into parent material. In places an impervious hardpan layer is found. It has about the same effect upon the vegetation as the ortstein in podzols (Pessin).

An example of the profile of a podzolized lateritic soil is given by the following description of a profile developed under a stand of longleaf pine in southern Mississippi:

A_o A thin layer of pine needles.

A_1 1 inch: dark layer of sandy loam with incorporated humus.

A_2 1-9 inches: reddish-grey leached sandy loam of a strongly acid reaction.

B 9-30 inches: intensely red to reddish brown clay of faint coarse lumpy structure, somewhat compacted and sticky, with dark brown veins and flakes; acid in reaction.

C Structureless sticky and mottled clay.

Table 9 presents results of analysis of a podzolized lateritic soil.

Table 9. Total Analysis of a Podzolized Lateritic Soil (Norfolk sandy loam) from Houston County, Alabama. (After Mark Baldwin, E. D. Fowler, and G. Edginton)

Horizon and depth	N	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	P_2O_5
	Per cent							
A_1: 0-6"	.025	91.23	0.48	3.81	Tr.	Tr.	0.10	0.02
A_2: 7-10"	.002	94.33	0.58	4.65	Tr.	Tr.	0.08	0.02
B_1: 11-37"	.008	85.18	1.14	9.06	Tr.	Tr.	0.13	0.01
B_2: 38-49"	.004	82.06	1.17	11.58	Tr.	Tr.	0.09	0.01
C: 50-80"	.002	81.96	1.25	11.67	Tr.	Tr.	0.09	0.02

Podzolized lateritic soils are usually porous, acid, and have a low content of nutrients. In many instances the deficiency of nutrients in all of the textural classes, including the heavy clays, makes these soils suitable only to pine species and other less exacting vegetation. Extensive areas of the podzolized lateritic soils in the southeastern United States support primarily slash, loblolly, and longleaf pine. In spite of a deficiency of nutrients, these stands attain on the whole a rather high productivity due to the long growing season and other favorable climatic conditions.

Two more or less distinct morphological varieties of lateritic soils are recognized: red soils and yellow soils. The color of these soils may be due to a difference in the degree of hydration of the iron. Red soils may represent the B horizon exposed by erosion (Stremme). Some iron may have been removed from the yellow soils during an earlier stage of impeded or sluggish drainage (Marbut). Yellow soils may also result from incipient podzolization (Afanasiev), or may represent a youthful stage in the development of red soils (Robinson).

There is a belief that the podzolized lateritic soils resulted from the leaching of laterites which were formed during the Tertiary Period (Glinka). At this time, according to Wegener, the Equator passed through southern Spain into the vicinity of the Caspian Sea and northern India. The largest part of the podzolized lateritic soils now known are confined to the southeastern United States, France, the Caucasian region, and Japan. These areas coincide with the unglaciated tropical regions as located by Wegener.

The outlined hypothesis is especially applicable to the leached soils of the Piedmont Plateau and Ozark Mountains, associated with shortleaf pine-oak type. These soils appear to belong to the podzolic group with only traces of lateritic processes manifested in the yellowish or reddish color of the substratum.

Figure 13 includes characteristic forest stands occurring on various zonal types of forest soils.

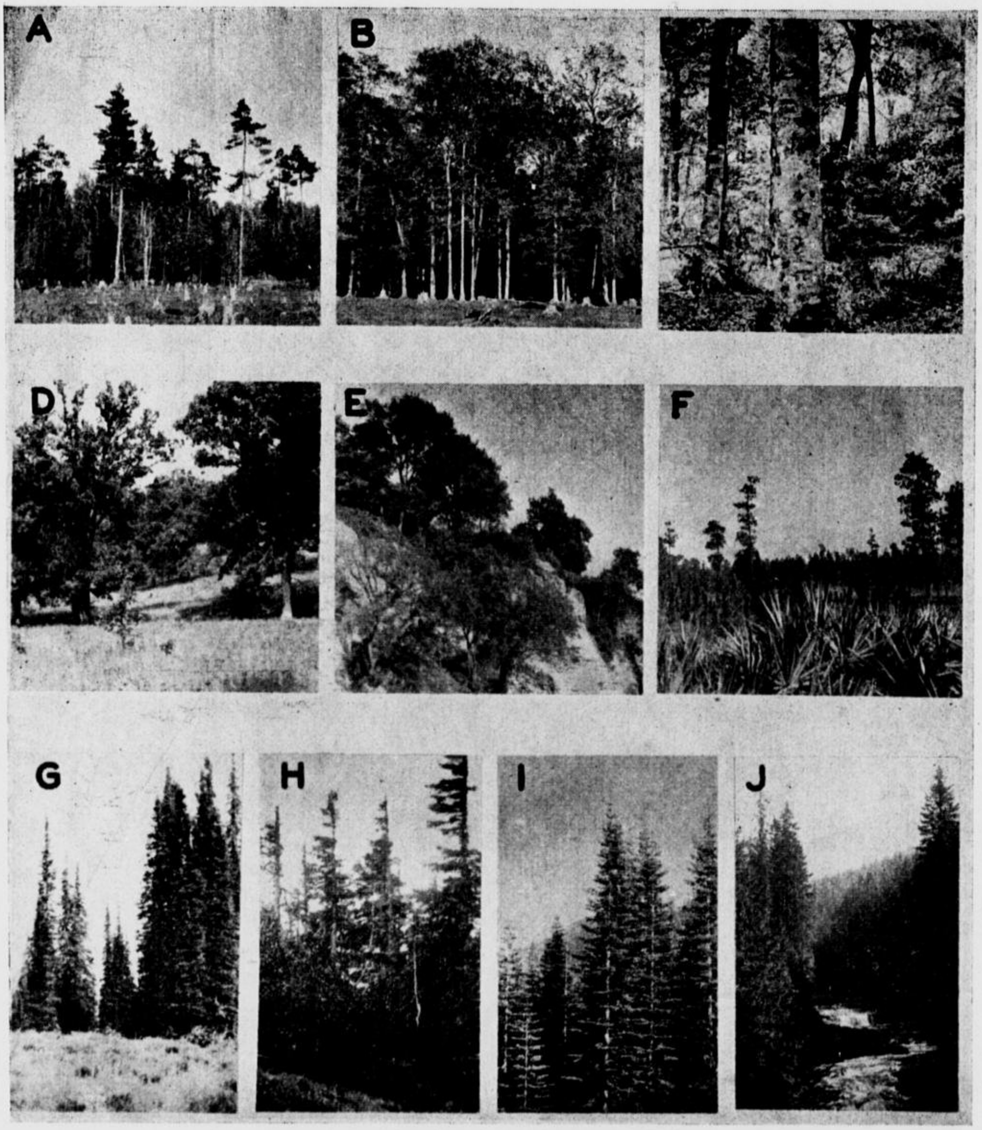
E. MOUNTAIN FOREST SOILS

The study of mountain soils by Dokuchaev revealed that the soil regions, or zones, succeed each other in a definite order as the altitude increases from sea level to the summit. This vertical zonality of mountain soils is analogous to the horizontal zonality found on the plains. The correlation between the vertical and horizontal zonalities of soil groups is especially pronounced in European Russia. The Great Russian Plain extends from the Arctic Circle to the Caucasian Mountains. This territory from north to south and from sea level to its highest altitude includes a wide range of climates and soil conditions (Zakharov). The attached diagram illustrates schematically the relationship involved (Fig. 14). The Rocky Mountains, as well as the other mountain ranges of the United States, present similar examples of the vertical zonality of soils (U.S.D.A.).

The distribution of different climatic-zonal types in the mountains is, of course, greatly affected by the geographical location, exposure, gradient, and composition of the parent rock, and the zonality of the soils is of an irregular character (Smirnoff, Neustruev). The differentiation of horizons and the development of a genetic soil type are less pronounced in the mountains than on the plains because of continuous erosion and deluvia tion. The deep and more fertile soils of deluvium are often intersected by the shallow and less productive residual soils of denuded areas, or by rock outcrops. The presence of rock fragments of various sizes is characteristic of mountain soils (Jenny).

The mountain soils of the foothills do not differ radically from the soils of the plains. Depending upon the geographic location of the mountain range, they may be either desert, prairie, or forest soils of any large group (Glinka, Meyer, Novak, Senstius). With an increase in elevation, the foothill soils of high mountains grade into mountain podzols, sod soils, peat bogs, mountain tundra, and primitive skeletal soils. Mountain podzols and sod soils are not quite comparable to the forest soils of the plains, and they are described below.

Mountain podzols. The cool and humid mountain belt of these soils is characterized by the prevalence of physical weathering, with little formation of the fine soil material. These soils have less distinct horizons than the podzols of the plains, and seldom have cementation of the illuvial layer or iron concretions. Nevertheless, the analysis of mountain podzols reveals a pronounced depletion of the upper layer in bases, sesquioxides, and colloids. The humus content is high, reaching in some cases 12 per cent. The exchange material is composed chiefly of humates which are saturated with hydrogen and give the soil an acid reaction (Zakharov).



Photos C, G and I courtesy of U. S. Forest service

Figure 13. Characteristic forest cover of the major soil groups. (A) **Hardpan podzol**—white pine, white spruce and balsam fir; (B) **Podzolic loam**—maple, basswood, hemlock and balsam fir; (C) **Weakly podzolized** or **melanized loam**—beech with understory of rhododendron; (D) **Grood silt loam**—oak and hickory prairie forest; (E) **Degraded rendzina**—oak prairie-forest; (F) **Podzolized laterite**—longleaf pine with understory of palmetto; (G) **Sod soil of high mountains**—alpine fir; (H) **Mountain podzol**—Norway spruce and mugho pine; (I) **Weakly podzolized mountain soil**—Douglas fir; (J) **Melanized alluvial soil of the mountains**—Norway spruce and European fir.

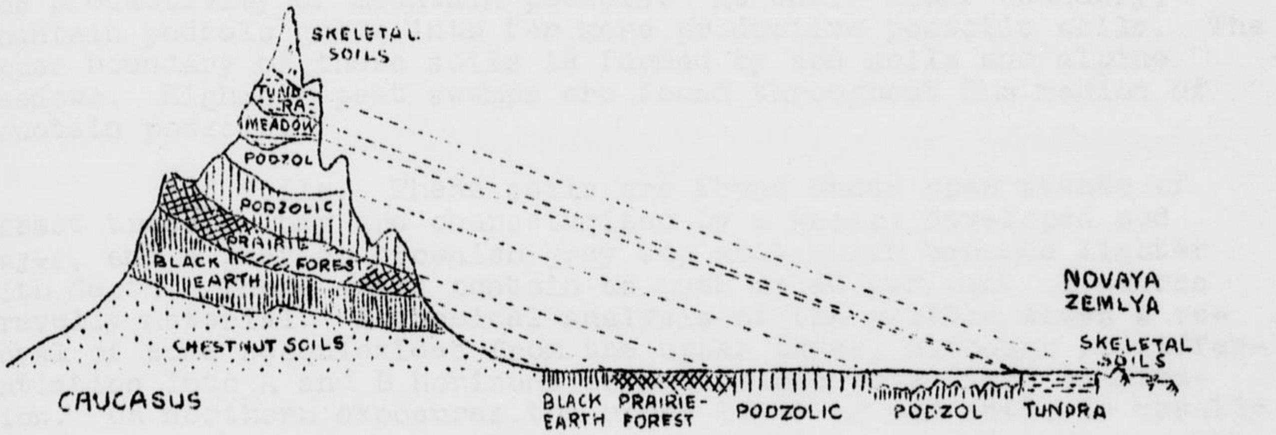


Figure 14. Relation between the horizontal and vertical zonality of soils in European Russia (Adapted from S. A. Zakharov).

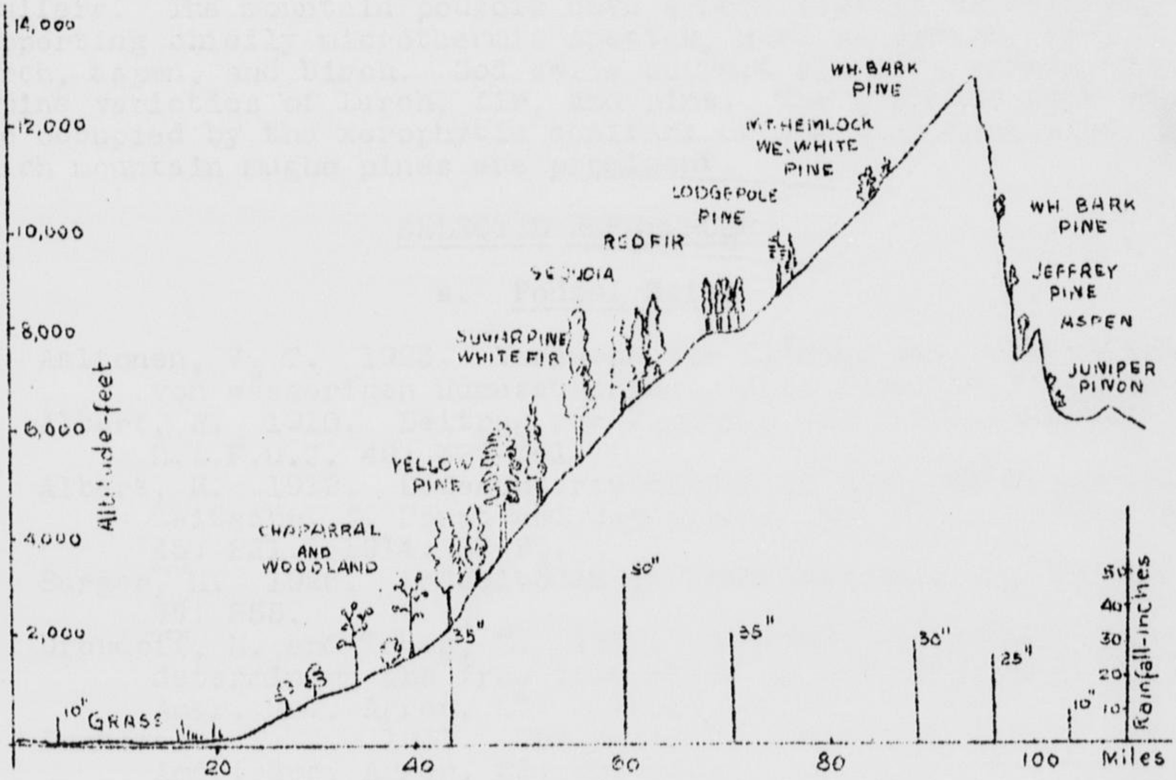


Figure 15. The effect of elevation and rainfall upon forest distribution in the Sierra Nevada Mountains (Adapted from U. S. Dept. Agr. Bul. 1495).

The properties of the soil, as well as the short growing season and the severe winds of this region, are responsible for the low productivity of mountain podzols. At their lower boundary, mountain podzols grade into far more productive podzolic soils. The upper boundary of these soils is formed by sod soils and alpine meadows. Highmoor peat swamps are found throughout the region of mountain podzols.

Sod Soils. These soils are found under open stands of forest trees. They are characterized by a weakly developed sod layer, and a grey or brownish grey top soil which becomes lighter with depth. These soils contain as much as 40 per cent of coarse gravelly material. A chemical analysis of the profile shows a removal of some sesquioxides from the upper layer, although no differentiation into A and B horizons is noticeable in a field examination. On northern exposures the upper layer of sod soils is usually light grey, whereas on southern exposures it is brownish grey. The sod soils are marginal forest soils. They border the podzols and penetrate as tongues into mountain meadow soils, or sometimes occupy small areas in the region of alpine meadows. In places they develop a deep humus horizon and attain a character of "alpine humus" soils (Leiningen, Jenny).

The forest vegetation of the mountain soils includes nearly all the species and forest types occurring on the plains (Fig. 15). The soils of the lower altitudes that are grouped with the grood or melanized soils support primarily hardwoods and some thermophillic conifers. The mountain podzols have a more limited vegetation, supporting chiefly microthermic species, such as spruce, fir, larch, aspen, and birch. Sod soils support sporadic stands of alpine varieties of larch, fir, and pine. The highmoor peat bogs are occupied by the xerophytic conifers of the high mountains, among which mountain mugho pines are prominent.

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CHAPTER VI

INTRAZONAL FOREST SOILS

A. RENDZINAS: HUMUS-CALCAREOUS SOILS

Rendzinas present an early stage in the development of soil from calcareous parent material. A high content of either incorporated or raw humus and calcareous substratum are the outstanding characteristics of these soils. These features of rendzina soils well justify their other accepted designation -- "humus-calcareous soils" (Sibirtzev, Glinka). Rendzinas occur throughout the entire forest region, being confined to isolated areas of outcropping limestone, dolomite, chalk, and lime-bearing shales.

Although calcareous rocks in time undergo the same changes as any other parent material, their high content of carbonates tends to promote the accumulation of humus and otherwise modifies the usual course of soil development.

In the region of true podzols, exposed calcareous rocks lead to the accumulation of peat-like raw humus with an alkaline reaction, attaining a thickness of nearly one foot (Galloway). Such youthful rendzinas, in spite of their alkaline reaction, often support acidophilous species of spruce and fir, in addition to white cedar and hardwoods (Tkachenko, Lang). In time the calcareous material undergoes weathering and leaching, and is transformed into a "calcareous podzol" or rather a podzol of calcareous substratum (See). In the proximity of the Great Lakes, such calcareous podzols often have strongly acid ortstein layers which rest upon alkaline, calcareous detritus (Wilde).

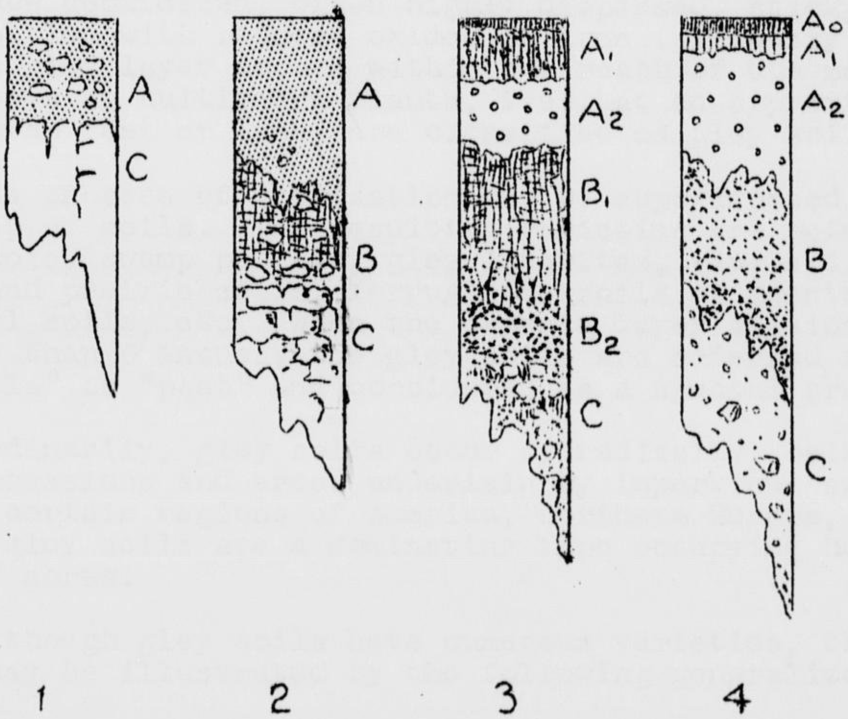
In the proximity of the prairie-forest border, rendzinas undergo a more complex sequence of changes. In such regions the initial stage of rendzina development is a skeletal calcareous debris, darkened by infiltrated humus, and giving effervescence with strong acids. As weathering proceeds, the upper layer of the rendzina loses its carbonates; the residue becomes smooth and silty in texture and develops a deep, dark or black humic horizon having a crumby structure. At this state rendzina soils are often similar to blackearth; they support either prairie vegetation or open forest stands having an abundant cover of grasses and are referred to as "prairie soils."

After invasion of forest vegetation the prairie rendzinas undergo degradation similar to that of Chernozems and eventually attain the profile of a grood or podzolic soil (Zvorykin).

In regions subject to laterization the rendzinas are gradually transformed into terra rossa or redearth soils (Lorenz, Neumayr).

Figure 16 shows four stages in the development of a rendzina.

Diagram 16. Metamorphosis of Rendzina into Podzolic Soil



1. Immature skeletal rendzina; 2. Fully developed rendzina or prairie soil; 3. Degraded rendzina or grey forest soil; 4. Podzolic rendzina or podzolic soil with calcareous substratum.

The forest vegetation often does not invade immature rendzinas until the reaction and the concentration of the salts in the upper layer are lowered by percolating water. The early pioneers on such degrading rendzinas have an extremely low rate of growth and are subject to premature death. Because of the intra-zonal occurrence of these soils, the "starving" or struggling trees of the rendzina forest belong to numerous species, both of hardwoods and conifers. The best development is attained, however, by the lime-loving or calcifilous species, such as oaks, hickories, walnuts, beech, ash, white cedar, juniper, Austrian pine, and a few other hardwoods and conifers. However, even these species attain a more-or-less normal growth only on strongly podzolized rendzinas. Strangely enough, the hemlock, one of the most acidophilous species, may also be found on alkaline, immature rendzinas.

B. GLEY or GROUND-WATER SOILS

Gley soils develop under the influence of ground water and are classed among the hydromorphous soils. Anaerobiosis and hydrolysis, dominating the strata of soil below the ground water table, produce deoxidized, often highly dispersed, sticky gley horizons, mottled with reduced oxides of iron (Wissotzky). Soils in which the gley layer occurs within the reach of the main root system of trees or cultivated plants, i.e., at an approximate depth of seven feet or less, are classified as gley soils.

The process of gleyization may be superimposed upon any genetic group of soils. The resulting varieties are referred to as gley podzols, swamp podzols, gley laterites, vlei soils, meadow soils, lowland prairie soils, ferruginous soils of mountain valleys, marl soils, etc. When the organic layer attains a thickness greater than 6 inches, the gley soils are referred to as "organic soils" or "peat" and considered as a special group.

Ordinarily, gley soils occur sporadically, being confined to depressions and areas underlain by impervious substrata. However, in certain regions of America, northern Europe, Siberia, and Africa, gley soils are a dominating type occupying hundreds of thousands of acres.

Although gley soils have numerous varieties, their morphology may be illustrated by the following generalized profile description:

A_0 Dark to black partly decomposed organic remains, often of peat-like nature.

A_1 Nearly black humic layer.

A_2 Light colored, podzolic or podzol-like leached layer.

B Brown or greyish-brown accumulative horizon enriched in sesquioxides; often not present.

G_1 Mottled, bluish-grey, rusty, bluish-brown, ochreous, or humus-ochreous gley.

G_2 Greenish or bluish, wet or moist, deoxidized gley layer, impoverished in iron and somewhat enriched in colloidal silica.

The reaction of forest gley soils is usually acid in the upper part of the profile, but may be neutral or alkaline in the zone of water saturation.

In the detailed genetic studies, the variations in the degree of soil drainage, or in the intensity of gleyization are expressed by a number of terms such as gley podzol, swamp podzol, podzolic gley soil, podzolic gley soil with a deep gley layer, peat podzol, gley podzolic peat soil, peaty gley soil and swamp peat soil (Zavalishin and Pronevich). These and similar terms have significance in the morphological nomenclature of soil genesis, but they are too long and confusing in practical soil classifications. Moreover, they have no direct bearing upon the productivity of soils, particularly forest soils.

The composition of the forest stand, its rate of growth, percentage of cull material, vigor of competing vegetation, possibilities of natural reproduction, stability of the forest against the wind, and other silviculturally important features are chiefly influenced by the position of the gley layer or its distance from the surface (Büsgen and Münch, Hesselman, Kruedener). This determines the accessibility of water, the extent of root penetration and the depth of well-aerated soil containing available nutrients. Considering the depth and position of the gley layer in relation to the occurrence of the A, B, and C horizons of a mature forest soil profile, the following three types of gley soils may be recognized.

Alpha-gley soils or Shallow gley soils, that is semi-swamp, more or less permanently wet soils with a shallow gley layer grading into A_2 or A_1 horizon.

Beta-gley soils or Mid gley soils, i.e., insufficiently drained, periodically wet soils with gley layer superimposed upon the B horizon.

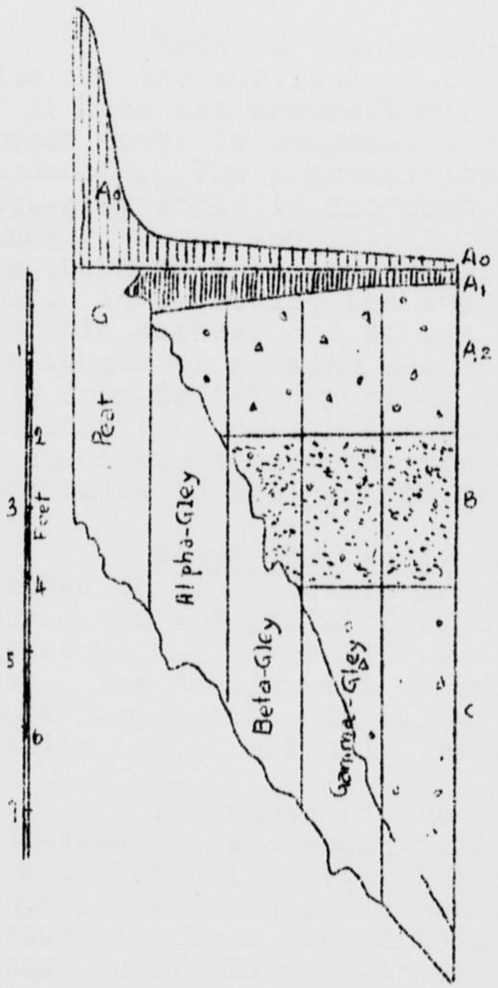


Figure 17
The position of the gley horizon in different types of soil

Gamma-gley soils or Deep gley soils, i.e., sufficiently drained, but rather moist soils with a deep gley layer occurring in the C horizon.

The relative position of the gley horizon in different types of gley soils is indicated schematically in Figure 17. It is obvious that the depth of the gley layer maintains the same ecological significance regardless of whether soil is or is not differentiated into distinct A, B, and C horizons.

Alpha gley soils. (Shallow gley soils). The gley layer protrudes through the leached horizon, and may reach the horizon with incorporated humus, being thus within about one foot of the surface.

In this type the influence of the ground water often masks all the other genetical features of the soil profile. Alluvial stream bottom soils, soils of semi-swamp flats of lacustrine clays or highly colloidal weathered drifts of early glaciations, and various swamp-border soils belong to this group.

The forest cover of alpha-gley soils is composed of a rather limited number of species which can tolerate deficiency of aeration. Spruce, balsam fir, cedars, bald cypress, pitch pine, black ash, elm, some oaks, cottonwood, and tupelo gum may be quoted as typical representatives. With some exceptions, the stands are of a low productivity and have a high percentage of cull material (Figure 18).

Beta-gley soils. (Mid gley soils). The gley horizon occurs immediately below the accumulative layer and sometimes grades into the latter, thus being at a depth of 2 to 3 feet from the surface. Percolating water and ground water contribute equally to the morphology of these soils. The soils of lower slopes in the mountains, shallow outwash or residual soils underlain by impervious strata of w eathered shale or boulder clay, borders of lowland prairie soils in transitional prairie-forest region, some red and yellow soils underlain by hardpan, and podzols of heavy texture with highly colloidal, accumulative layers are typical examples of beta-gley soils.

In the summer period, the surface layers of these soils are usually dry. In fall, and particularly in the spring, however, water saturates the entire planting layer. An examination of open trenches or at least borings with auger to a minimum depth of 3 feet may be necessary to reveal the presence of the typical "mottling" of the gley horizon and the true nature of these soils.

Being a transition, this type of soil offers a suitable site for the survival of both upland and lowland forest trees, even if it does not assure their successful growth. Consequently, the forest cover is composed of numerous species, both conifers and hardwoods. The productivity and the stability of forest stands on beta-gley soils is hindered by a number of adverse conditions (Burger, Nemec and Kvapil, Tiurin et al). The roots of the trees are confined to a comparatively shallow surface layer of well aerated soil. As a result, the supply of available nutrients is limited. Periodic wetness and effect of early and late frosts shorten greatly the length of growing season. Upland species suffer in spring and fall from deficiency of aeration, whereas lowland species suffer and sometimes perish in summer from drouth. The abundance of weakened specimens encourages the development of parasitic organisms which contribute to the general decadence of the stand.

Gamma-gley soils (Deep gley soils). The gley horizon reaches its full development in a deeper part of the parent material, usually at a depth of from 5 to 7 feet. However, slight mottling may occur in the proximity of the B horizon, at a depth of about 4 feet. The development of mull humus is often characteristic of gamma-gley soils. In all other respects, the composition of soil profile is but slightly influenced by the ground water.

The roots of the trees develop in a sufficiently deep, well-aerated, and potentially nutritive layer of soil, and receive some additional moisture from the ground water. Of great importance is the relatively stable ground water table, protected from evaporation by a substantial mantle of soil. Such favorable conditions usually lead to an exceptionally rapid growth of timber and to general stability of forest stands. The composition of stands does not differ conspicuously from those growing on true upland soils. However, the presence of a deep gley layer may be responsible for the occurrence of more exacting species than are ordinarily found in a given region on upland soils of similar texture.

Figure 19 includes profiles of soils formed under influence of ground water table.

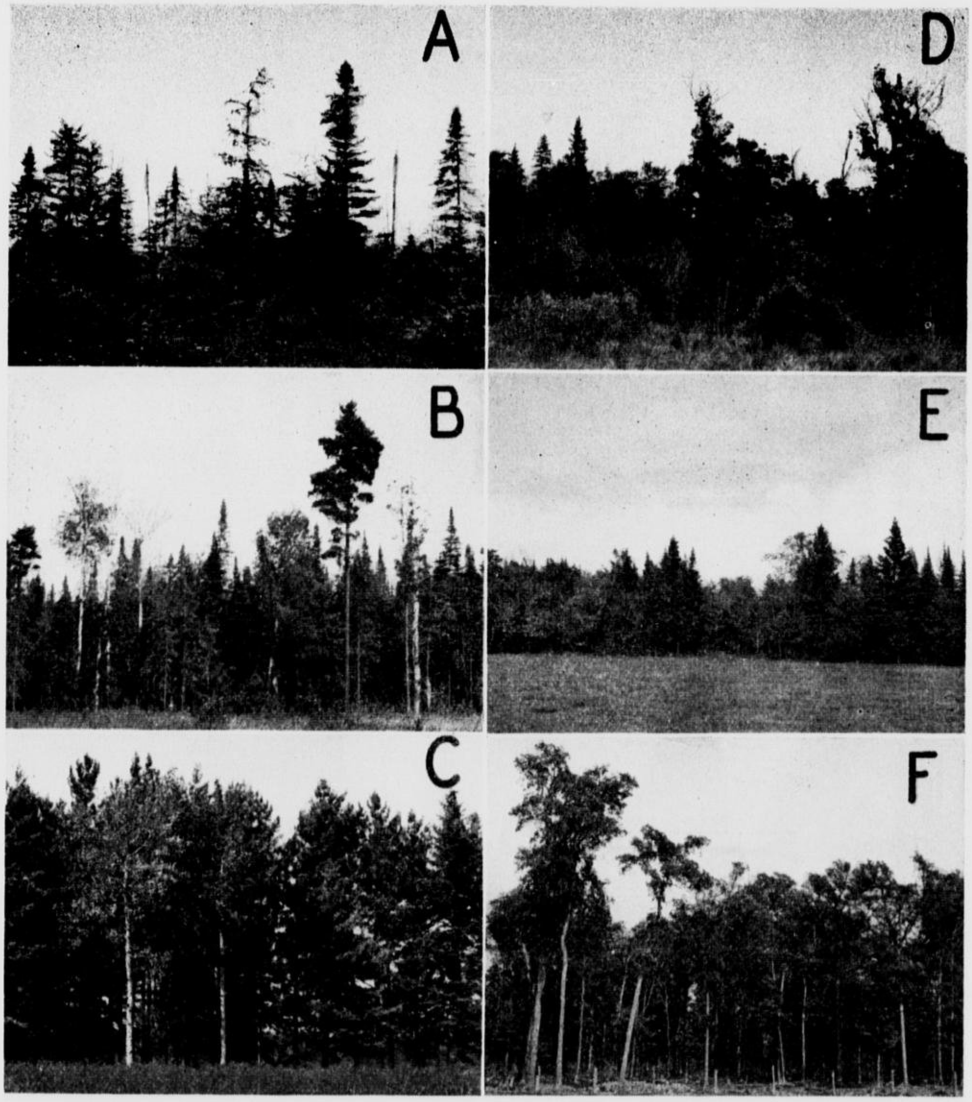


Fig. 18. Forest cover associated with gley soils in Podozol region of Wisconsin. (*A*) Black spruce and tamarack on alpha-gley swamp-border sand; (*B*) mixed stand of white spruce, balsam fir, white pine, aspen and paper birch on beta-gley sandy podzol; (*C*) white and red pine with some aspen and white spruce on gamma-gley bor sand; (*D*) hard maple, red maple, rock elm and black ash with some balsam fir on alpha-gley podzol loam; (*E*) mixed stand of hard maple, basswood, American elm, white pine, balsam fir and white spruce on beta-gley podzolic loam; (*F*) hard maple and basswood on gamma-gley mull loam. *A*, *B* and *C*—Sandy outwash of recent glaciation; *D*, *E* and *F*—Heavy drift of old glaciation.

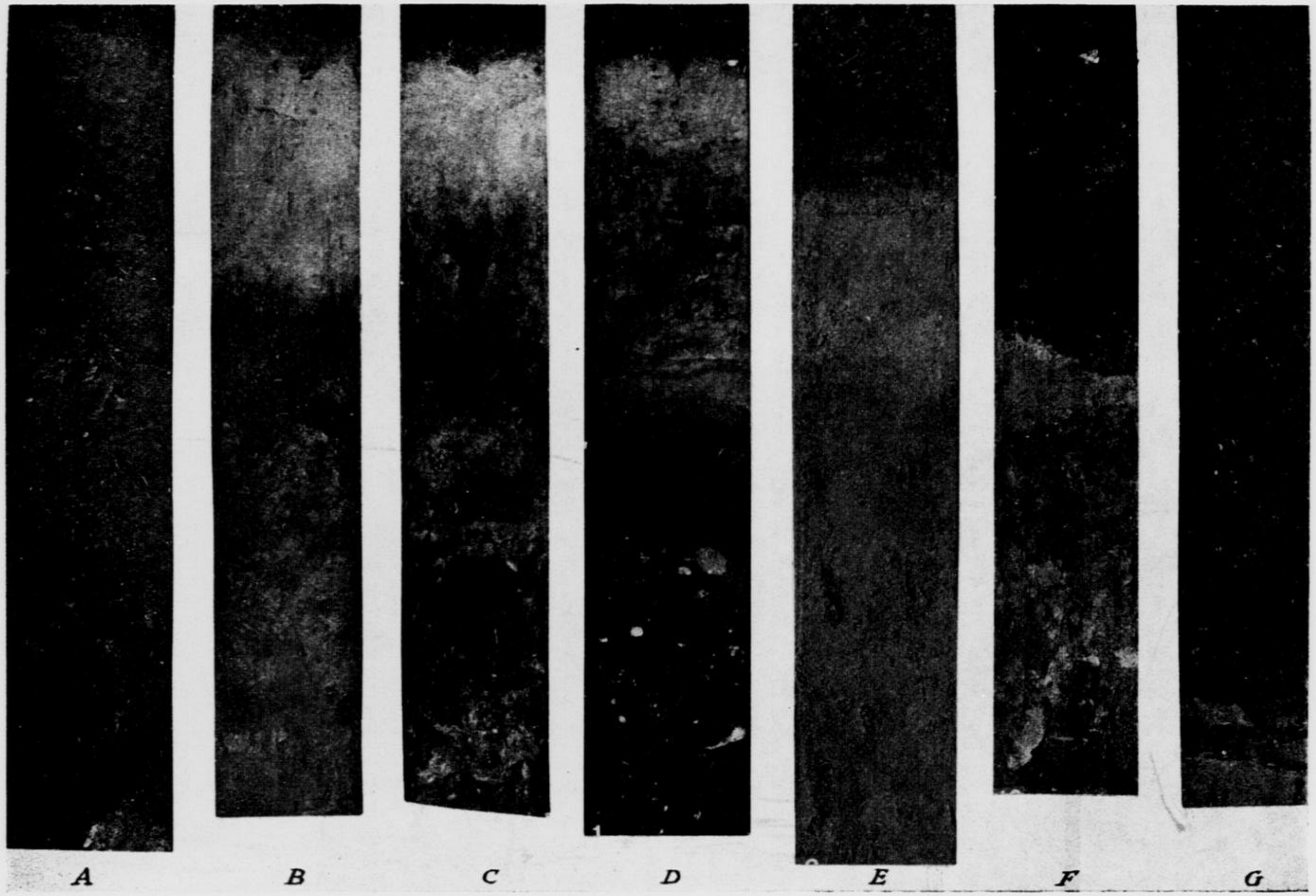


Figure 19. Examples of soils formed under influence of ground water: A—Weakly podolized soil with a deep gley horizon; Gamma-gley loam; B—Gamma-gley loam podzol; C—Beta-gley podzolic loam; D—Alpha-gley podzol; E—Alpha-gley alluvial sand; F—Muck; G—Peat. Note characteristic discoloration or mottling of water-logged layers.

C. MOORS: CUMULOSE or ORGANIC SOILS

Organic soils are formed under conditions of excessive moisture resulting from either high humidity or impeded drainage. They are composed of a surface layer of organic remains usually exceeding 6 inches in thickness, and a water-logged gley substratum. The organic soils formed in depressions are called "low moors" or "swamp soils." The organic soils developed on uplands of highly humid, cold regions are called "high moors" or "raised bog soils" (Nichols).

The detailed classification of organic soils is based upon the composition of the accumulated remains, and they are designated a s "sedge peat", "woody peat", "moss peat", "sedge-moss peat" and so forth. Sometimes the classification is more specific, and types such as "Hypnum-sedge peat" and "Sphagnum peat" are recognized. Furthermore, organic soils are classified according to the degree of decomposition of the organic matter into "fine textured" or "well decomposed", "fairly well decomposed", "coarse textured", or "poorly decomposed" (Sookachev, Tacke, Dachnowski-Stokes). If an organic soil contains 20 per cent or more of mineral material, it is referred to as "muck" or "sapropel" (Stebutt).

Low moor or swamp soils. Low moor soils are formed throughout forest region by accumulation of plant remains in shallow lakes, ponds, and abandoned stream meanders. The process of development is usually initiated by reeds, sedges, and similar shore-line plants which gradually creep toward the center of the basin as their remains accumulate and offer them a suitable foothold. The accumulation of debris is assisted by algae growing on the bottoms, and mosses which float on the surface as consolidated layers or mats. Such mats of mosses and other water-loving vegetation may cover the lake completely and convert it into a"quaking bog" or quagmire. The floating mat may attain a considerable thickness, become water-logged and sink to the bottom of the lake as an inter-layer of the eventual peat deposit. If conditions permit, shrubs and trees invade the shore deposits and floating mats, and contribute to the development of peat. Thus, depending upon the nature of plant remains, the swamp deposits may consist of several more or less distinct layers of sedimentary aquatic peat, sedge peat, moss peat and woody peat.

In areas subject to periodic overflow, organic detritus is enriched in silt and clay particles sedimented during inundations and giving rise to muck soils or sapropels. In some instances such soils are formed in grassy swamps or marshes where sedges, cat-tails, and reeds release in decomposition a certain amount of mineral "earthy" matter which infiltrates into the organic residue.

The peat and muck formed in lakes or swamps with hard water are underlain by a calcareous layer of marl or bog lime, accumulated by precipitation from solution, from animal shells, and carbonate secretions of algae.

Moss peat has the lowest content of nitrogen and mineral nutrients, whereas sedge peat and muck, the highest. Woody peat occupies an intermediate position. Almost invariably moss peat has an extremely acid reaction; the reaction of other types varies from strongly acid to alkaline.

High moor soils. Low temperature and the associated adverse conditions of high mountains and coastal regions arrest the activity of microorganisms and lead to the development of peat deposits not only in depressions but on upland areas as well. Because of retarded decomposition, remains of plants, chiefly mosses, accumulate and raise above the neighboring ground as extensive heaps. From this characteristic form, the names "raised bogs" or "high moors" were derived.

In some instances, high moors originate under forest cover and their development is related to the process of podzolization. The depletion of the surface layer of a forest soil in bases promotes the accumulation of raw humus which increases the water-holding capacity and encourages the invasion of mosses, especially Sphagnum. In time mosses cover the area as a solid blanket. The insulating effect of Sphagnum results in considerable difference between the summer temperatures of soil and atmosphere, hindering the normal transpiration of trees. Forest stands gradually degenerate and give way to high moor vegetation of heath shrubs, mountain pines, and other species of an xerophytic nature (Ramann, Tanfiliev).

High moor peat has essentially the same properties as moss peat of swamps; it is extremely acid and low in nutrients.

Table 15 summarizes the general characteristics of various types of peat, as classified by Dachnowski. Table 16, adopted from Wilde and Hull, includes the average values from total analyses of the most important peat materials.

Table 16. Total Analysis of Moss, Sedge and Woody Types of Peat (Weighed Averages)

Type of Peat	O.M.	SiO_2 & insolubles	N	P_2O_5	K_2O	CaO	Fe_2O_3 + Al_2O_3
Bog-moss peat (Sphagnum)	97.8	0.7	0.92	0.04	0.06	0.20	0.25
Brown-moss peat (Hypnum)	94.5	1.5	2.09	0.06	0.08	1.00	0.60
Sedge peat (Corex)	95.3	0.9	2.91	0.10	0.15	1.95	1.00
Woody peat (Deciduous and coniferous)	94.5	1.7	2.05	0.11	0.12	1.41	1.37

Although organic soils are of numerous varieties, they have the same general morphology. The profile consists of a purely organic surface layer of varying thickness (A_o), a black, partly mineral, partly organic transitional layer (A_1), and a mineral gley horizon (G).

The following descriptions illustrate the morphology of the most important types of the organic soils.

Table 15. Characteristics of Different Classes of Peat

Major Classes	Types of Peat	Color, Texture, Structure
I. Sedimentary peat	Oozy, macerated, or pulpy peat	Olive green to black; amorphous and sticky.
	Calcareous sedimentary peat	Gray to grayish brown; coarse to finely divided; crumbly.
	Silicious sedimentary peat	Brown to black; fine grained; plastic to friable.
Ia. Sedimentary-fibrous peat	Cattail peat, Tule peat, etc.	Dark brown to black; partly stringy fibered; dense, plastic to lumpy.
II. Fibrous peat	Reed peat	Yellowish to dark brown; coarse to fine fibered; matted to felty porous, brittle.
	Sedge peat	Brown; coarse to fine fibered; matted to felty porous.
	Hypnum moss peat	Yellowish to dark brown; fine fibered.
	Sphagnum moss peat	Yellowish to reddish brown; coarse to fine fibered; spongy porous.
	Heath shrub peat	Brown to reddish brown; coarse fragmented; firm, lumpy.
IIa. Woody-fibrous peat	Willow-alder peat	Brown to dark brown; fibered to coarse woody, granular; sticky to crumbly.
	Bay shrub peat	Dark brown; fibered to woody, granular.
III. Woody peat	Coniferous woody peat	Reddish or dark brown; coarse to granular; loose to firm, lumpy or crumbly.
	Mixed woody peat	Brown; woody to granular; lumpy to friable.
	Deciduous woody peat	Brown to black; woody to granular; lumpy or loamy.

Moss peat formed in stagnant Sphagnum swamp or "bog" supporting black spruce and tamarack:

A_0 23 inches. Slightly decomposed fibrous remains of mosses of yellowish-brown color grading into more compact, dark brown sedge-moss peat. Strongly acid.

A_1 5 inches. Transitional layer of greyish-brown sand with some incorporated remains of sedges and aquatics. Acid.

G Bluish-green sand. Neutral.

Woody peat formed under northern white cedar and balsam fir in a locality with a slow but continuous underdrainage:

A_0 36 inches. Partly decomposed, brown to black remains of swamp trees, mainly white cedar, with many fragments of wood retaining their identity. Peat is slimy to the touch and has a strong, disagreeable smell of hydrogen sulfide. Strongly acid.

A_1 36 to 42 inches. Plastic, wet clay high in organic matter, of a black color. Slightly acid.

G Wet sand with some gravel and varying amounts of clay, green mottlings, and agglutinations. Alkaline.

Muck formed under tag alder in an area subject to overflow:

A_0 3 inches. Dark brown, partly decomposed organic matter of somewhat granular structure.

A_1 3 to 24 inches. "Sapropel" layer; black, plastic and moist mixture of dispersed organic matter and clay, becoming dark or brownish-grey at the lower limits of the horizon. Slightly acid.

G Compacted gley layer of a silty clay texture with brownish and greenish mottlings. Slightly alkaline.

Moss peat of both high moors and low moors support highly acidophilous tree species. Outstanding among them are black spruce, tamarack, Scotch pine, several species of the mountain pines, and swamp birch. Woody peat is correlated with a broad variety of swamp conifers and hardwoods, such as white spruce, balsam fir, white cedar, black ash, red maple, swamp maple, elms, and willows. Muck soils are characterized by an abundance of alder, occurring in pure stands or in mixture with numerous water-loving species. Sedge peat supports marsh vegetation (Cajander, Kotilainen, Sookachev). Forest stands on all types of organic soils, as a general rule, attain but low or mediocre productivity.

Figure 20 presents typical forest stands occurring on organic soils.

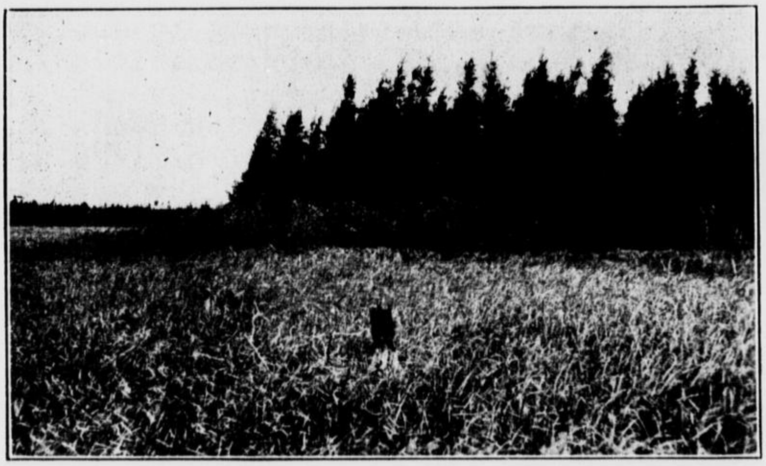


Figure 20. Cover types of organic soils. Top: Marsh grass grading into stagnant moss peat swamp with stand of tamarack. Bottom: Mixed stand typical of woody peat swamps having a slow but permanent drainage.

D. IMMATURE OR EMBRYONIC SOILS

Immature forest soils are confined to areas modified by recent processes of erosion, i.e., denuded slopes and deposits produced by water, wind, or gravity. The profile of such "embryonic" soils is composed of an unaltered parent material (C), and a more or less developed humic layer (A_1), with various amounts of litter (A_0). In time these soils undergo the process of differentiation into horizons, and become mature or fully developed. However, this may be prevented by continuous denudation and deposition.

The group of embryonic soils includes rocky soils, barren soils, alluvial soils, denuded soils, and deluvial soils.

Rocky soils. Rock outcrops, stony and gravelly soils of steep slopes, and skeletal soils of colluvial deposits in many instances support isolated struggling "pioneers", or sporadic stands of low productivity. However, some trees are able to derive sufficient moisture and nutrients even from the barren rocks, and stands of a fairly high density and rate of growth may be found on such habitats. Species of spruce on granitic rocky soils of mountains, and species of pine on sandstone outcrops are striking examples.

Barren sands. Humus-deficient sands include recent wind and water deposits, such as blow sands, sand dunes, beach sands, and sandy fans of streams and rivers. The forest cover of these deposits is limited to a few less exacting species, such as pines, willows, and cottonwood. Control of erosion is the chief reason for afforestation of barren sands.

Alluvial soils. The alluvial or "stream-bottom" soils are post-glacial deposits of rivers and creeks. They are characterized by a deep humic horizon and commonly a high ground water table. They support a diversity of forest types, the composition and productivity of which are determined by texture and drainage. Stands of bald cypress, tupelo gum, and other hardwoods of Mississippi lowlands present one of the world's outstanding examples of forest cover on alluvial soils.

Denuded soils. Soils of denuded areas vary in their properties depending upon the thickness of the eroded layer and the nature of the exposed subsoil. The hypothesis that erosion renews the fertility of the soil by exposing the unleached substratum is highly dubious. As a general rule, the productivity of denuded soils is low and it is difficult to reforest them.

Deluvial soils. The deposition of eroded material on the lower slopes, in valleys or in depressions gives rise to "over-wash" or deluvial soils. Ordinarily these soils have a fine texture, a high content of humus, and a large supply of nutrients. In some instances, the profile of deluvial soils consists of several layers of humus buried at various depths under alternating mineral strata. The occurrence of the more exacting species and a high rate of growth of the forest stands usually marks the areas of deluvial soils.

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Figure 21 shows an approximate distribution of the broad soil-forest provinces in the United States. These provinces are characterized by the prevalence of certain tendencies in the development of soil profile, and by the occurrence of the typical climax forest cover. In forestry, these broad land units, each with its own climate, soil, and vegetation, serve as an important ecological framework which facilitates the translocation or "naturalization" of exotic species, and the establishment of general silvicultural policies.

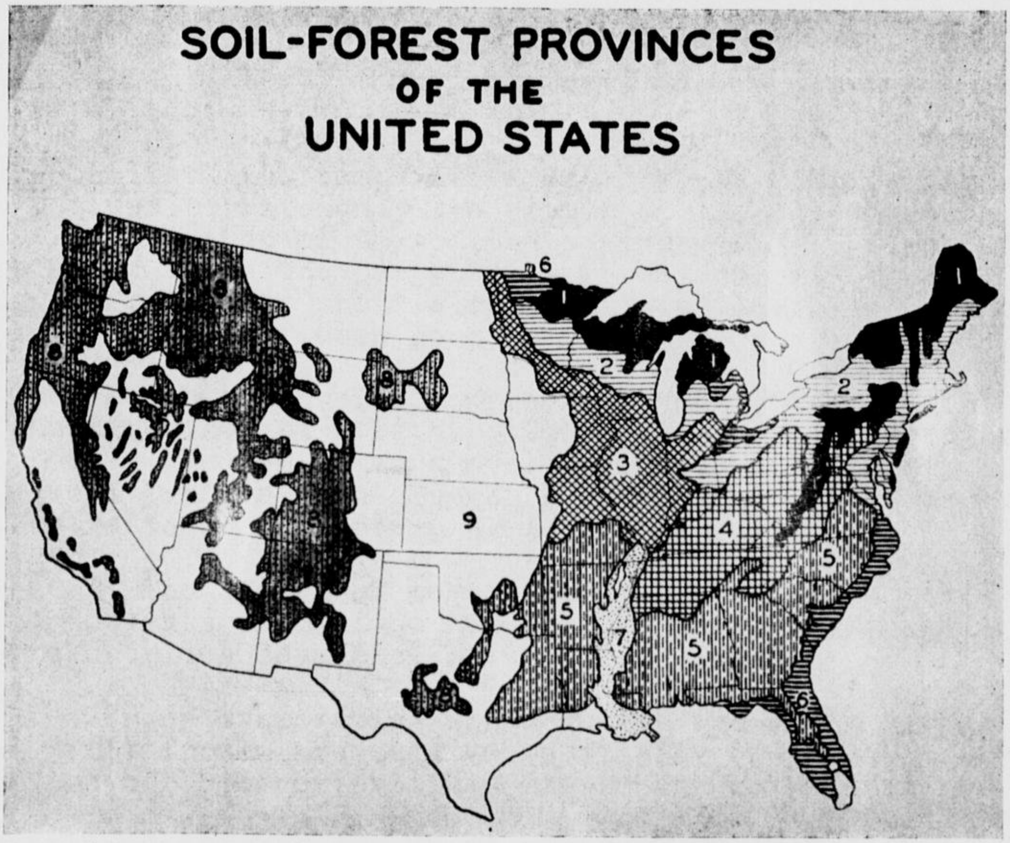

Figure 21. Major Groups of Soils and Forest Cover of the United States.

1. PODZOLS
Spruce-Fir; Hemlock-Yellow Birch

2. PODZOLIC SOILS
White Pine; Maple-Basswood-Beech

3. GROODS
Oak-Hickory; Prairie-Forest

4. MELANIC SOILS
Chestnut-Oak-Tulip Poplar

5. LATERITIC SOILS
So. Hardwoods; Oak-Shortleaf Pine;
Lablolly-Longleaf-Slash Pines

6. GLEY SOILS
Lowland Hardwoods and Conifers

7. ALLUVIAL SOILS
Cypress-Tupelo-Red Gum

8. UNDIFFERENTIATED SOILS OF THE WEST

SEMI-DESERT SOILS
Chaparral: Pinon-Juniper

MELANIC SOILS
Douglas Fir-Yellow Pine

PODZOLIC SOILS
Western White Pine
Western Red Cedar-Hemlock

MOUNTAIN PODZOLS
Spruce-Fir

SOD SOILS
Subalpine Forest

9. NON-FOREST SOILS

CHAPTER VII

NON-FOREST SOILS

In many instances, non-forest soils are interspersed in forest regions. Attempts are sometimes made to afforest these soils and it is essential for the forester to have a general knowledge of their properties.

Tundra soils. Low temperature and a short growing season of arctic regions permits only the growth of lichens, mosses, and low shrubs. The remains of these plants accumulate in depressions and on flat areas where the perpetually frozen subsoil creates swamp-like conditions. The profile of such "wet tundra" or muskeg soils is similar to that of moss peat.

The better drained portions develop "dry tundra" or heath soils characterized by a rather thin layer of dry, partly carbonized remains and a greyish-brown gravelly substratum. A faint differentiation of soil profile into greyish leached layer and a brownish accumulative layer may occur, as in podzol soils.

At the limits of vegetation growth, tundra soils grade into the "deserts of minimum temperature" with their skeletal soils, i.e. rock detritus devoid of humus.

Strong evaporating winds during the early spring when the soil is still frozen are said to be chiefly responsible for the destruction of trees established in the tundra region.

Mountain meadow soils. These soils are formed under the grass vegetation of "alpine meadows" bordering podzols and sod soils of the mountains. They are shallow, stony and gravelly, with a peat-like or muck-like humus layer. In spite of severe climatic conditions, soils of mountain meadows have a high content of nitrogen and mineral nutrients, and are regarded by some students as the "chernozems of high altitudes." A short growing season is, probably, the main obstacle to the establishment of forest vegetation on these soils.

With increase in elevation, mountain meadow soils grade into mountain tundra soils and skeletal barrens, essentially similar to those of the arctic regions.

Chernozem or black earth soils develop in regions of continental climate with hot, dry summers and cold winters. In such regions, insufficient moisture prevents forest growth and the vegetation consists of prairie grasses. The remains of the grasses, particularly the roots, do not undergo complete decomposition, but accumulate in the upper part of the soil as humus. The climate of chernozem region limits leaching to readily soluble bases. Sodium and potassium may be entirely removed by the percolating water, whereas calcium and magnesium accumulate in the deeper soil layer, the so-called "zone of carbonate accumulation." In most cases, bases are continually returned to the surface layer of the soil by prairie vegetation.

The morphology of the chernozem soils is illustrated by the following profile description:

A_0 Prairie mulch of partly decomposed grasses, about 1 inch in thickness.

A_1 20 inches: humic horizon of a black color, of crumby, persistent structure, with a rather dense network of the roots of grasses, and passages of earthworms and prairie animals.

A_2 20 to 45 inches: transitional horizon of a dark brown color with black humic tongues, of a coarse crumby, or fine nut structure; more compact in the lower portion.

B 45 to 60 inches: illuvial horizon of a yellowish grey color with pseudomycelium and concretions of accumulated $CaCO_3$, practically structureless and porous, enriched in the lower part in $CaSO_4$. (gypsum)

C Yellowish-buff loess.

The A_2 horizon in many cases is not recognizable.

The content of humus, in some black earth soils, may be as high as 20 per cent, and the depth of humic layer as much as 5 feet. The content of humus decreases toward both humid and arid regions and the soils are classified accordingly into "deep" or "rich" and "shallow" or "thin" chernozems.

Black earths are among the most fertile agricultural soils of the world; they possess ideal physical properties, nearly neutral reaction, multitude of organisms, and high content of nutrients. These features, however, are of little value to the growth of trees; because of unfavorable climate, forest plantations usually degenerate on black earths before attaining an age of forty years. A comparatively fair success in tree planting is achieved on the "poorest", or "degraded" black earth soils located near the podzolic boundary.

<u>Prairie soils</u> formed on calcareous rocks in podzolic regions are closely related to chernozems in both morphological and ecological respects. However, prairie soils lack the stability of true blackearth in regard to their content of bases and reaction. An absence of specific forest organisms, particularly mycorrhizae, is believed to be one of the chief adverse conditions handicapping afforestation of prairie soils.

With increase in aridity, chernozems are replaced by <u>chestnut</u> and <u>brown soils</u>, supporting "dry prairie" vegetation. High concentration of salts, strongly alkaline reaction, and toxicity of accumulated sodium ion, aside from deficient precipitation, are likely to cause great difficulties in the establishment of forest trees on these soils.

<u>Savanna soils</u> develop under prairie vegetation in the lateritic region of alternate dry and wet periods. The genesis and ecological properties of these soils are closely related to those of the black earth soils. However, the warm temperature throughout the year promotes a rapid and nearly complete decomposition of organic matter.

Consequently, the savanna soils contain only moderate amounts of humus and preserve the typical red color of lateritic soils. In many instances, savanna soils develop on areas previously covered with tropical or sub-tropical forests.

Alkali soils are formed in the arid or semi-arid climates under condition of temporarily excessive saturation, and are found sporadically in the region of chernozems and desert soils. They include three morphological varieties: solonchak, solonetz, and solodi.

Solonchaks are confined to depressions with impeded drainage in which surface streams and subterranean seepage accumulate great quantities of soluble salts. During drought periods the carbonates, sulfates, and chlorides of calcium, magnesium, and sodium move upward with the evaporating water and accumulate in the surface soil layer. Sodium salts are the most abundant and are chiefly responsible for the alkaline reaction and toxicity of the solonchaks.

The vegetation of solonchaks is limited to a few haolphytic species.

Solonetz soils are characterized by a fairly deep ground water level, a peculiar columnar structure, and a considerably lower concentration of salts in comparison with solonchaks. The lower concentration of salts is chiefly due to the fact that capillary water does not reach the soil surface. In some instances solonetz soils are derived from solonchaks which undergo de-alkalization because of the dispersing action of the sodium ion and the partial destruction of the base exchange compound.

The solonetzs support predominantly halophytic grasses, but scattered struggling oaks may be found occasionally on these soils.

Solodi soils are degraded or leached solonetz soils. The upper layer of these soils is impoverished in humus and sesquioxides but enriched in amorphous silica. Their profile, therefore, is similar to that of podzolic soils. However, the process of solodization is effected chiefly by hydroxyl ions, whereas the process of podzolization is due to hydrogen ions. The solodi soils are the least toxic of the group of alkali soils, and, in some cases, they support fairly productive stands of oaks and other forest trees.

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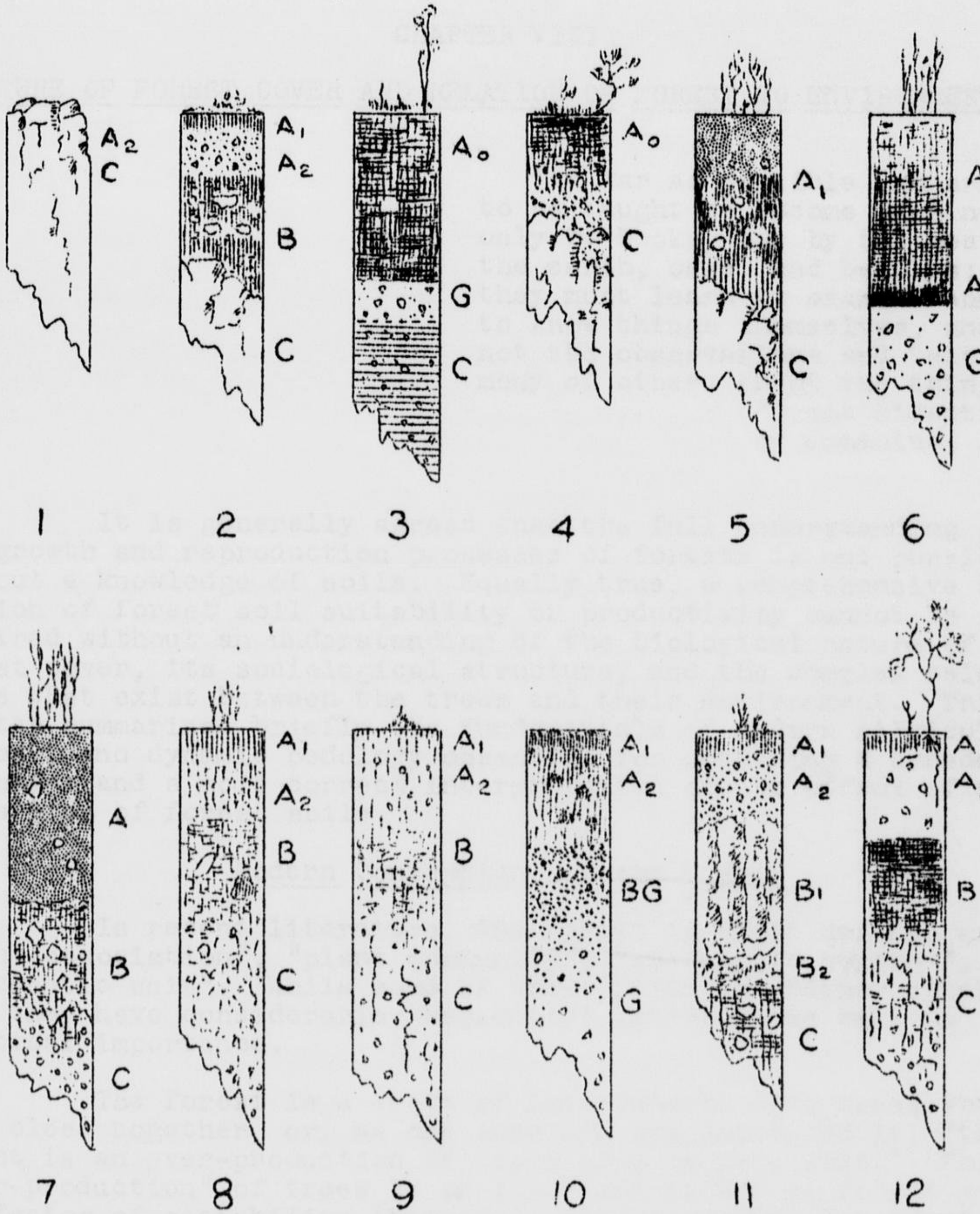

Figure 22

<u>Non-Forest</u> <u>Soils</u>: 1. Skeletal soil; 2. Heath soil; 3. Muskeg soil; 4. Mountain tundra soil; 5. Mountain meadow soil; 6. Marsh soil; 7. Chernozem soil; 8. Chestnut soil; 9. Grey soil; 10. Solonchak soil; 11. Solonetz soil; 12. Soloti soil.

PART III

SOIL AS A MEDIUM FOR TREE GROWTH

(Physical, Chemical, and Biological Properties of Forest Soils)

CHAPTER VIII

NATURE OF FOREST COVER AND RELATION OF FOREST TO ENVIRONMENT

"As far as possible men are to be taught to become wise not only by books, but by the heavens, the earth, oaks, and beeches; they must learn to examine and to know things themselves, and not the observations and testimony of others about the things."
"Great Didactics"
by Comenius, 1632

It is generally agreed that the full understanding of the growth and reproduction processes of forests is not possible without a knowledge of soils. Equally true, a comprehensive conception of forest soil suitability or productivity cannot be acquired without an understanding of the biological nature of forest cover, its sociological structure, and the complex relationships that exist between the trees and their environment. This chapter summarizes briefly the fundamentals of modern silviculture, ecology, and dynamic pedology essential for obtaining a broader viewpoint and a more correct interpretation of the effect of various properties of forest soils.

Modern Conceptions of the Forest

In recent literature, the forest is often defined as a "plant association", "plant community", "geographic complex", or "biocenotic unit". While some of these terms are rather scholastic, they have considerable theoretical interest, as well as practical importance.

The forest is a tract of land covered with trees which grow close together, or, as one American has expressed it, "the forest is an over-production of trees on a certain area." This "over-production" of trees is an important factor of forest growth; the factor of sociability (Morozov). Trees growing far apart and trees growing close together vary in their height and diameter growth, size of crowns, form of stem, and quality of wood produced. Trees in the open live their normal age, whereas most of the trees in a dense forest are eventually killed by their neighbors. The natural reproduction of isolated trees is exposed to adverse climatic influences, while the reproduction in a closed stand develops under the protection of a canopy. In these ways, the density of the stand brings about a certain morphological structure of the forest, social differentiation or struggle for life among species and specimens (Darwin), as well as their mutual cooperation in growth (Mathew). Hence, the forest is called a community of trees.

In a young forest there may be as many as 50,000 seedlings per acre, while in a forest stand one hundred years old there may be only 200 or 300 trees per acre. Through this enormous rate of mortality, nature eliminates weak individuals incapable of competing with their more vigorous associates. If seedlings in artificial reforestation are planted in too wide a spacing a true forest is not created, but rather an orchard of short, brushy trees, worthless as timber. There is no struggle for life in such plantations, and unfit specimens have a chance to grow and reproduce. Thus, tree planting, disregarding the social aspects, tends to bring about a general degradation of the present stand, as well as degeneration of the future forest which may originate from the inferior seed trees.

The trees are the most outstanding, but not the only constituents of the forest. Each forest stand is associated with shrubs, woody and herbaceous plants, mosses, lichens, fungi, bacteria, protozoa, worms, insects, birds, and animals. The occurrence of all these organisms is not accidental since their existence depends upon the food furnished by their associates. For this reason, the forest is referred to as an association of mutually related plants and animals, called "Biocenose", "Lebensgemeinschaft" or "life unit" (Müller). The competition or antagonism, commensalism, symbiosis, sap. rophytism, and parasitism are the basic forms of interrelationship (Braun-Blanquet) that keep all of the associated members in a state of a "biological equilibrium".

In spite of great cyclic deviations in the composition of the biocenose, the disturbance of biological equilibrium by man's activity may cause grave consequences. In localities where wolves, foxes, and other predators are exterminated, the number of rabbits or other rodents may increase to such an extent as to arrest the natural, as well as the artificial regeneration of the forest. The destruction of shrubs and ground vegetation by grazing may induce an emigration of birds from the area and thus reduce the chances for forest reproduction and distribution. Furthermore, the absence of birds may permit the local multiplication of destructive insects, like the Gypsy moth and Nun moth, and the subsequent devastation of extensive forest tracts.

The distribution of both plants and animals is limited by the conditions of environment. Certain specie s of plants and animals thrive and propogate in one physiographic medium, or struggle, degenerate, and die off in another. In this manner, the influence of environmental factors brings together the species adapted to more or less similar conditions of climate and soil. The resulting combinations of life-communities and physiographic conditions are called "life zones" (Merriam) or "geographic complexes". The forest stands of a uniform composition, and uniform habitat or environment, are examples of such geographic complexes.

Trees planted in an unsuitable environment usually perish during the first few growing seasons. If such trees accidentally survive, they do not produce viable seed and are doomed to gradual extinction. Interference with their normal metabolism is likely to occur because of the absence of some associates of the soil-forest complex, viz. mycorrhizae or other useful organisms. The absence of hyperparasites, combined with unfavorable environmental conditions, may convert the struggling plantations into dangerous breeding centers for pathogenic fungi and harmful insects.

The wholesale post-war destruction of Norway spruce plantations in Central Europe serves to illustrate the fate of reforestation violating the environmental requirements of tree species (Nechleba).

Biological Properties of Trees as Related to Environmental Conditions

Through evolutionary processes, trees acquire certain internal characteristics impressed upon them by the environmental factors, viz. light, temperature, and moisture. Knowledge of those characteristics of different tree species, particularly tolerance to shade, temperature requirements, resistance to frost and drought, and ability to withstand an excess of water, forms an important prerequisite to the study of soil-forest relationships.

Light requirements. From the time of seed germination, trees continually struggle with their neighbors for light. If a tree is suppressed by its neighbors and does not obtain sufficient light, it either dies or barely exists, producing but little wood. In northern forests may be found suppressed spruce trees one hundred years old and only one-half inch in diameter and three feet high.

The minimum amount of light required for survival of trees varies with different species. Some trees are satisfied with a very small amount of light, and their seedlings may survive under the dense canopy of a matured stand. Such trees are the tolerant species. Other trees require a considerable amount of light, and their seedlings can develop only under a sparse canopy or in open areas. These trees are the intolerant, or light demanding species.

In the constant struggle of trees for existence, the more tolerant species have a better chance to win the battle and to displace intolerant species. Thus, the degree of tolerance to a great extent determines the ultimate composition of natural forest stands, and is of great importance in silvicultural cuttings and reforestation.

Intolerant trees are faster growing during their youthful stage than the tolerant species. On the whole, however, the tolerant species produce considerably higher yields of timber. The intolerant species are, in general, frost and heat resistant, and may be planted in the open; tolerant species are subject to damage by frost and sunscald, and can be planted only under a protective canopy.

Below are listed some of the more important tree species, according to their degree of tolerance.

Very Tolerant	Tolerant or Intermediate	Intolerant
Yew	Douglas fir	Ponderosa pine
Hemlock	Silver fir	Red pine
White fir	Noble fir	Austrian pine
Balsam fir	Big tree	Scotch pine
Engelmann spruce	No. white pine	Jack pine
Sitka spruce	We. white pine	Lodgepole pine

Very Tolerant	Tolerant or Intermediate	Intolerant
Norway spruce	Loblolly pine	Longleaf pine
White spruce	Pitch pine	Shortleaf pine
Red spruce	Yellow birch	Larch
We. red cedar	Chestnut	Tamarack
No. white cedar	Walnuts	Alder
Red wood	Hickories	Aspen
Beech	White ash	Paper birch
Hard maple	Tulip poplar	Cottonwood
American elm	White oak	Black locust
Basswood	Red oak	Willows

The light conditions are peculiarly related to the nutrient requirements of trees. The greater the amount of light, the less of mineral nutrients are required to produce the same yield of timber, other conditions being the same. Vice versa, the greater the amount of available nutrients, the more overshading the species can stand. Species which grow on sandy soils with a low content of available nutrients are high light-demanding species, such as scrub oaks, jack pine, Scotch pine, paper birch, aspen, and willows. On the other hand, tolerant species such as spruce, fir, hard maple, and basswood require a fair amount of either organic or mineral plant food.

Temperature requirements. Temperature determines the "growing season" of trees, i.e. the period during which wood is produced. A certain amount of heat throughout the growing season is necessary for the development of viable seeds, and, hence, for the existence of tree species. Extremes of heat and cold may kill the trees by coagulating the protoplasm or precipitating the proteins.

The temperature requirements of trees vary considerably within the same species, and only broad groups may be recognized, as follows:

Megathermic trees requiring a warm climate and long growing season: Palms, laurels, magnolia, southern oaks, tupelo gum, red wood, bald cypress, slash pine, longleaf pine, and other southern pines.

Mesothermic trees growing in a temperate climate: Chestnut, oaks, hickories, walnuts, tulip poplar, beech, maples, basswood, ash, elm, white pine, red pine, western yellow pine, hemlocks, Douglas fir, and some fir species.

Microthermic trees tolerating cold climate and short growing season: Aspen, birch, alder, willow, mountain ash, jack pine, Scotch pine, lodgepole pine, spruce species, larch, alpine fir, and mountain pines.

In general, megathermic or thermophilic species develop in regions characterized by a high activity of soil organisms, and rapid decomposition or "mineralization" of organic remains. Microthermic species develop in regions characterized by a low activity of soil organisms, accumulation of raw humus, and leaching of salts from the upper soil layers. Consequently, the thermophilic trees feed primarily on mineral salts in solution, whereas the microthermic trees have an ability to derive their nutrients from organic colloids of raw humus, and are sometimes called "raw humus species."

Moisture requirements. All the life processes of trees go on in water solution, and as soon as the water supply is exhausted, the trees wither and die. More than any other factor, water affects the distribution, and growth of forest vegetation. According to their water requirements, trees are divided into the following groups:

Xerophytic or drought-resistant trees survive with small amounts of available water. Typical examples of this group are jack pine, Scotch pine, longleaf pine, red cedar, scrub oaks, black locust, and Russian olive.

Mesophytic trees require a fair amount of moisture. This group embraces the great majority of tolerant hardwoods and conifers.

Hygrophytic or moisture-loving trees are, as a rule, very sensitive to drought and can tolerate a high content of moisture. Typical trees of this group are: black ash, some willows, river birch, alder, tupelo gum, most of the spruces, tamarack, bald cypress, and other swamp conifers and hardwoods.

Drought-resistant species are confined either to dry regions or to sandy soils, whereas moisture-loving species are confined to humid regions or to heavy and moist soils.

Relation of Forest Vegetation to Soil

Soil-forest relationship in folk terminology. The relationship between soils and forest vegetation has long been known to the rural people. The early settlers of the Lake States region, for example, considered "white pine soils" as fair pasture, "Norway pine soils" as mediocre fields, and "jack pine soils" as soils unsuited for agricultural use (Mayr). At present, the expression "hardwood soil" commonly refers to a good agricultural soil, whereas the expression "hemlock soil" refers to a soil of rather unsatisfactory productivity. "Balsam flats" in the farmer's mind are associated with heavy, moist, and cool soils, suitable for grazing rather than for cultivation.

"In the Southern States," writes Hilgard, "the classification of uplands into 'pine lands' and 'oak lands' is universal, and is associated with certain limits of valuation, both by assessors and purchasers. Within each of these two classes, however, there are well-defined gradations of cultural value according to the kind (species) e.g. of pine or oak that occupies the ground, either alone, or in mixture with other trees whose presence or absence is considered significant. In the case of 'bottoms' or alluvial lands, corresponding distinctions and classifications obtain; we hear of hickory, beech, gum, and cherry bottoms, hackberry hummocks, etc., each name being associated with certain cultural values or peculiarities well understood by the farming population."

Numerous commonly used terms such as "cedar swamp", "leatherleaf bog", "muskeg", "quagmire", "pocosins", "flat woods", "pine barrens", and "chaparral", express the characteristic features of both soil and its associated vegetation and thus confirm the fact of correlation that exists between soil and floristic cover. In the initial stage of ecological research, the folk terminology served as a valuable guide to soil scientists and foresters and helped to establish a number of important relationships between soil and vegetation. With the accumulation of knowledge, however, the students of forest soils came to realize that not all of the relationships between the soil and tree growth are necessarily "obvious", but may be "concealed."

Obvious relationships. An obvious relationship may be illustrated by the following examples: Jack or Scotch pine on sandy soil; hard maple or basswood on heavy soil; alder on muck or wet soil. Relationships of this kind are evident even to a non-technical man who has had some contact with the forest, and can be easily explained by assuming that Jack and Scotch pines require the perfect aeration of sandy soil, maple and basswood the abundant mineral nutrients of heavy soil, and alder the abundant moisture of a swamp soil.

Concealed relationships. Numerous species of trees occur on soils which vary greatly in their texture, drainage, and fertility. For instance, white pine or aspen occur on sandy as well as on heavy soils, on well drained as well as on poorly drained soils, on soils high in nutrients as well as on soils poor in nutrients. A careful investigation shows, however, that white pine avoids the poorest sandy soils, such as wind-blown sands, the soils of recently burned areas with a low content of humus, soils of extreme reactions, and bogs with stagnant water. If the study is not limited to the distribution of trees alone, but considers also the rate of growth, and intensity of natural reproduction, it will be found that the optimum growth of white pine is confined to the well aerated heavier soils with a fair content of moisture and available nutrients. Moreover, white pine, or any other species, exhibits on different soils great dissimilarities in the form of its stem, crown and root system. Hilgard describes as many as four distinct morphological varieties of post and bla ck oaks adapted to upland loams, sandy ridges, flatwoods, and black calcareous soils of the South.

Ecological amplitude. The occurrence of any tree species is determined first of all by the so-called "ecological amplitude" of the species. Ecological amplitude refers to the range of environmental conditions in which a certain species can exist. The alder is limited in its distribution to soils with a high content of moisture, and hence has a narrow ecological amplitude. White pine or aspen survive under a wide range of conditions, and have a wide ecological amplitude.

Competition of species. Aside from the ability of trees to survive under different conditions of environment, their distribution depends upon their ability to compete with other vegetation of about the same ecological amplitude. In this respect the weight of seeds, ability to produce sprouts, and the light requirements of trees are the important properties which determine the relative success of each competing species. Aspen, for example, can grow equally as well as hard maple on a well drained silt loam soil. Yet, aspen is a light demanding tree, whereas hard maple is a tolerant tree. The young reproduction of maple can develop under the crowns of aspen, but the aspen cannot grow in the shade of the hard maple canopy. Hence, hard maple will eventually crowd out the aspen, and will form a pure maple stand. The same relationships are observed in the cases of light demanding Jack pine and tolerant white pine; light demanding paper birch or pin cherry and tolerant yellow birch and hemlock; light demanding European birch and tolerant Norway spruce.

Mass action of the forest. The occurrence of a tree species on a specific type of soil depends to some extent on the composition of the forest of the entire region as well as on the size of the area occupied by a soil type. For example, a few acres of heavy soil in a region of sandy soils would hardly support hard maple or hemlock, but more likely stands of pine, since most of the region is occupied by the pine species.

Accidental disturbances. Sometimes certain species may temporarily occupy an area after the original forest stand has been destroyed through accident. Numerous tamarack swamps in the Lake States at present support white cedar and spruce, the tamarack having been destroyed 50 years ago by saw-fly.

Modifying influence of climatic factors. The conditions of climate radically change the suitability and productivity of soils having the same textural and mineralogical composition. A sandy soil of granitic outwash may be a satisfactory site for spruce in the cool and moist climate of Alaska, but is unsuitable to the same species in the continental conditions of Central Wisconsin. Austrian pine in Bohemia has a comparatively short growing season and shows signs of starvation on soils low in nutrients. However, the same species grows satisfactorily on barren sites in the Mediterranean region, where its seasonal grow th is considerably longer.

These examples are sufficient to illustrate the fact that climate and soil are two inseparable growth factors. In consequence of this, all classifications of the various soil properties are valid from an ecological standpoint only within a specific climatic region.

The maxim of Pfeil "no general rules in forestry" was not intended by its author to introduce into forest management the spirit of anarchistic disorder, but to protest against unjustified generalizations of local experiences--generalizations which disregarded the modifying influence of environmental factors and contaminated silvicultural theory with an untold number of controversies.

Forest Succession

Pioneer species. Logging and forest fire may temporarily change the natural distribution of tree species. The forest cover of cut-over or burned-over areas only in rare cases consists of the same species that previously grew on the area. As a rule, logging or fire is followed by the development of temporary stands of so-called pioneer species. The pioneer species are usually light demanding; they have low nutrient requirements and can withstand frost and sunscald, common on cut-over land. Typical pioneer species are: scrub oaks, aspen, paper birch, grey birch, pin cherry, jack pine, Scotch pine and many other pines. Under favorable climatic conditions, however, some tolerant or semi-tolerant species, such as white fir, Douglas fir, and spruce, may act as pioneers.

Local succession. When the reproduction of pioneer species reaches the age of 20-30 years, tolerant species, such as white pine, spruce, hemlock, hard maple, and yellow birch, begin to develop under the protection of pioneer crowns. The tolerant species gradually suppress the pioneers, which die off as soon as they are over-shaded by the tolerant trees, and the temporary or pioneer stand is replaced by the permanent forest stand. This process is called a local succession of the forest.

General succession. Besides the local succession, the forest shows a general succession, or a general movement toward a few climax formations. The climax formations include a few tolerant species, which are best adapted to the climate and soil of the region. For example, in the northern part of the Lake States region the climax formation is a mixture of hard maple, beech, basswood, yellow birch, and hemlock.

Succession and soil development. The general movement of forest toward the climax is closely related to the gradual changes which take place in the soil profile. Soils are subject to progressive weathering, and in a long run tend to increase their colloidal content and water-holding capacity. Hand in hand, the xerophytic species of light soils are gradually substituted by the mesophytic species of heavier or moister soils. The accumulation of humus, and podzolization of the soil have a similar effect on the distribution of species since both of these processes have a tendency to increase the water holding capacity of soil.

Importance of succession in reforestation. The succession of tree species, particularly the local succession, has considerable significance in reforestation practice. Some light sandy soils of this country supported a number of virgin white pine stands of fairly good growth. This fact led to the inference that light soils were suitable for planting w hite pine. However, white pine plantations on such soils have either perished, or show very poor growth. This happened because the reforestation practice has disregarded the principles of natural succession of trees. White pine of the virgin forest has invaded the light sandy soils at a time when the soil was covered by a thick layer of duff, and was protected by a canopy of the pioneer crowns: i.e., in an environment greatly different from that of a cut-over area. In recent times it has been proven on numerous occasions that the survival of white pine is greatly increased if the forest succession is imitated by previous planting of pioneer species. European practice has gone so far in this direction as to plant white birch as a nurse crop to protect the subsequently underplanted spruce from direct exposure, while mugho pine is planted along with the spruce to provide a layer of pine litter.

Productivity of Forest Soil

Productivity and soil dynamics. The recent teachings of pedologists present soil as a "continually changing medium which is a function of the geological substratum, environmental influences, and activity of organisms" (Stebutt). In the light of this definition, the soil and forest stand are not two independent bodies, but are integrated parts of the same "dynamic system". Therefore, the composition and productivity of a forest soil is affected by all the modifications of environment which may result from man's activity, viz. logging or thinning of stands, planting of trees, burning of slash, removal of litter, pasturing, and so forth. The studies of forest soils have actually shown that even minor silvicultural treatments bring almost immediately marked changes in the composition of the soil.

Growth factors. The rate of wood production results from the influence of two broad, not sharply delineated groups of growth factors: primary or physiographic factors, and secondary or biogenic factors.

Primary factors originate from conditions common to barren or cut-over land, i.e. general climate, topography, drainage, soil texture, and mineralogical composition of soil. Secondary factors of growth include inherent properties of the forest stand and influences of the environment which it creates, especially influences of the specific climate under the forest canopy, forest litter, and products of its decomposition, and associated flora and fauna.

The physiographic factors have a rather constant value and represent a certain potential ability of land to produce timber, or the potential productivity of the forest soil. The potential productivity is estimated by means of soil survey or soil analysis and is used in conjunction with yield tables as a basis for land appraisals and calculation of the financial possibilities of reforestation.

The yield of wood actually produced by a stand at a certain age is a concrete expression of all, measurable and non-measurable factors of forest growth, and represents the actual productivity of a forest soil. In practice, the actual productivity is determined by measuring the age, heights, and diameters of trees on sample areas, and by estimating, with the help of volume tables, the amount of lumber, pulpwood or firewood in board feet or cords produced per unit area. The actual productivity is of prime importance in evaluation of forest property, taxation, and calculation of the annual cut in forests managed on a sustained yield basis.

It may be readily seen that forest stands on soils of the same potential productivity may show considerable variations in their rate of growth. These variations may result from inherited weaknesses of the stand or may be due to incidental injuries by frost, sunscald, drought, and excessive rains. Improper planting, planting unreliable stock, removing litter, pasturing the forest stand, and other man-caused disturbances may also be responsible for poor growth on soils having a high potential productivity.

Correlation of soils and rate of growth. Since the productivity of forest land is influenced by a great number of incidental factors, no direct correlation between the soil and forest need be expected in any individual case. At the same time, a study of a considerable number of forest stands, growing under similar soil conditions, reveals the dominating influence of soil upon the rate of forest growth. In such studies the accumulated data for each soil type are subjected to statistical treatment. Such treatment eliminates all incidental yields, falling outside the limits of the standard deviation, and establishes the average rate of growth which may be generally expected on the soil type in question.

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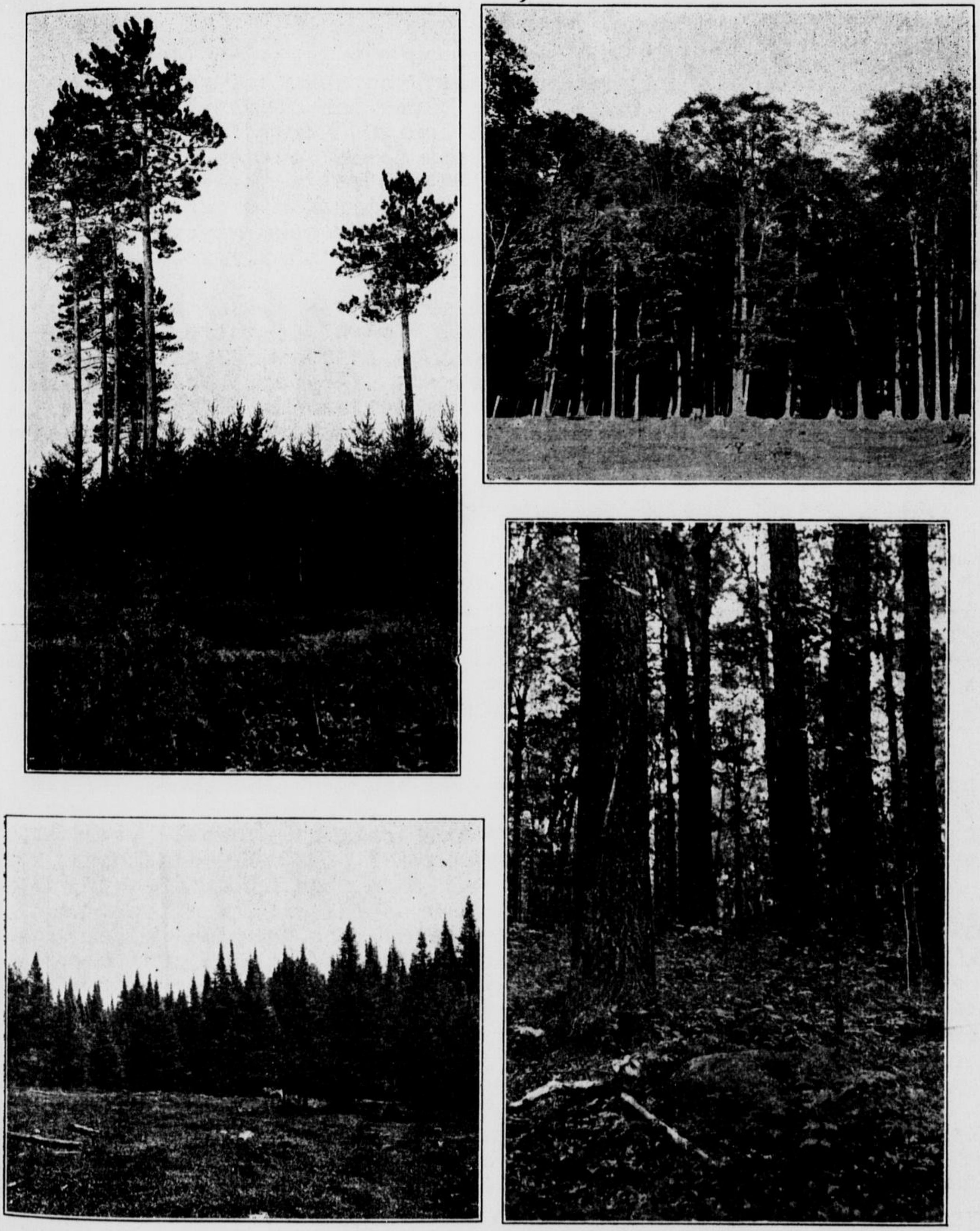

Figure 23. Forest Succession. N. W.: Pioneer stand of intolerant jack pine invading a sandy outwash af-er red pine had been largely destroyed by fire; S. W.: Second-growth white spruce on a clay soil of old glacial rift; rather rare example of a tolerant species acting as a pioneer; N. E.: Climax stand of northern hardwoods ith some hemlock and balsam fir on a leached loam; S. E.: Climax stand of hard maple and basswood on a umus-incorporated silt loam.

PHYSICAL PROPERTIES OF FOREST SOILS

Soil Texture

Soil material may be divided into two fractions: coarse material, which includes particles larger than 0.05 mm. in diameter, viz., stones, gravel, and sand, and fine soil material, which include particles smaller than 0.05 mm. in diameter, viz., silt, clay, and colloids. The separation of these two fractions is made by shaking soil with water and allowing the suspension to settle. After one minute, the coarse soil material has settled, whereas the fine soil material stays in suspension. The relative amounts of the coarse and fine soil materials determine soil texture.

The coarse soil material represents the "skeleton" of the soil; its function is largely limited to the physical support of plants, and it is practically inactive in plant nutrition. On the other hand, the fine soil material is the active portion of the soil, which through its absorptive and nutritive properties fulfills manifold ecological functions. It is the carrier of life in the soil, or as Stebutt says, it is the "soil protoplasm".*

The Influence of Soil Texture upon the Natural Forest Growth

The ability of soil to retain water depends upon the amount of the fine soil material present. The higher the amount, the greater is the soil moisture content, other conditions being the same. Since the soil pores are filled with either water or air, an increase in the fine soil material, and consequently in soil moisture, leads to a decrease in soil aeration. Finally, the fine particles are the chief source of easily soluble substances, which serve the trees as nutrients.

Thus, soil texture materially influences the three basic factors in forest growth: soil moisture, soil aeration, and soil nutrients. Because various tree species have different requirements for these three factors, their distribution and rate of growth are often closely correlated with the soil texture (Kruedener). In general, soils with a low content of the fine soil material, i.e., sandy soils, support only trees which have low requirements for moisture and nutrients, viz., pines, scrub oaks, white birch, aspen, etc. On the contrary, soils with a high content of fine particles, i.e., loam soils, support trees which have high requirements for moisture and nutrients, viz., species of spruce and fir, hard maple, basswood, elm, white ash, etc.

In the virgin forest there may be found many instances where the correlation of soil texture and forest growth is masked by the influence of other factors, especially by the ability of forest stands to modify the environment. Through a succession of pioneer and basic species, forest stands adjust the soil to the requirements of tree species which compose them. For example, cut-over sandy soils

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*Perhaps the colloidal fraction (particles less than 0.0001 mm. in diameter) is alone responsible for the activity of the fine soil material, since the absorptive ability of colloidal particles is incomparably greater than that of the silt and coarser clay. However the colloids tend to adhere to the silt and clay particles, and cannot be completely separated in the ordinary analyses of soil.

of Wisconsin are suitable only for jack pine, or at best, for red pine. However, as soon as these pioneer species become established, they moderate the extremes of climate, particularly high temperature, with the canopy of their crowns, and accumulate litter and humus which increase the water holding capacity and supply of plant nutrients of the soil. Thus, they create conditions suitable for the establishment of white pine, which may gradually replace the pioneer species. Similarly, the modifying influences of other pioneer forest stands diminish the significance of soil texture and allow other species to succeed on soils with a relatively low content of the fine soil material.

Significance of Soil Texture in Forest Planting

In artificial reforestation, the soil of a cut-over or burned-over area has no protection from wind and sun rays. Such soils lack, as a rule, the protective layer of forest litter. Their readily available nutrients are leached away by rains which fall on the exposed barren surface. Under these conditions, the fine soil material becomes the decisive factor in the successful establishment of planted seedlings As observations show, in reforesting well drained Wisconsin soils, the most important species require for a fair growth the following minimum amount of the fine soil material: jack pine - 5 per cent; Norway or red pine - 10 per cent; Scotch pine - 10 per cent; white pine - 15 per cent; red oak - 25 per cent; white spruce, Norway spruce, and most of the hardwoods - 35 per cent.

On the basis of these data, as well as on the basis of the study of natural distribution of species, the following simple classification has been adopted for use in the local reforestation practice.

Relation of Soil Texture to Tree Planting

Percentage of fine material	Soil Class	Reforestation possibilities
Less than 5	Coarse sand	No profitable reforestation except in cases of wind erosion control. Russian olive, black locust, drought resistant varieties of cotton wood.
5-10	Medium sand	High light demanding pioneer species, chiefly jack pine, black locust, and cottonwood.
10-15	Fine sand	High and medium light demanding pines, chiefly Norway pine, Scotch pine, and jack pine.
15-25	Sandy loam	All pines including tolerant species such as white pine.
25-35	Light loam	Hardwood and conifers with medium requirements for moisture and nutrients, such as red oak, yellow birch, white pine, and European larch.
35 or more	Heavy loam	Conifers and hardwoods with high requirements for moisture and nutrients, such as white and Norway spruce, European fir, white ash, elms, basswood beech, oaks, walnuts, and hickories.

It should be understood that the planting possibilities depend not only on soil texture, but also on a number of other factors, such as exposure, ground water level, chemical composition of soil, particularly soil reaction, etc. The choice of species and their adaptation to different soil types also varies greatly with different climatic conditions. Therefore, the knowledge of planting possibilities in other regions is a matter of local experience, derived from observations of both the natural distribution of trees and the conditions in artificial plantations.

In textural analyses it should be remembered that forest soils are not always uniform in their composition, and hence, the whole soil profile to the depth of about 4 feet should be carefully examined as to the distribution of the fine soil particles. First of all, the amount of fine soil material must be determined in the upper soil layer of 0 to 8 inches. This surface layer serves as a growing medium during the most important early period of seedling growth, and is especially important in nursery soils as the chief carrier of fertilizers. If the soil grades with depth into lighter material, it will not have any detrimental influence upon the growth of seedlings in the nursery, but it is wise in such a case to be rather conservative as to the selection of species for planting. For instance, if a sandy loam layer is only 8 inches deep and grades into sandy subsoil, it is better to plant on such a soil, red pine instead of white pine. Similarly, silt loam soil about 12 inches in depth underlain by stratified sand and gravel should be reforested to white pine rather than to hardwoods or spruce. If the upper soil layer grades into heavier material, it may be detrimental in nursery soils because of excess of water in the spring. In planting, however, a heavier layer occurring at a depth of from 1 to 2 feet determines the water-holding capacity of the soil and supply of nutrients, since the roots of planted seedlings will reach this layer in a short time. Hence, the amount of the fine soil material in this layer will determine the selection of species for planting.

If the heavier soil layer occurs at a depth of 2 to 4 feet, it will still have a pronounced influence upon the growth of seedlings. Of course, this influence will vary, depending on the depth of the heavier material, textural composition of the entire profile, and the age of the plantation. Therefore, in dealing with soils of this kind, no definite rule can be established, but in general, the presence of a deeper subsoil layer allows more freedom in the selection of species for planting. For instance, if a light loam soil is underlain at a depth of 3 feet by a heavy glacial till, spruce may well be planted instead of white pine. On the other hand, a pure sandy soil underlain at a depth of 4 feet by a layer of clay cannot be reforested with spruce, but at best with the better pine species, since it will take a number of years before the roots of the seedlings will be able to utilize the capillary water as well as nutrients of the heavy clay subsoil. The fact should not be overlooked that some subsoil layers may be detrimental to seedlings, either because of high concentration of salts (Podzol, Rendzinas), or because of very high content of colloids which in the dry season cut off the capillary movement of ground water (inter-layers of weathered shale).

Importance of Soil Texture in Cuttings and Thinnings

A knowledge of soil texture is essential in all silvicultural operations, especially in thinnings and selective cuttings, since it greatly affects the intensity of cutting and the choice of species which should be protected. For example, it would not be profitable to improve by cutting an oak stand on soil which has less than 20 per cent of fine material because the oak on such soil will not produce a satisfactory yield of timber. The only cutting which might be useful in this case would be for underplanting the area with pine species. For similar reasons, it would be advisable to give preference in release cuttings on light sandy soils to pines rather than to white spruce or other tolerant conifers.

In cuttings for the underplanting, it is again necessary to consider the soil texture. The heavier the soil, the greater is the danger of growth of competing ground vegetation, when sufficient light is available. Hence, a denser canopy of the thinned stand should be maintained in order to control the competition of weed species. For instance, an oak stand on soil containing 10 per cent of fine soil material may be thinned as much as 80 per cent of the normal density for the purpose of underplanting with pines; but an oak stand on soil having 30 per cent of fine soil material should be thinned not more than 40 per cent of the normal density in underplanting with spruce.

The Importance of Soil Texture in Forest Nurseries

The nursery soil must have a sufficient amount of nutrients, so that the seedlings do not suffer from under-nourishment. Also, the nursery soil must have a fairly high water-holding capacity; otherwise, the seedlings suffer from extremes in moisture content, even in nurseries with artificial watering. To satisfy these requirements, the nursery soil should have a rather high content of fine particles. At the same time, nursery soils with too high an amount of fine soil material are subject to heaving or freezing out of seedlings, owing to their excessive saturation in the periods of fall and spring frosts. Also, the seedlings on heavy nursery soils suffer greatly through the breaking of the roots during the spring transplanting, since heavy soils often remain frozen at this time. In view of these facts, the most desirable content of fine soil material of nursery soil ranges from 15 to 25 per cent.

The application of commercial fertilizers in the form of mineral salts is at present a common practice in maintaining the fertility of nursery soils, particularly those of a sandy nature. Unfortunately, in applying fertilizers, as a rule, too little attention is being paid to the fact that the introduced salts must be balanced in the soil by a certain amount of colloidal material.

If fertilizers are applied to a soil having an insufficient content of colloids, they may be soon washed out by rains or artificial watering. In times of drought, the moisture of soils, deficient in colloidal material, rapidly decreases through evaporation. As a result of this, fertilizers are carried upward and accumulate at the soil surface. In this way, the concentration of fertilizer salts may increase from about 500 parts per million to several thousand parts per million in the surface inch. This high concentration is responsible for the chemical injury or "burning" of the roots of the seedlings. For this reason, light nursery soils should be enriched in colloidal material by the addition of clay, peat, or forest litter, or the fertilizer should be added as a compost.

Structure of the Soil

Soil structure refers to the arrangement of individual soil particles into aggregates. The formation of structural aggregates takes place because of the action of electrolytes, colloids, freezing, drying, soil organisms, and roots of vegetation.

The structure of soil may greatly modify the influence of soil texture. This is especially true in the case of heavy clay soils. The structureless soils of this kind suffer, at least periodically, from an excess of moisture and insufficient aeration. They support, therefore, saprophytic conifers such as spruce and fir. The roots of such trees feed almost exclusively on the surface raw humus layer, and thus avoid the adverse influence of poorly aerated mineral soil. On the other hand, structured soils of similar texture have adequate conditions of drainage and aeration, and hence, support a wider range of hardwoods and conifers. In some cases, clay soils have such a well-developed structure of the deeper layers that they behave more as sandy soils than as clay soils. Soils of this nature support stands of jack, Norway, and other pines, which require a high degree of soil aeration. Lacustrine clays of the Superior series in Wisconsin may serve as an example of this condition.

For these reasons it is important, in all soil studies, to give particular attention attention to the structure of the different soil layers.

With regard to the structural features, forest soils may be classified into the following types:

Single-grained -- an incoherent condition of the soil mass with no arrangement of the individual soil particles into aggregates.

Massive -- showing no evidence of any distinct arrangement of the soil particles. Puddled. Found in soils of heavy texture.

Platy -- aggregates form plates or layers 1/16 inch or more in thickness, lying parallel to the soil surface. Usually of medium to hard consistence. Common in podzolic soils.

Crumby -- porous aggregates of irregular shape, of a medium to soft consistence, 1/8 to 1 inch in diameter. Fine crumby -- $\frac{1}{4}$ inch, or less in diameter. Coarse crumby -- $\frac{1}{2}$ inch, or more, in diameter. Common in humic soil layers.

Granular -- aggregates of more or less subangular or rounded shape, or medium consistence, varying in size up to $\frac{1}{4}$ inch in diameter. Is characteristic of Brown forest soils.

Nut-structure -- compact aggregates, more or less rounded in shape, of medium to hard consistence, usually from $\frac{1}{4}$ to 1 inch in diameter. Fine nut-structure -- most of aggregates close to $\frac{1}{4}$ inch in diameter. Coarse nut-structure -- most of aggregates $\frac{1}{2}$ inch, or more, in diameter. Occurs in Grey forest soils.

Columnar - large aggregates in the form of more or less regular columns with vertical cleavage planes, and longer vertical than horizontal axes. Occurs in subsoil layers.

Lumpy -- aggregates of irregular shape, of medium to hard consistence, from 1 to 3 inches in diameter. Fine lumpy -- most of the lumps are close to 1 inch. Coarse lumpy -- most of aggregates are 2 inches or more in diameter. Confined to heavy soils.

Cloddy -- aggregates of irregular angular shape, 3 inches or more in diameter.

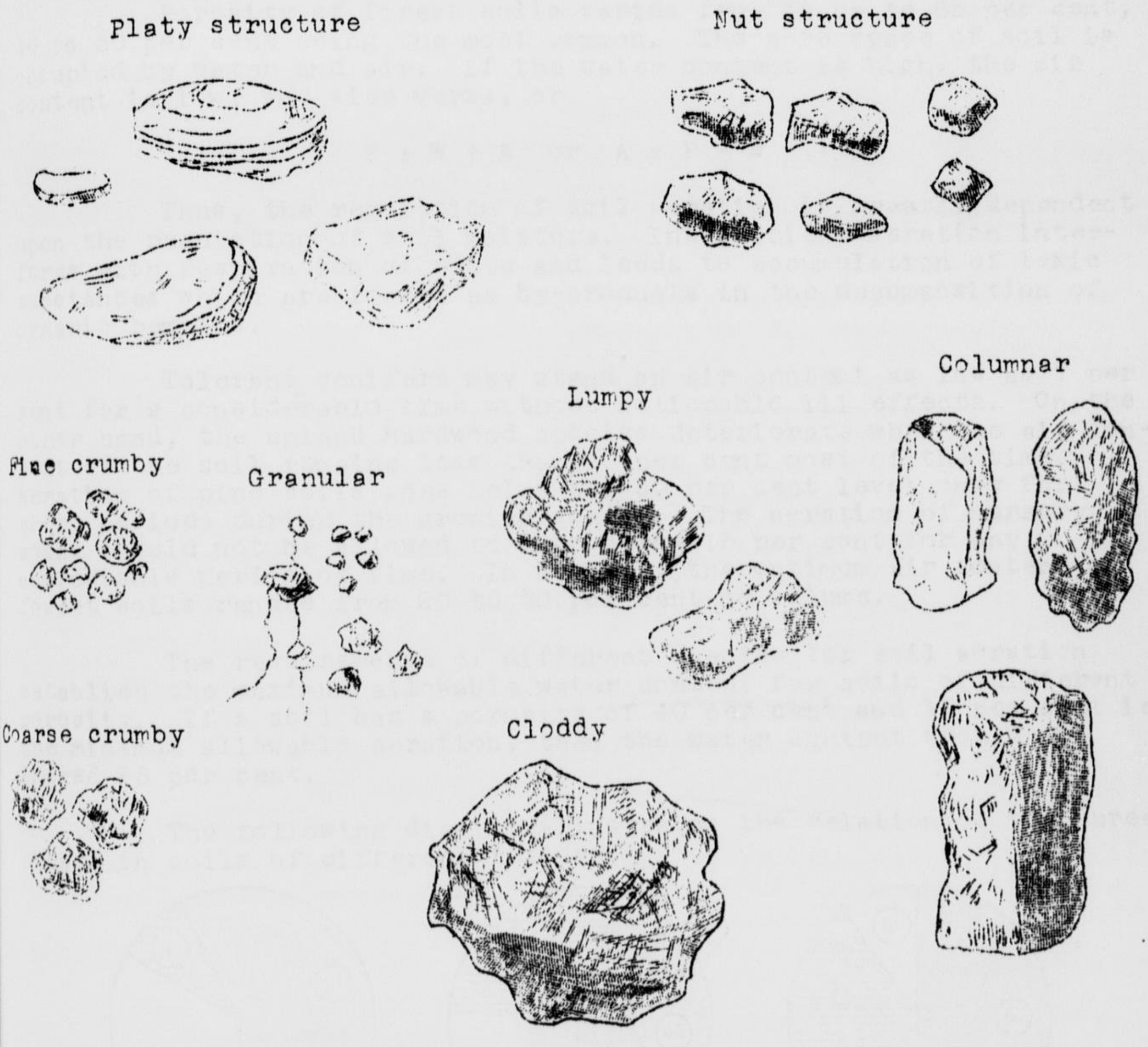


Figure 24

Types of structural aggregates of forest soils

Porosity, Aeration, and Water Content of Soils

The porosity of a soil is determined by its texture, structure, and compactness. The coarser soils usually have less pore space than fine-textured soils because of their relatively smaller surface area and closer contact of the particles. However, puddled or cemented heavy soils, particularly sandy clays, may have a porosity lower than that of sandy soils.

Porosity of forest soils varies from 30 up to 65 per cent, 40 to 50 per cent being the most common. The pore space of soil is occupied by water and air. If the water content is high, the air content is low, and vice versa, or

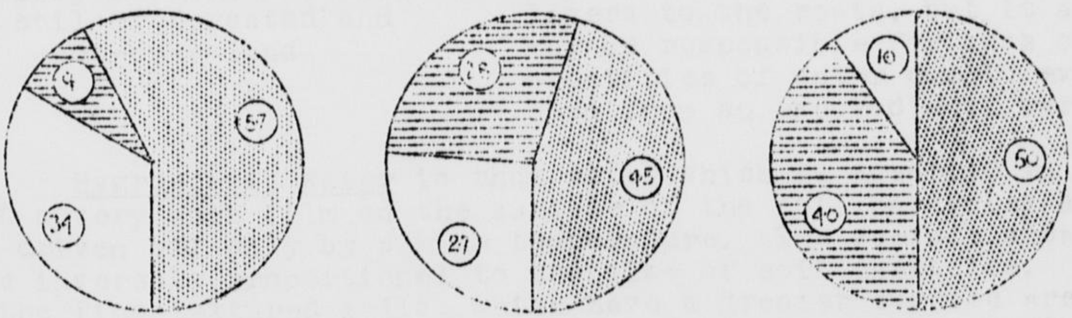
$$P = W + A \quad \text{or} \quad A = P - W$$

Thus, the regulation of soil aeration is greatly dependent upon the regulation of soil moisture. Insufficient aeration interferes with respiration of roots and leads to accumulation of toxic substances which are formed as by-products in the decomposition of organic remains.

Tolerant conifers may stand an air content as low as 7 per cent for a considerable time without noticeable ill effects. On the other hand, the upland hardwood species deteriorate when the air content of the soil remains less than 10 per cent most of the time. Aeration of pine soils goes below the 30 per cent level only for short periods during the growing season. The aeration of nursery soils should not be allowed to drop below 15 per cent for any appreciable period of time. In general, the optimum air content of forest soils ranges from 20 to 30 per cent by volume.

The requirements of different species for soil aeration establish the maximum allowable water content for soils of different porosity. If a soil has a porosity of 40 per cent and 15 per cent is the minimum allowable aeration, then the water content should not exceed 25 per cent.

The following diagram illustrates the relation of the three phases in soils of different texture.



1 2 3

Figure 25

Relative contents of solids (shaded), water (cross-hatched), and air (white) in different forest soils at a depth of 2 feet; (1) Outwash Jack pine sand; (2) Nut-structured morainic silt loam of oak-hickory type; (3) Podzolized lacustrine clay supporting white spruce and balsam fir.

Water occurs in soils in three forms: gravitational, capillary, and hygroscopic.

Gravitational water, also called free water, responds readily to the pull of gravity. It passes through the soil and is largely responsible for removing soluble substances. It often excludes the air and interferes with oxidation processes and respiration of the roots. Most of the free water is undesirable from the standpoint of plant nutrition.

Capillary water is held by the soil colloids and in the narrow spaces between the soil particles by means of surface tension. The greatest portion of capillary water is available to plants.

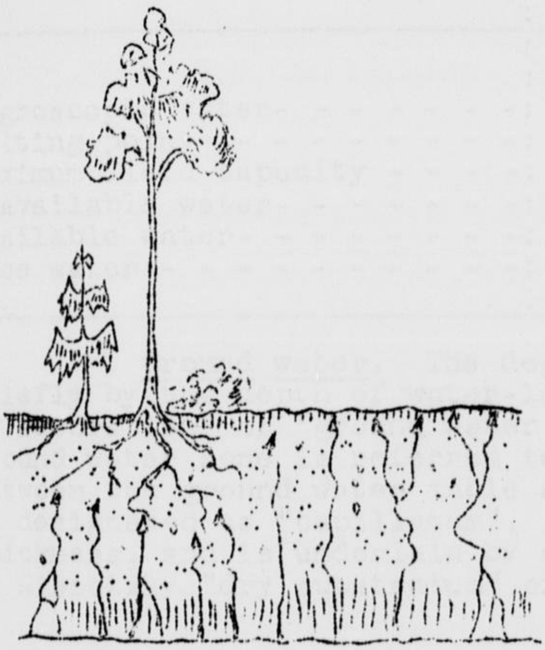


Figure 26
Capillary movement of water in soil of forested and cut-over land

Under the influence of surface tension the capillary water moves independent of gravity. Ordinarily, this movement is in a vertical direction, due to evaporation from the surface or absorption by the root systems. The rate and distance of capillary movement depends chiefly upon the texture and structure of the soil. It is much slower in clays than in sandy soils, but the opposite is true in regard to the distance to which water may be drawn. Capillary flow may be promoted by loosening and granulating of clay soils and by compacting of sandy soils.

Capillary movement may greatly benefit the growth of trees by supplying water from the deeper soil layers to the roots, but it also may be responsible for loss of large quantities of water due to evaporation from an exposed soil surface.

Hygroscopic water is that water which is adsorbed in the form of a very thin film on the surface of the soil particles and may be driven off only by a high temperature. The surface area of soil is inversely proportional to the size of soil particles. Therefore, the fine-textured soils, which have a greater surface area, hold a larger amount of hygroscopic water than the coarse-textured soils.

Since the hygroscopic water is not available to the trees, a condition of so-called "physiological dryness" may occur on highly colloidal clays. Under such conditions trees may suffer from drouth, even though a soil contains a comparatively high percentage of water. Physiological dryness accounts for the occurrence of pines and other xerophytic species on some clay soils.

The moisture content of soil (in per cent on an oven dry basis) at which plants permanently wilt is called "wilting coefficient". The water content of soils corresponding to the wilting point is somewhat higher than the amount of hygroscopic moisture because a fraction of the capillary water is also unavailable to plants. The work of Briggs and Schantz indicated that the permanent wilting point is about the same for all plants growing on the same soil.

The relative amounts of different forms of water for sandy and clay soils, reported by Lyon and Buckman, are shown in table 17.

Table 17. Contents of Water in Different Form Characteristic of Sandy and Clay Soils

Forms of water	Sandy soil	Clay soil
	per cent	per cent
Hygroscopic water	3.0	10.0
Wilting point	4.4	14.7
Maximum field capacity	17.0	40.0
Unavailable water	4.4	14.7
Available water	12.6	25.3
Free water	8.0	5.6

Ground water. The degree of soil drainage is determined chiefly by the depth of water-logged gley layer, called also "zone of saturation" or "ground water horizon". The upper limits of the ground water zone is referred to as "ground water table". The zone between the ground water table and the margin of capillary effect is designated as "capillatum". The zone of ground water varies in thickness, and is underlain by an impervious layer which is termed by Wissotzky "dry substratum" or "dead horizon of dryness" (Fig. 27).

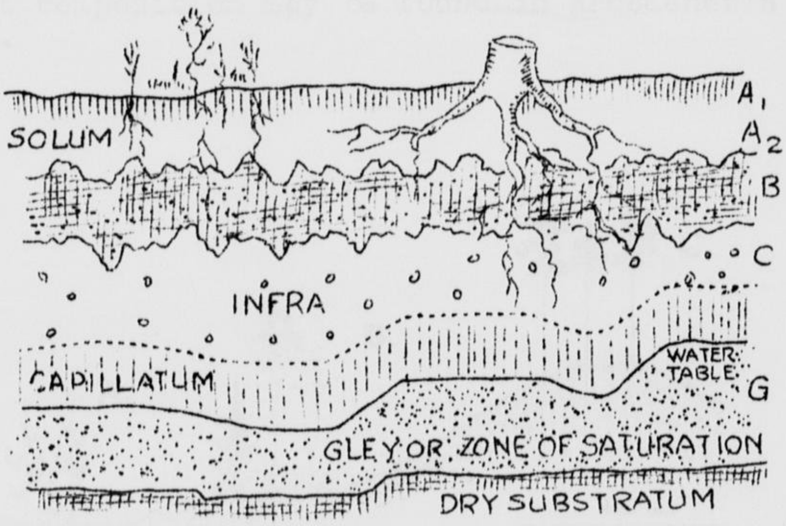


Figure 27. A schematic profile of a forest soil influenced by ground water (After Wissotzky)

Ground water table delineates the depth of well-aerated soil (Fig. 28), and is closely correlated with the total supply of available nutrients. Deficiency of air and presence of toxic reduced compounds as a rule prohibit the development of roots below the ground water table (Büsgen and Münch). The roots of bald cypress, pitch pine, and several other species, however, are known to penetrate the water-logged horizons (Adamson, Hesselman, McQuilkin).

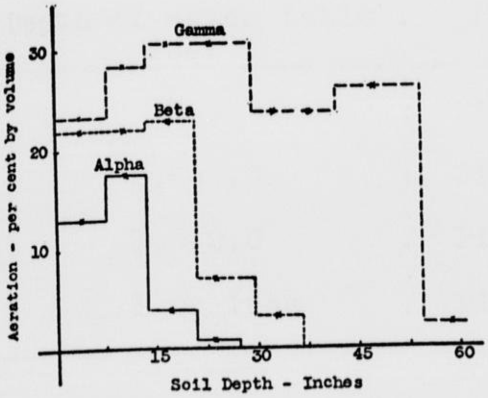


Figure 28. Aeration of soils having the ground water table at an approximate depth of 25 (alpha), 40 (beta), and 70 (gamma) inches, respectively.

Ground water level is a factor of far-reaching influence in regard to the distribution and growth of forest vegetation. It determines three basic forms of forest cover: swamp forest, confined to peat and muck soils; lowland forest occupying poorly-drained mineral soils; and upland forest occurring on well-drained soils (Fig. 29). The effect of ground water table upon the growth of Norway spruce is illustrat- by the correlation established by Sookachev and his associates (Table 18). Because Norway spruce is a water-tolerant species, the depressing effect of excessive moisture is not manifested until the water table approaches the surface soil. However, many species react unfavorably at considerably deeper level of the ground water. The reaction of vegetation to a certain depth of ground water is a lso greatly influenced by the climatic conditions of the region, particularly air humidity. Figure 30 and Table 19 present correlation of forest growth with the ground water table as observed by Wilde and White under Wisconsin conditions. A general scheme of the relationship that exists between ground water level and forest composition may be found in Kruedener's Monograph on forest types.

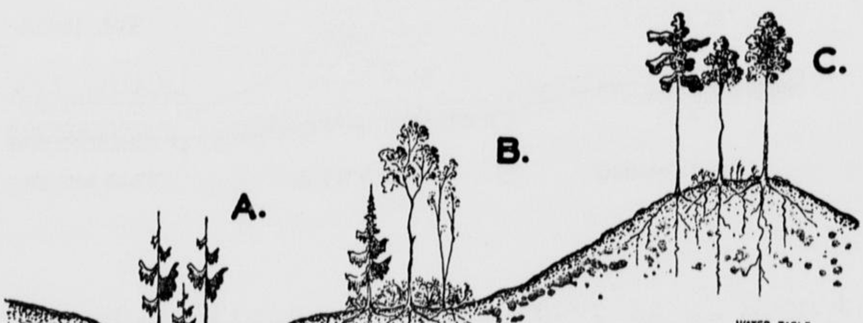


Figure 29. Relation of forest to ground water table: A. Swamp forest; B. Lowland forest; C. Upland forest.

Table 18. The Rate of Growth of Norway Spruce in Relation to Ground Water Table

Depth of water table feet	Floristic type of forest cover	Site index
5-7	Picetum fruticosum	Very high (I)
2.5-3.0	Picetum oxalidosum	High (II)
1.5-2.0	Picetum equisetosum	Low (IV)
1 or less	Picetum caricetum	Very low (V)

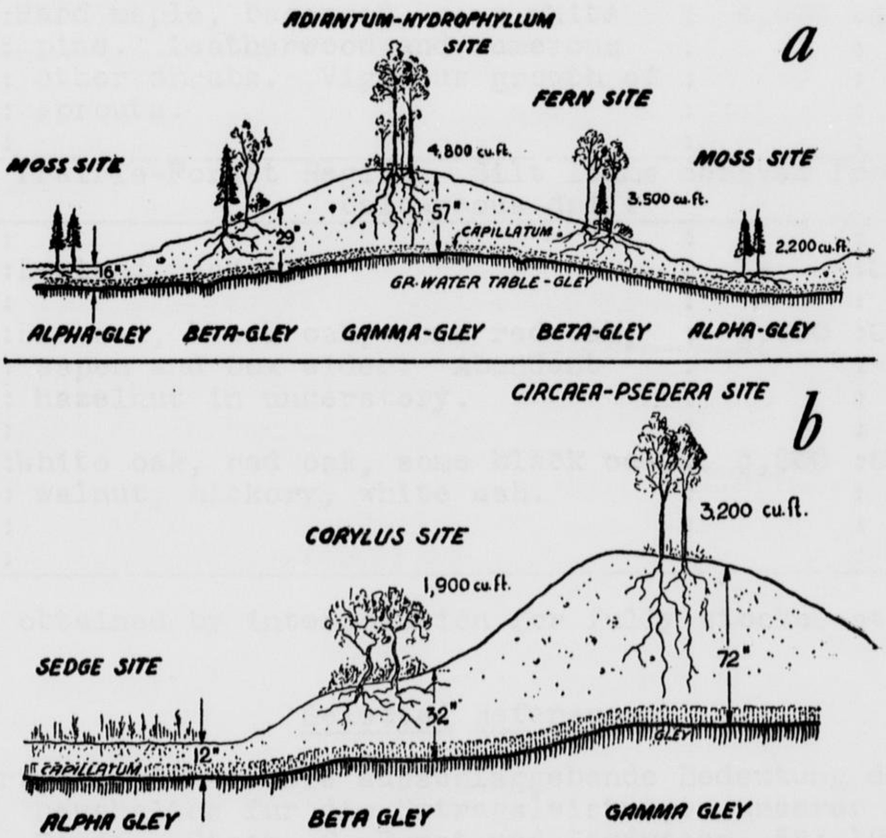


Figure 30. Effect of ground water level upon the distribution and rate of forest growth in Wisconsin. (a) Old granitic drift in podzol region of northern Wisconsin (Colby series); (b) Recent calcareous drift in prairie-forest region of southern Wisconsin (Miami series).

Table 19. Correlation of the Ground Water Table with the Composition and Growth of Forest Vegetation in Wisconsin

Depth of ground water table feet	Composition of forest stand	Yield at 100 yrs. cu. ft.*	Floristic site
A. Podzol Region. Silty-clay loams derived from old granitic drift			
1-1.5	Balsam fir, white spruce, some black ash and red maple. Understory of mountain ash, tag alder, willows, and dogwood.	2,200	Sphagnum-Polytrichum-Carex-Equisetum site
2.0-3.0	Hard maple, rock elm, red maple, some basswood, yellow birch, balsam fir and white spruce. Hard maple and basswood inferior.	3,500	Fern site
4.0-5.0	Hard maple, basswood, some white pine. Leatherwood and numerous other shrubs. Vigorous growth of sprouts.	4,800	Adiantum-Thalictrum-Hydrophyllum site
B. Prairie-Forest Region. Silt loams derived from recent calcareous drift			
0.7-1.2	Lowland meadow.	-	Carex site
2.0-3.0	Bur oak, black oak, some red oak, aspen and box elder. Abundant hazelnut in understory.	1,900	Corylus site
4.0-5.0	White oak, red oak, some black oak, walnut, hickory, white ash.	3,200	Circaea-Amphicarpa-Psedera site

* Yields obtained by interpolation for fully stocked stands.

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CHAPTER X

CHEMICAL PROPERTIES OF FOREST SOILS

"The soil is the chemical laboratory of nature in whose bosom various chemical decompositions and synthesis reactions take place in a hidden manner."

Berzelius.

The Significance of Soil Chemistry in the Study of Forest Soils

Opinions regarding the relative importance of the physical and chemical properties of soil to plant growth have varied considerably during the different periods in the development of Soil Science. The pioneers in pedology, the agronomists, inherited from the rural people a basic information on the physical features of soils, such as classification of soils into sand, loam, and clay; wet and dry soils; deep and shallow soils; stony and stone free soils; level, rolling and rough soils, etc.

In the early days of scientific soil research, the pedologists concentrated their interest upon the chemical composition of soils and pedology became synonymous with agro-chemistry. The outstanding scientists of this period--Boussingault, De Saussure, Liebig, Lawes, Gilbert--established the basic relationships in plant nutrition and revealed the significance of artificial fertilization. However, the chemical analysis of soils had been accomplished by the use of strong hydrochloric acid, which extracted much greater quantities of salts than were actually available to plants. For this reason a close correlation between chemical composition of soils and plant growth was not found. It was this state of analysis that led S. W. Johnson to proclaim in the American Journal of Science in 1861 that he "would rather trust an old farmer for his judgment of land than the best chemist alive."

Subsequently, the interest in soil chemistry declined, and attention was turned to the physical properties of soils. The study of soil physics, particularly of soil colloids, resulted in some valuable information regarding the cultivation and drainage of soils. In the course of time, with an increase in theoretical knowledge, soil science again focused its attention on soil chemistry. This time, the work of soil chemists on the availability of salts to the plants, fixation of plant nutrients, base exchange properties of soil, and soil reaction has shown a close relationship between the chemical composition of soils and plant growth. This newer knowledge, accumulated during the last 20 years, has solved many old problems of forestry and is becoming a basis of mensuration studies, forest planting, and nursery practice.

The progress of soil chemistry owes much to studies of native vegetation and virgin soils which had been advocated by Hilgard and his followers. One of Hilgard's statements related to soil analysis is of particular interest to the student of forest soils:

"Since the native vegetation normally represents the results of secular or even millenial adaptation of plants to climatic and soil conditions, the use of the native flora seems eminently rational. Moreover, it is obvious that if we were able to interpret correctly the meaning of such vegetation with respect not only to cultural conditions and crops, but also as regards the exact physical and chemical nature of the soil, so as to recognize the causes of the observed vegetative preferences, we should be enabled to project that recognition into those cases where native vegetation is not present to serve as a guide; and we might thus render the physical and chemical examination of soils as useful practically, everywhere, as is, locally, the observation of the native growth."

SOIL REACTION

Derivation and Meaning of pH

Acidity in solution is said to be due to an excess of H-ions over OH-ions; likewise, alkalinity to an excess of OH-ions over H-ions. Pure water contains equal numbers or concentrations of H- and OH-ions, and hence is neutral. When acid is dissolved in water, it gives rise to H-ions but not to OH-ions; accordingly, there results a greater concentration of H-ions than OH-ions in the solution, thus causing it to become acid. When an alkali is dissolved in water, it gives rise to OH-ions but not to H-ions, and hence there results a greater concentration of OH- than H-ions in the solution, thus causing it to become alkaline.

The concentrations of acidity and alkalinity found in soils and plant and animal tissues are relatively low, and the direct expression of the correspondingly low concentrations of H- and OH-ions in ordinary terms gives rise to fractional values which are inconvenient to express and use. To avoid this inconvenience, the pH scale and method of expression was devised by Sorensen. The symbol "pH" refers to the intensity factor of acidity due to H-ions. The pH value derived under this system is simply the logarithm of the reciprocal of the H-ic concentration, and this value has an integer even for the lowest acidities and alkalinities. For example, suppose the H-ion concentration of a solution is 1/1000 gram per liter, what is the pH of this solution? The reciprocal of 1/1000 is 1000. The logarithm of 1000 is 3. Hence, the pH of this solution is 3. It so happens that the pH value for water is 7, and hence a pH of 7 designates neutrality. Since the pH values are logarithmic functions of the reciprocal of the H-ion concentration, the smaller they are, the greater the H-ion concentration or the acidity.

When the pH values become greater than 7, it follows from the law of mass action that the OH-ion concentration becomes greater than the H-ion concentration, and hence the solution becomes alkaline. The greater the value above 7, the greater the alkalinity. For example, a pH of 8 designates an alkalinity which is proportional or equivalent to the acidity at pH 6, and so on.

Whenever there is added to water an acid, or a substance like aluminum sulfate which forms an acid after being added to water, the pH value of the solution becomes less than 7, and the solution is then said to be acid. Similarly, whenever there is added to water an alkali, or a substance like calcium or sodium carbonate which forms an alkali after being added to water, the solution becomes alkaline, and the pH value becomes greater than 7.

The pH scale is thus well adapted for use when dealing with relatively small intensities and quantities of acids and alkalies such as are found in soils, plants, and animals.

Influence of Soil Reaction Upon the Distribution and Growth of Forest Trees

The reaction of the soil affects forest trees either directly through the influence of H- and OH-ions and the balance of acidic and basic constituents, or indirectly by affecting the physical condition of the soil, availability of nutrients, solubility and potency of toxic agents, and activity of the useful and parasitic soil organisms.

Neither mineral nor organic soils more acid than pH 3.7 support normally developed forest stands. The areas of this degree of acidity are, as a rule, covered with the heaths of low shrubs and lichens, or with the bog thickets. The only trees, which may accidentally be found on such areas, are rare super-acidophilous species (Scotch pine); however, the occurrence of even these trees is always sporadic and their growth is dwarfed.

The soils of a pH 3.7 to 4.5 are largely correlated with acidophilous conifers (black spruce, tamarack, hemlock, etc.), and with some light demanding deciduous trees (aspen, white birch). These very strongly acid soils are unfavorable to the majority of other forest trees, due to toxicity of ferrous iron, manganese, and especially aluminum, which are liberated to a considerable extent as soon as the reaction of a soil is less than pH 4.5.

The strongly acid soils of a pH 4.5 to 5.5 are well adapted to the majority of conifers and many of the deciduous trees, with the exception of some of the better hardwoods (white ash, basswood, etc.); the low availability of nutrients, viz. nitrate nitrogen, calcium, and phosphates, is the reason for the absence, or inferior growth of these latter species on acid soils.

The moderately, or slightly acid soils of a pH 5.5 to 6.9 are characterized by high activity of micro-organisms, energetic humification, high availability of mineral plant nutrients, friable structure, and good aeration. In turn, these soils tend to produce high yields of timber, especially of the better hardwood species. However, when the reaction of soil approaches neutrality, certain conifers (Norway spruce) often become subject to fungous diseases.

The alkaline soils of a pH 7.1 to 8.0 support largely the stands of southern hardwoods (oaks, hickory, walnuts, etc.); the majority of other valuable trees, especially conifers, do not grow on alkaline soils, or grow unsatisfactorily. The very fact of the existence within acid forest regions of extensive prairie areas with alkaline soils proves that the forest soil and the acid soil are nearly synonymous. The unfavorable influence of alkaline soils upon the forest trees is either due to toxicity of OH-ions, which are considerably more injurious than H-ions, or to the excess of calcium or magnesium carbonates, causing a lack of available iron, resulting in chlorosis, a general disturbance in the assimilation of other nutrients, and often fungous diseases.

The strongly alkaline soils of a pH 8.1 to 8.5 contain an excess of OH-ions as well as those of sodium, chloride, and sulfate, which make the soils of this reaction toxic to all forest trees. Open stands of struggling, dwarf hardwoods, particularly oaks, are nearly the only forest cover found here.

The soils still higher in alkalinity than pH 8.5 are occupied entirely by the lower plants of halophytic nature and are absolutely unproductive sites from the forestry standpoint.

The Significance of Soil Reaction in Reforestation

From a practical standpoint, a knowledge of soil reaction becomes of great importance in reforestation work when the trees are raised from seeds in the nursery, or when young, tender seedlings are transplanted into the field. Under such circumstances, high concentration of either hydrogen or hydroxyl-ions may easily have a detrimental effect upon the germination of seeds, early development of seedlings, and the growth of transplanted stock.

This is of particular importance because of the fact that the soils of this country on which artificial reforestation is contemplated have all possible grades of reaction. In the region of northern latitude are found extensive areas of strongly acid soils of pH 4.0 and less. On the other hand, all over the forest region occur formations of limestone, dolomitic rocks, and the calcareous lacustrine deposits with a reaction higher than pH 8.0. Often the alkalinity of the soil is also brought about by the sedimentation of basic material in areas subject to over-flow, or by energetic hydrolysis that causes the liberation of bases and alkali salts of mineral and organic compounds. It is obvious, therefore, that before selecting an area for a nursery, or planting certain species of trees, one should obtain reliable information in regard to the pH value of the soil.

Reaction of Nursery Soil

In nursery practice the reaction of the soil is responsible not only for the growth of seedlings of different species, but at the same time it is a factor which controls development of parasitic soil organisms, the rate and kind of fertilizers that should be applied, and even the amount of watering.

In general, the most desirable reaction of nursery soil lies between pH 5.0 and 6.0. A reaction less than pH 4.5 is unsatisfactory because of unfavorable influence of the toxic soil agents and low availability of nutrients. A reaction of soil higher than pH 6.5 is undesirable in the nursery, since it provides the optimum condition for the development of damping-off fungi, eel worms, and other soil parasites that cause the death of seedlings.

Reaction of Planting Sites

The soil is not a homogenous medium as to the pH value, and in many cases the trees may escape the unfavorable influences of extreme reaction by feeding on the less acid or less alkaline portions of soil. Particularly the seedlings which originated by natural or artificial seeding have a chance to adapt themselves to the condition of soil reaction; the roots of such seedlings, right after germination, work gradually into the soil and avoid the places of toxic H- or OH- concentration. In planting, however, the roots of seedlings are placed deeply in the soil and are, to a considerable extent, subjected to whatever extremes of reaction that may exist.

It is for these reasons, chiefly, that the natural occurrence of certain species on a soil of a certain average reaction is not always proof of the suitability of this soil for planting with the same species as occur naturally. The only way, therefore, to assure the success of planting is to plant the species of trees on soil of an optimum reaction for that species.

The rule of thumb that may be followed in planting is that the conifers should neither be planted on very strongly acid (less than pH 4.5), nor alkaline soils (more than pH 7.0), whereas the hardwoods on neither strongly acid (less than pH 5.5), nor strongly alkaline soils (more than pH 8.0). There are, indeed, a number of exceptions to this general rule. Yellow birch (Betula lutea), for instance, is a hardwood species that does its best on the strongly acid soils, and may survive even on very strongly acid soils. Hard maple (Acer saccharum) may produce high yield of timber on strongly acid, as well as alkaline soils, whereas white ash (Fraxinus americana) and some southern hardwoods (hickory, walnuts) may not even survive on strongly acid soils. On the other hand, jack pine (Pinus banksiana) is a conifer that does fairly satisfactorily on alkaline soils as high in reaction as pH 8.0. White pine, as well as Norway spruce (Picea excelsa) may grow satisfactorily within a very wide range of reaction, from pH 4.5 to pH 7.0, and may survive on very strongly acid, or alkaline soils, while red pine (Pinus resinosa) has a very narrow, sharply pronounced optimum between pH 5.0 and 6.5, etc. The knowledge of the precise pH requirement of numerous other species is a matter of local experience, derived from the observations of both the natural distribution of trees and conditions in artificial plantations.

Essential Elements and Their Influence upon the Growth of Trees

Ten elements are essential for plant growth. They are: carbon, oxygen, hydrogen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, and iron. The memorizing of these elements is facilitated when their symbols are written in the following order:

C. H O P K (I) N S CaFe Mg

Carbon, hydrogen, and oxygen are present in such quantities in nature that they never become critical. Sulfur, calcium, magnesium, and iron are deficient only in rare cases. Nitrogen, phosphorus, and potassium are often deficient in soils, and are of chief practical importance in plant nutrition. Recently it has been found that small amounts of several of the so-called minor or rare elements may play an important role in the development of plants. These elements include boron, manganese, zinc, and copper.

Nitrogen

Nitrogen is an essential constituent of protein and protein-like compounds. If nitrogen is deficient, the plants show a stunted growth; the leaves or needles are of a yellowish-green or reddish-green color; the leaves are shed early; the lateral buds die, leaving the shoots bare; the root-system is under-developed, being largely fibrous. The addition of nitrogen fertilizers is followed by an almost immediate increase in vegetative growth and development of deep green foliage.

An excess of nitrogen results in abnormally large and succulent growth of the aerial portion of the seedlings and creates an unbalanced physiological condition. Thinning of the cell walls occurs, and the sclerenchymatic tissue is reduced; the stems become soft and tender, and the leaves crinkled and sappy. As a result, the seedlings lose their resistance to drought, frost, and diseases.

Nitrogen-bearing substances undergo gradual changes in the soil, which are affected by microorganisms. As a result of these changes, the protein compounds are oxidized into amino-acids, ammonia, and finally to nitrates. The latter two forms are the most important sources of readily available nitrogen. The majority of forest trees, especially the conifers of saprophytic nature such as spruce, fir, and hemlock, have the ability to utilize the nitrogen of ammonia, and, perhaps, still less oxidized nitrogenous compounds. On the other hand, exacting hardwoods growing on well-drained soils, such as white ash, oaks, walnuts, and hickories, feed preferably on nitrogen in the nitrate form.

The content of total nitrogen in the surface 8-inch layer of virgin forest soil varies from 0.1 to 0.3 per cent. The content of nitrates seldom exceeds 25 p.p.m. because of the high solubility of these compounds. The content of ammonia may accumulate in the humus layers of forest soils in amounts as high as 70 p.p.m.

Phosphorus

Phosphorus is a constituent of the nucleus, and plays an important part in cell division and development of meristem tissue. It aids in the efficiency of the chloroplast mechanism and in the transformation of carbohydrates. It acts as a catalyst in respiration reactions.

In spite of these important functions of phosphorus in the plants, deficiency of phosphate is not as readily manifested as that of nitrogen, and is often overlooked. A stunted root system with coarse brown rootlets is the most obvious manifestation of deficient phosphorus. Sometimes the phosphate starvation results in the degeneration of lateral buds, and the appearance of a bronze-purple color of leaves.

The addition of phosphate fertilizers increases somewhat the foliage of seedlings, brings about a more efficient assimilation of carbon dioxide as well as a better utilization of nitrogen, potash, and other nutrients, and encourages development of lateral and fibrous roots. All of these changes, however, take place rather slowly, which minimizes the noticeable effect of phosphate fertilizers

The development of a sturdy root system through the influence of phosphate prevents winter injury of seedlings and prepares them for rapid development in the spring. This effect of phosphorus is of special significance in clay soils where the roots tend to be underdeveloped, and the seedlings suffer from heaving.

The content of available phosphorus pentoxide (P_2O_5) varies in virgin forest soils from 10 to 200 p.p.m. High light-demanding pine species are satisfied with very low contents of phosphorus. The maximum requirements for phosphorus are made by upland hardwoods. A content of P_2O_5 of 100 p.p.m. in the soil is sufficient for most forest trees.

Potassium

Potassium speeds up the assimilation of carbon dioxide, and is important in the formation and utilization of sugar and starch in plants, synthesis of proteins, and cell division. Under the conditions of reduced insolation potassium seems to partly fulfill the function of light.

The deficiency of potash leads to the development of weak seedlings with a stunted root system and with soft and sappy leaves. In time, the leaves may become dull and scorched in color; they age prematurely, become bronzed, and die at the tips or along the edges.

The addition of potassium fertilizers increases the assimilation of carbon dioxide, facilitates the entry of water into the seedlings, and increases the utilization of nitrogen. This, in turn, leads to a more rapid growth and the production of more vigorous and resistant seedlings.

Of particular importance is the influence of potash in counteracting the harmful effect of excessive nitrogen. Potash fertilizers in proper amounts seem to be especially effective in reducing the root rot of the older seedlings, caused largely by Fusarium fungi. Because resistance of seedlings to frost is directly related to the content of sugar, potash plays an outstanding part in the production of hardy stock.

The content of available potash (K_2O) in virgin forest soils fluctuates from 25 to 200 p.p.m. The amount of potash which satisfies the majority of tree species is 100 p.p.m. As in the case of phosphorus, the pine species are satisfied with negligible amounts of potash, whereas the upland hardwoods demand the greatest content.

Calcium

Calcium influences the growth of forest trees directly as a plant nutrient, and indirectly by affecting soil reaction and other soil properties. It is particularly important in development of roots and root hairs. Calcium pectate serves as the cementing material between the cell walls, and plants deficient in calcium are characterized by weakness of tissue. Calcium aids in the process of absorption of water and nutrients by maintaining the permeability of cell walls. It neutralizes toxic by-products formed in growth processes.

In soils calcium balances the effect of other elements, such as sodium, potassium, magnesium, aluminum, and manganese, which in absence of calcium may become toxic to the plants. Development of soil microorganisms depends greatly on the amount of calcium. As a result of this, the formation of either raw humus or mild humus is closely associated with calcium content of soil.

Deficiency of calcium results in stunted growth and discoloration of the roots. The lack of calcium may also cause brown spotting and death of leaves.

The amount of calcium varies in forest soils from 400 to several thousand parts per million, depending upon the reaction and the base exchange capacity. With the exception of a few calciphilous species, forest trees are satisfied with moderate amounts of calcium, such as 1,000 p.p.m., or 5 m.e. per 100 grams.

Magnesium

Magnesium is a constituent of chlorophyll molecule. It promotes the utilization of phosphorus and occurs chiefly at the growing tips.

Magnesium starvation may occur occasionally in nature and cause premature defoliation, preceded by chlorosis. In contrast to calcium deficiency, magnesium starvation does not affect the roots until later in the life of the plant. Magnesium salts in excess produce harmful effects, which may be lessened by the addition of calcium salts. It appears that plants require some definite $CaO:MgO$ ratio for their successful growth.

The content of magnesium in forest soils is usually from one-fifth to one-third that of calcium.

Iron

Iron is essential in the formation of chlorophyll, and its deficiency results in yellowing of the leaves, called chlorosis.

A deficiency of iron occurs in nature usually only in the presence of a high concentration of calcium carbonate.

Sulfur

Sulfur is a constituent of proteins and plays an important role in respiration of plants. A deficiency of sulfur is manifested in a similar manner to that of nitrogen deficiency. Several cases were reported where the addition of sulfur increased the growth of forest seedlings.

Boron

Boron acts largely as a catalyst. A deficiency of boron is marked by a depressed growth rate, distorted leaves, death of the terminal growing point, discoloration and lack of vigor of roots, and brittleness of stems and leaves. An excess of boron has been found to reduce the chlorophyll content and to check root development.

Boron in small quantities has been found essential to the proper growth of citrus and pecan trees. An excess of this element caused a browning of leaves and premature leaf fall of walnuts.

Zinc

Zinc seems to have an effect similar to boron, acting as catalyst in certain species.

Deficiency diseases, such as pecan rosetts, have been controlled by the spraying of leaves with zinc solutions. Applications of zinc sulfate corrected the pathological condition of apple, pear, plum, cherry, and citrus trees.

Manganese

Manganese is thought to be related to enzymatic action, synthesis of chlorophyll, and carbon assimilation. There are some indications that it increases the mobility of calcium and magnesium and stimulates oxidation reactions.

A deficiency of manganese caused premature leaf fall and death of growing shoots in citrus plants. A form of chlorosis characterized by yellow areas located away from the veins has been noted in a number of plant species. Manganese chlorosis of pin oak, both in the nursery and in plantings, has been reported on soils with high contents of calcium carbonate.

Small amounts of manganese sulfate increased the ammonification and nitrification in soils, but large quantities became toxic and caused browning of roots and bleaching of leaves.

Copper

The exact function of copper in plants is not understood, but most workers agree that it is necessary for the proper function of chlorophyll and for seed formation.

Chloratic conditions of deciduous fruit trees on sandy soil were corrected by copper sulfate applied either to the soil or directly to the leaves. Die-back of citrus trees has been corrected by the use of the same salt. Walnut trees affected with "yellows" responded readily on some soils to the application of copper sulfate.

Availability of Nutrients, Their General Effect, and Their Balance

The nutrients which occur in soil as unweathered minerals or raw organic remains are not available to the plants because of their low solubility in water or weak solutions. Yet these nutrients represent the principal capital of soil fertility. From this capital plants draw an annual income of available nutrients, released at various rates as soluble fraction. The content of available nitrogen and potash of soils usually constitutes about 1 per cent of the total content of these elements; the content of available phosphorus and calcium may be as high as 10 per cent of the total content.

Adverse conditions, such as poor aeration, unsuitable reaction, presence of toxic substances, or a high concentration of soluble salts may greatly interfere with availability of nutrients.

The nutrients may also be rendered unavailable by "fixation", or a conversion of soluble salts into difficultly-soluble compounds. Incorporation of soluble nitrogen in the cells of microorganisms, formation of insoluble calcium phosphate, or iron and aluminum phosphates, and conversion of soluble potash into secondary micas are examples of such fixation.

In some instances the availability of nutrients is intimately associated with the presence of specific microorganisms, for instance, nitrifying bacteria, sulfur-oxidizing bacteria, or mycorrhizal fungi.

Organic matter when applied to soil at an insufficient depth, or as a top dressing, may arrest the downward movement of the roots. In this way, organic matter may deprive seedlings of nutrients, chiefly potash and phosphorus, present at a greater soil depth. This type of potash and phosphorus starvation is common, in more or less pronounced form, in nurseries where organic remains are not thoroughly distributed through the entire plowed layer.

The conditions rendering certain nutrients unavailable may cause either starvation of seedlings or may disturb the ratio of nutrients and result in the production of an unbalanced planting stock.

Early students of plants and environment were inclined to over-emphasize the role of water in plant growth and paid little attention to nutrients. The noted text on plant ecology by Warming is a striking illustration of this trend of thought. The original Danish edition of this book considered exclusively the moisture conditions. Only after this work had been translated into German and revised by Graebner, did the influence of soil nutrients receive deserved attention.

The underestimation of plant food importance was particularly marked in regard to tree growth. Until very recently, many practical foresters maintained that the rate of forest growth is not dependent upon the supply of nutrients. A number of reasons were responsible for the establishment of this belief: the moisture conditions usually show a close correlation with the solubility or availability of nutrients; forests are able to replenish soil fertility by obtaining traces of essential nutrients from deep soil layers and returning them in the form of leaf litter; the trees may obtain or render available some nutrients, particularly nitrogen, through the activity of mycorrhizae and nitrogen-fixing bacteria.

In actuality, if trees, hardwoods as well as conifers, are planted on soils containing no plant food, their growth is arrested as soon as the supply of nutrients stored in the seed is exhausted. Species that have small seeds, such as spruce, elm or ash, react immediately to a deficiency of soil nutrients. Species that have a large supply of plant food in the cotyledons, such as oaks and walnuts, show a rapid early growth regardless of soil fertility. Seedlings may survive on poor soils for a considerable number of years, producing no top growth, but concentrating all available energy upon the dow nward extension of the roots. As Liebig expressed it, "The roots search for the nutrients as though they had eyes..." In case the starving seedlings obtain plant food at a greater soil depth, or receive an application of fertilizers, they may recover and gradually attain a satisfactory development. In many instances, however, during the period of starvation seedlings are killed by root-rot fungi or other parasites.

The growth of plants is not exactly governed by the "law of minimum." However, it is important to remember that the soil productivity is comparable to any power-utilizing machine. The presence of all growth constituents in reasonable amounts is just as necessary for satisfactory plant production as the presence of the smallest screw or spring is essential for the efficient operation of a machine. This fact is often overlooked in soil fertility maintenance. In numerous instances the failure of treatments to produce satisfactory results due to the lack of a certain minor element is attributed to the inefficiency of fertilizers used.

Although balanced, low level of fertility of nutrients is objectionable because the seedlings do not reach a plantable size within a short period, such as 2 or 3 years. Yet, in time, the seedlings on soils of relatively low total fertility may attain satisfactory development through the fixation of atmospheric nitrogen and the utilization of nutrients in the deeper soil layers. Ultimately, such seedlings may prove to be a better planting stock than the seedlings raised on a soil with excess of certain nutrients. An excess of soluble nitrogen may exert a particularly harmful influence because it encourages excessive top growth. In some instances, continuous application of nitrogen fertilizer produced seedlings with crowns weighing twenty times as much as their root systems. The small root systems of such "forced" seedlings may not be able to supply sufficient water to compensate for transpiration losses, and the stock may easily perish from drought. The harmful effects of nitrogen are encountered especially on soils deficient in potassium and phosphorus as both of these elements contribute greatly to the physiological vigor of seedlings and the development of their root systems.

Nutrients exert a profound influence upon the anatomical structure of plants. A complete or a partial starvation is manifested by a degeneration of the pith. Too rapid growth, caused usually by a high content of nitrogen, leads to thinning of cell walls. A deficiency of phosphorus, and perhaps other clements, results in under-developed nuclei in the parenchymatic cells. In fact, any discrepancy in the nutritional balance produces some abnormality of the seedling tissue. All of these anatomical abnormalities may have a direct bearing upon the resistance of seedlings to adverse conditions of environment.

The availability of nutrients is reflected in the chemical composition of plants. Therefore the analysis of plant tissue may detect the deficiency of nutrients or their unbalanced ratio. The concentration of salts in the cell sap varies with soil fertility and may serve as an index of the resistance of seedlings to frost.

A deficiency of certain nutrients may disrupt the normal course or metabolism and synthesis of salts present in the plant sap. As a result, unutilized salts may accumulate in large amounts and plasmolyze the leaf tissues of the plants. Such an accumulation of salts may be particularly expected under conditions of high temperature and frequent watering.

In the early days of silviculture the quality of planting stock was judged according to the size and color of the foliage. In time it was realized that the survival of seedlings in the field depends to a large extent upon the development of the root systems, particularly upon the relation between the size and weight of crowns and the roots. Thus, a satisfactory top-root ratio became one of the essential requirements of plantable seedlings. Recently, another important step toward the improvement of trees for planting was made by specifying a minimum acceptable stem diameter. It is very probable that eventually the physiological vigor of the seedlings will also be considered in the evaluation of planting stock, at least inasmuch as such vigor is expressed in the external or internal properties of the seedlings, viz. dimensions of the buds, structure of tissues, concentration of cell sap, and chemical composition of the plants.

Toxic Agents

The productivity of a soil may be limited not only by the absence of nutrients, but also by the presence of toxic substances or a high concentration of salts. The toxicity of soil is seldom manifested in the immediate injury of plants. More commonly, a gradual deterioration takes place. In the early stages a toxic effect may not be discernible without careful microscopic examination of the plant tissue. Soil toxicity is most dangerous during the first month of seedling growth.

A toxic concentration of soil solution frequently occurs in regions adjacent to prairie, particularly in depressions accumulating runoff waters. An injuriously high content of salts may also result from a heavy application of fertilizers, or from lack of colloidal material and the subsequent accumulation of fertilizer salts on the surface as a result of evaporation. In some instances, a high calcium content, or high temperature and moisture, affect an abnormally rapid course of biological processes, leading to an accumulation of soluble salts in excessive quantities. Soils treated with manures and sludge fertilizers are subject to this type of injury. Toxic quantities of soluble aluminum and manganese occur in deeper layers of podzol soils and inhibit the downward penetration of the root systems. The injury by an excess of salts is manifested by a blackening or "burning" of the roots and wilting of the seedlings.

The soils derived from calcareous rocks in many cases contain carbonates of calcium and magnesium in sufficient amounts to be toxic to forest trees, particularly conifers. The toxicity is evidenced by stunted growth and chlorotic condition. In nurseries carbonates may be introduced by the application of hard water. The injury of nursery stock usually occurs when the soluble bicarbonates are brought to the surface by evaporation and deposited to form a carbonate crust.

In soils of forest nurseries a toxic condition in various degrees may result from the application of fungicides and insecticides. Aluminum sulfate used in large quantities for deep acidification of soil and control of damping-off fungi may strongly depress the growth of seedlings and bring about a gradual deterioration of stock. The adverse effect is partly due to the direct toxicity of aluminum ions, and partly due to fixation of available phosphorus in the form of insoluble aluminum phosphate. The toxicity is most pronounced in non-calcareous light sandy soils, where the injury may be caused by a concentration as low a s 200 p.p.m. of aluminum sulfate salt. The toxic intermediate products of sulfur oxidation may destroy the germinating plants if sulfur is applied shortly before seeding. On sandy soils of a pH 6.0 an application of 300 pounds per acre of sulfur powder at the time of seeding proved to be decidedly toxic. Lead arsenate, applied to nursery soils for the poisoning of white grubs, has caused numerous injuries to nursery stock. The toxicity is due to both the lead and arsenic ions. A burning of the roots and reddening of the leaves are the symptoms of injury. Injured seedlings seldom recover completely. On poorly buffered and acid soils a content of lead arsenate higher than 100 p.p.m. is detrimental.

Several cases of seedling injury by sodium salts have been reported from nurseries in the Prairie and Rocky Mountain states. A continuous application of nitrate of soda may lead to an accumulation of toxic quantities of sodium in the exchange material after the nitrate ion has been removed by the plant.

Potassium carbonate in wood ashes is often the cause of barren spots in recently cleared nurseries or on cut-over lands.

Hydrogen sulfide accumulating in large amounts in poorly drained soils high in organic matter, especially in stagnant deposits of peat, is of a toxic nature, and may exert an adverse influence upon the growth of trees in such localities. A high content of ferrous iron in the gley layer of poorly drained soils is believed to exert a toxic effect.

The injury from creosote is a rather common case in nurseries using impregnated bed boards. The injury is usually confined to a narrow strip of seedlings adjacent to the frames. The losses of oil and grease from nursery equipment or dispersion of oil used in road treatments are sometimes responsible for deterioration of nursery stock and the roadside plantations. Discarded waste, such as garbage, cinders, soap water, and cleaning solutions cause decadence of trees around dwellings.

Fresh sawdust applied in large quantity exerts a strong depressing influence upon the growth of young seedlings. This effect is caused chiefly by the inhibition of nitrification processes and partly by the presence of toxic substances, such as oils and resins. The application of nitrate fertilizers may alleviate this condition to some extent.

The following table summarizes the most common remedies used in counteracting soil toxicity.

Causes of plant injury	Remedy
High acidity	Lime. Organic remains high in bases. Complete fertilizer in liquid form including sodium, potassium or calcium nitrate.
Active aluminum and manganese in ortstein layers.	Deep plowing to increase oxidation and leaching. Application of organic remains. Forced nitrogen fertilization. Lime or wood ashes in exceptional cases.
Reduced compounds in gley layers.	Tile drainage. Deep plowing or rototilling to increase oxidation. Correction of nutrient deficiencies.
High concentration of salts.	Abundant watering. Application of acid peat. Deep plowing or rototilling. Raising field crops with high nutrient requirements.
Excess of carbonates.	Deep acidification of soil with aluminum sulfate, iron sulfate or sulfur. Application of strongly acid peat, raw humus, and acid liquid humates. Phosphoric acid. Sprays containing iron. Injections of iron citrate in older trees.
Excess of sodium.	Abundant watering. Acid peat. Sulfur. Calcium sulfate. Ammonium sulfate. Maintenance of adequate potash supply.
Excess of potash.	Abundant watering. Deep rototilling. Ammonium sulfate and low grade superphosphates.
Aluminum sulfate or lead arsenate.	Application of organic remains high in bases. Heavy applications of low grade superphosphate. Ammo-phos and nitrate salts in solution. Liquid humates. Lime in exceptional cases.
Creosote and waste products.	Abundant watering. Deep plowing. Liquid humates low in soluble salts. In rare cases scraping off surface soil and application of complete fertilizer.
Sawdust or any raw organic matter with high C/N ratio.	Nitrate or ammonium fertilizers. Active humus. In exceptional cases well rotted manure.

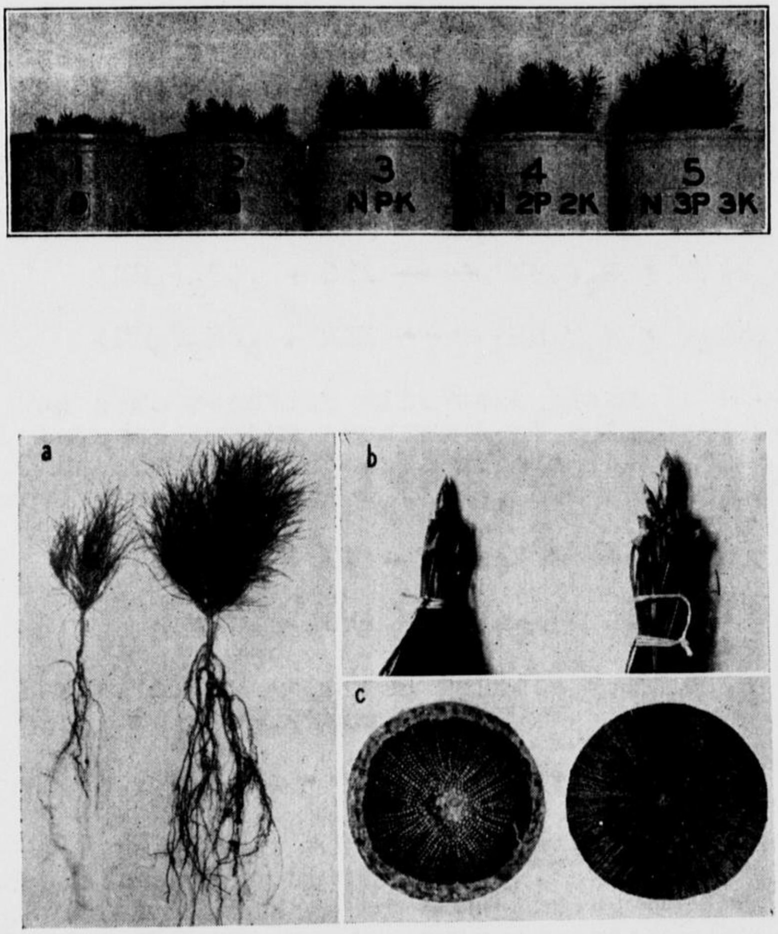

Figure 31. Effect of nutrients upon the development of forest seedlings. Top: White spruce seedlings raised in quartz sand cultures with nitrogen and varying amounts of phosphorous and potash. Bottom: (A) Red pine seedlings raised on a nursery soil deficient in nutrients and soil supplied with a complete balanced fertilizer; (B) Effect of fertilizers upon the development of buds; (C) Effect of fertilizers upon the development of seedling tissue.

Exchange Properties of Forest Soils

If a soil sample of known chemical composition is treated with an aqueous solution of ammonium sulfate, the analysis of the leachate will show some removal of ammonia and a gain in the content of calcium and magnesium. This is because the colloidal fraction of the soil has exchanged some of its basic cations for ammonium ions. An exact analysis of the leachate after such an "exchange reaction" will show that the solution has preserved its original ionic concentration and hence the loss of absorbed ammonium was compensated for by the release of an equivalent amount of other cations. This process may be illustrated by the following type equations:

$$(NH_4)_2SO_4 + CaX \longrightarrow (NH_4)_2X + CaSO_4, \text{ or}$$

$$(NH_4)_2SO_4 + 2KX \longrightarrow (NH_4)_2X + K_2SO_4$$

The same reaction will take place if a solution of some other salt is used in the treatment of soil instead of ammonium sulfate. Thus, fertilizing soil with a solution of sodium nitrate will produce, among other reactions, the following:

$$NaNO_3 + KX \longrightarrow NaX + KNO_3, \text{ or}$$

$$2NaNO_3 + CaX \longrightarrow Na_2X + Ca(NO_3)_2$$

The salts in solution replace from acid soils not only bases but also hydrogen, thus:

$$KCl + HX \longrightarrow KX + HCl$$

As a result of ionic exchange, an application of fertilizers leads commonly to the absorption of the positively charged cations with the release of other bases or hydrogen into the soil solution. The released cations combine with the liberated anions or acid radicals to form acids and salts of varying solubility. The acids and easily soluble salts, such as HCl, H_2SO_4, H_2CO_3, KCl, Na_2CO_3 and $CaCl_2$ may be leached from the soil by percolating water. The insoluble compounds, i.e., $CaCO_3$, $MgCO_3$, and Ca_3PO_4 remain "fixed" in the soil. The conversion of a soluble phosphate salt into the insoluble tri-calcium phosphate is a most outstanding example of such fixation:

$$KH_2PO_4 + Ca_3X \longrightarrow KH_2X + Ca_3PO_4$$

The understanding of exchange reactions, arrived at during the past two decades, has revolutionized the whole concept of plant nutrition and has placed fertilizer practice upon a firm scientific foundation.

The colloidal fraction of soil, capable of retaining and exchanging positively charged ions of bases and hydrogen is termed the "base exchange complex", "ion exchange compound", or simply "exchange material." This exchange material exists in two forms, namely, mineral and organic. The mineral or "zeolytic" fraction consists of an aluminum or iron silicate clay mineral, whereas organic or "humate" fraction is a lignin-like humus compound. In spite of their entirely different composition, both materials show a great similarity in many respects. Their chemical structure is based upon tetravalent elements, namely silica and carbon. Although the mineral exchange material is formed of ultra-microscopic crystals, these crystals have a porous structure allowing the penetration of water and ions as do the organic colloids. With respect to the retention of nutrients both fractions act inseparably in the soil and their common effect is measured in terms of "soil base exchange capacity."

In the determination of base exchange capacity, a sample is leached with a solution of a certain salt, such as NH_4Cl, $BaCl_2$ or $CaCl_2$ until it is completely saturated with the cation of the solution used. This cation in turn is removed by leaching with an acid or solution of some other salt, and is then determined quantitatively giving the base exchange capacity of the soil. The results are usually expressed in milliequivalents or in milligrams of absorbed base per 100 grams of soil sample.

The exchange capacities of various mineral soil fractions, as determined by König and Hasenbeumer by treatments with K_2HPO_4, are as follows:

Diameter of soil particles mm.	Absorbed K_2O mg. per 100 .
1.0 - 0.5	1.6
0.5 - 0.25	3.2
0.25 - 0.10	23.2
0.10 - 0.05	117.6
0.05 - 0.01	249.6
0.01 - 0.002	337.6
0.002 or smaller	597.2

These data suggest that soil particles significant in exchange reactions do not exceed the size of 0.05 mm. in diameter. The soil fraction of these diameter sizes consists of finer silt and clay, i.e. the material which stays in water suspension for a period of one minute or longer. It is very probable that the relatively high exchange capacity of the particles ranging in diameter from 0.05 to 0.01 mm. is largely due to the colloids of ultra-microscopic size adhering on their surface.

The absorption of ions by organic matter is also influenced by the size of the particles or degree of humification. However, no direct correlation can always be established because of the great variation in the composition of organic matter, particularly in its content of lignin-like compounds.

From the determination of nearly a thousand samples of sandy nursery soils, completed by the Soils Department of the University of Wisconsin, it appears that the exchange capacity of mineral separates smaller than 0.05 mm. in diameter and organic constituents averages about 25 and 100 m.e. for 100 grams, respectively. Consequently, the organic matter of a sandy nursery soil is four times as efficient in the retention of nutrients as the mineral colloids. In other words, if a nursery soil has 14 per cent of silt and clay, 4 per cent of organic matter and a base exchange capacity of 7.5 m.e. it is likely that approximately 3.5 m.e. are due to mineral matter and 4 m.e. to the organic fraction.

The rela tive proportion of various ions absorbed by the soil exchange compounds depends partly upon the "energy of absorption" of these ions and partly upon their concentration in the solution.

The energy of absorption or "replacing power" usually increases with valence and atomic weight. Thus, the Ba-ion is more readily absorbed by the soil than the Ca, Mg, K, or Na ions, the latter having the lowest energy of absorption. However, hydrogen and ammonia are exceptions. Thus, the replacing power of the most important ions is given in the following order of diminishing activity:

$$H^+ \; Ba^{++} \; Ca^{++} \; Mg^{++} \; K^+ \; NH_4{}^+ \; Na^+$$

The energy of absorption is not necessarily a criterion of the stability of the ions in the exchange compound. While H-ion is absorbed and held more energetically than others, the more readily absorbed ions of the alkali metals are also more readily displaced by the other ions.

These relationships are subject to modifications effected by the relative concentration of ions present in the soil solution, the exchange reactions being governed by the "law of mass action." According to this law any ion absorbed by the exchange material may be replaced by another ion occurring in soil solution in considerable excess. Consequently, all of the bases and hydrogen may be replaced by ammonia if the soil is repeatedly leached with a solution of ammonium sulfate or ammonium acetate. The absorbed ammonia may be replaced by calcium by a similar treatment with calcium chloride. After the compound is completely saturated with the Ca-ion, this ion may be in turn removed and the colloids resaturated with NH_4-ion by treatment with ammonium acetate. The law of mass action has explained many relationships incomprehensible to the chemists of the old school.

Under natural conditions, the exchange compound of soil is saturated predominantly with either hydrogen or calcium, occurring in various proportions, as these ions usually dominate the soil solution. The application of fertilizers, however, may greatly change the natural ratio and saturate the soil colloids with other ions such as those of ammonium, potassium or sodium. Soils having the exchange material saturated with bases have a neutral or alkaline reaction and are referred to as "base saturated" soils. The soils in which the exchange compound is, to a great extent, saturated with hydrogen are of acid reaction and are known as "base unsaturated" soils. The latter condition is a more common case in forest soils.

The high capacity of exchange material for holding water and influence of absorbed bases on the coagulation of colloids and the development of soil structure exert a profound influence upon the physical properties of soils.

In plant nutrition, exchange material acts as a storehouse in which bases are preserved in a form available to plants and yet not easily removable by water. The carbonic acid, excreted by the root hairs, exchanges its hydrogen for ammonia, potassium and other bases of the exchange compound. These enter the soil solution and form with liberated acid radicals the soluble bicarbonates which are utilized by the root systems.

The level of base exchange capacity determines the rate at which fertilizer may be safely applied to nursery soils. On heavy textured soils, rich in organic matter, and having an exchange capacity of about 15 m.e. per 100 g., as high an application as 1,500 pounds of total salts per acre may be a safe and economical practice, since most of the nutrient cations will be absorbed and preserved from leaching by the base exchange material. In dealing with the sandy soils, especially those poor in humus, and with a capacity not exceeding 5 m.e. per 100 g., a direct heavy application of fertilizers would be very uneconomical as most of the applied salts would be leached out before the seedlings could utilize them. Hence, on such soils the applied fertilizers must be incorporated in compost or in the tissues of catch crops, or added to the soil in small portions as liquid fertilizer distributed over the whole period of stock development.

In order to attain a greater freedom in fertilizer practice, the general tendency in dealing with sandy nursery soils is to increase the soil exchange capacity to an approximate level of 10 m.e. per 100 grams by application of clay, peat, or other suitable organic remains.

Because of the great affinity of exchange material to react with the dissociated ions of the soil solution, some harmful constituents may be eliminated from the soil by introduction of the desirable ones. In this way, nursery soil may be freed of toxic Na-ions, accumulated from repeated applications of sodium nitrate, by introduction of potassium chloride fertilizer. The treatment of nursery soils with sulfur is essentially a similar process in which the hydrogen ions of the sulfuric acid which is formed frees the soil of an excess of calcium.

The exchange capacity values summarizing the total effect of both mineral and organic colloids, i.e. clay and humus, are valuable not only in fertilizer practice but in the entire technique of forest soil utilization, particularly in the selection of species for planting.

In this respect, the exchange capacity determined throughout the soil profile is of particular significance as it reflects the physical, chemical, and genetical nature of the soil. Table 1 presents the exchange capacity of several typical soil profiles from the state of Wisconsin. Table 2 contains characteristic values of the exchange capacity determined in the 10-inch layer of soils from old cut-over lands of the Lake States region.

The values in this table are rather low in comparison with the analyses of the virgin or recently cleared soils because of the decomposition of the humus. Thus, these figures represent a prevailing condition of planting sites and to a great extent are correlated with the content of moisture and available nutrients found in soil surrounding the root system of seedlings immediately after planting.

Table 23

Exchange Capacity of Representative Genetical Types of Forest Soils from Wisconsin

Bor Sand		Podzol Loam		Nut-structured Mull Loam		Gley Loam	
Horizon	m.e./100 g.	Horizon	m.e./100 g.	Horizon	m.e./100 g.	Horizon	m.e./100 g.
A_o	13.7	A_{oo}	76.3	A_{oo}	87.3	A_o	65.5
A_1	7.8	A_o	83.2	A_1	21.5	A_1	32.2
A_1	5.7	A_2	4.3	A_2	6.72	A_2	6.7
A_2B	2.1	B_1	7.4	A_2B	11.04	B	11.7
A_2B	1.9	B_1	15.6	B_1	17.57	BG	8.3
C_1	0.4	B_2	15.9	B_2	13.66	G_1	6.1
C_2	0.5	C	12.1	C	7.06	G_2	5.4

Table 24

Exchange Capacity of the Surface 10-Inch Layer of Soils from Old Cut-over Areas

Aeolian Sand	Outwash Sand	Outwash Loamy Sand	Partly Assorted Sandy Loam	Morainic Light Loam	Outwash: Silt Loam	Lacustrine Clay
Milliequivalents per 100 grams						
1.2	2.1	4.2	7.9	11.7	14.0	21.3

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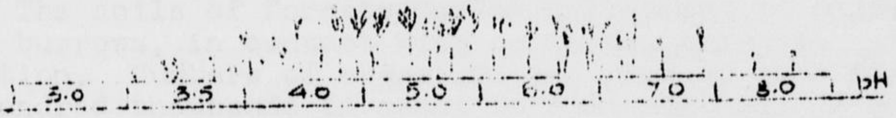
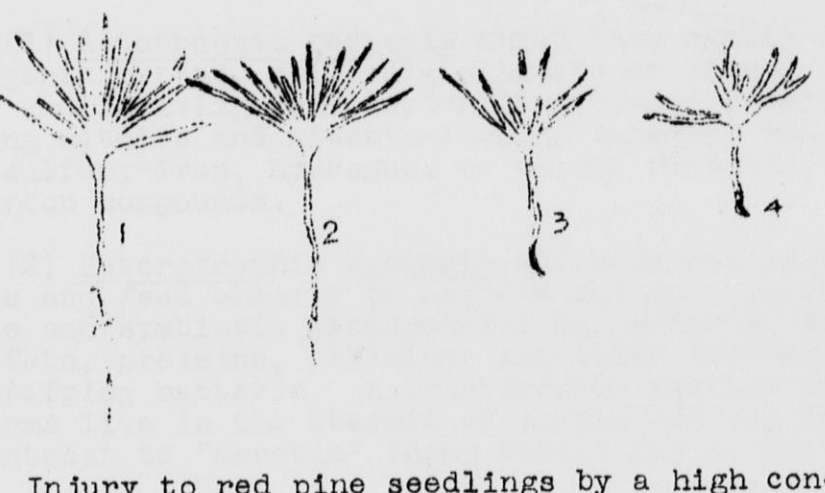


Influence of soil reaction upon the germination and early growth of red pine seedlings.

Influence of a complete N-P-K fertilizer upon the development of Norway spruce seedlings in quartz sand cultures: 1-check; 6; 150 lbs. of ammonium sulfate and 300 lbs. of 0-20-20 fertilizer per acre.

Influence of surface application of organic matter upon the development of Norway spruce seedlings: 1-Fertilizer and organic matter distributed to a depth of 6 inches; 2-Organic matter applied as a top dressing.



Injury to red pine seedlings by a high concentration of salts: 1. Check; 4. Fertilizer accumulated at the soil surface in a concentration of 5,000 p.p.m.

Figure 32. Some effects of soil properties upon the early development of forest seedlings.

CHAPTER XI
ORGANISMS OF FOREST SOILS

Introduction

The soils of forests harbor multitudes of organisms living in burrows, in contact with colloidal material, and in the soil solution. Numbers of organisms per gram of soil range from several hundred thousands in sands to many millions in rich mull loams. Their total dry weight in one acre of forest soil is often as high as 20,000 pounds.

The soil organisms exert a profound influence upon both the genetical development of soil profile and the growth of forest vegetation. Nearly all members of the soil population are employed in the decomposition of organic remains. Organisms increase the availability of plant food through oxidation, evolution of carbon dioxide, and symbiotic action, or render nutrients unavailable through reduction and incorporation in the protoplasm of their bodies. The fixation of atmospheric nitrogen and carbon is primarily a biological process. Both metabolism and physical adsorption of salts on the surface of organisms aid greatly the retention of plant food in the upper soil layers. The organisms modify the mobility of soil colloids and affect the formation of soil aggregates. Some forms hasten the germination and distribution of seeds, while others destroy the seed, root systems and other plant tissues.

The entire soil population, or "edaphon", includes bacteria, fungi, actinomycetes, algae, protozoa, nematodes, worms, insects, rodents, moles, shrews, and other soil-inhabiting animals.

Bacteria

The bacterial population of soil falls into two broad groups determined by the mode of nutrition:

(1) Autotrophic bacteria which live wholly or partially without organic matter, utilizing elements or simple compounds for energy and deriving body carbon from carbon dioxide. To this group belong nitrite and nitrate-forming bacteria and bacteria oxidizing sulfur, iron, hydrogen, or carbon monoxide, methane and similar carbon compounds.

(2) Heterotrophic bacteria which do not assimilate carbon dioxide and feed chiefly on organic matter. To this group belong free and symbiotic nitrogen-fixing bacteria, bacteria decomposing fats, proteins, cellulose and other carbohydrates, and some denitrifying bacteria. A considerable portion of heterotrophic forms live in the absence of oxygen and are called "anaerobic" in contrast to "aerobic" forms developing in the presence of air.

The outlined division is of a great practical importance in relation to forest soils, particularly in relation to the management of forest nursery soils. The organic matter is essential in tree nutrition, as well as in the maintenance of soil fertility. The normal nutrition of trees cannot proceed without participation of soil bacteria. Some of these organisms live on organic residues, which they tend to destroy, while others not only prefer purely mineral substances but may even be injured by the presence of organic matter. Under natural conditions all of these seemingly paradoxical tendencies are in perfect correlation, at least in regard to the nutrition of tree species native to a definite set of soil conditions. However, unskilled silvicultural practices, such as inappropriate cuttings, introduction of unsuitable new species, and especially unbalanced application of organic matter and mineral fertilizers, may easily destroy the existing equilibrium of bacteria and upset the nutrition of forest stand or nursery stock. Thus, the maintenance of the soil microorganisms in a state of natural balance and in harmony with the higher forest vegetation is one of the important problems of modern silviculture.

The following outline covers the more important nutritional effects exerted by various groups of bacteria.

(a) Protein-Decomposing and Ammonifying Bacteria

The bulk of nitrogen in soil, forest litter and organic fertilizers is in the form of proteins and their derivatives. These substances cannot be utilized by trees directly and must first be broken down into simple compounds such as ammonia and nitrates. The process of decomposition of proteins into carbon dioxide, water and mineral salts is accomplished by combined action of chemical, enzymatic, and biological agents. Among the latter a prominent role is played by both aerobic and anaerobic bacteria (Bac. mycoides, Bac. subtilis, Bact. vulgare, Bac. putrificus, and many others).

In the course of decomposition of proteins a great number of intermediate compounds and by-products are formed. Their nature depends upon degree of soil moisture, aeration, reaction and other conditions. In some instances, the chain of these transformations is included, by accumulation of ammonia which is released as a final waste product of metabolism of ammonifying bacteria. Under aerobic conditions, however, ammonia may be further transformed into nitrates by nitrifying bacteria.

(b) Nitrifying Bacteria

The transformation of ammonia nitrogen into nitrates is accomplished by two groups of aerobic bacteria. Some of these oxidize ammonia to nitrites (Nitrosomonas), whereas others oxidize the nitrities into nitrates (Nitrobacter), according to the following approximate equations:

$$2\ NH_3 + 3\ O_2 \longrightarrow 2\ HNO_2 + 2\ H_2O$$

$$2\ HNO_2 + O_2 \longrightarrow 2\ HNO_3$$

Good aeration, adequate supply of water, fairly high temperature, presence of buffers, and the absence of large quantities of soluble organic matter or highly concentrated salts are essential for the success of nitrification. As a rule, nitrification is promoted by a reaction approaching neutrality, although some organisms specifically adapted to acid media produce nitrates in forest soils having a reaction as low as pH 4.8.

The maintenance of soil in a condition suitable for the propagation of nitrifying bacteria is important chiefly in dealing with deciduous, lime-loving tree species requiring nitrogen in the form of nitrates. On the other hand, certain deviations from the nitrification optimum may be tolerated in stands and nurseries with acidophilous and especially saprophytic conifers, as such species readily utilize the nitrogen of ammonia, and possibly amino-acids.

(c) Denitrifying Bacteria

Under anaerobic conditions certain bacteria derive their oxygen supply from the oxides of nitrogen. In this process the nitrate is reduced to nitrite and further to elementary nitrogen with the simultaneous oxidation of other food substances by the microorganism involved. The group of bacteria capable of denitrification includes hundreds of autotrophic and heterotrophic species greatly diversified in their other activities.

The reduction of nitrates to nitrites usually takes place in a neutral or somewhat alkaline medium. In acid soils nitrates are likely to be reduced to ammonia with nitrites as an intermediate product.

Denitrification exerts an adverse influence upon the growth of trees, especially hardwoods, by depriving them of nitrogen in general, or of readily available nitrates in particular. In some instances, denitrification and subsequent formation of ammonia prevents the loss of available nitrogen from leaching.

(d) Nitrogen-Fixing Bacteria

Although an abundant supply of elementary nitrogen is always present in the atmosphere, it is not available to trees until it is converted into the form of simple organic or mineral compounds. A rather negligible portion of this conversion is accomplished by electrical discharges, and the rest by the activity of nitrogen-fixing organisms, particularly bacteria. The bacteria utilizing or "fixing" elementary nitrogen occur in nature either as free organisms or in symbiosis with higher plants. The latter group forms nodules on the roots and are commonly referred to as "nodule bacteria." The process of nitrogen fixation, resulting in an accumulation of proteins in the bodies of bacteria, is somewhat similar to the formation of carbohydrates by green plants.

The free nitrogen-fixing organisms include aerobic and anaerobic forms. Aerobic forms (Azotobacter) are extremely sensitive to the acidity of soil and other conditions, and their distribution is confined chiefly to well-aerated loam soils with reaction above pH 6.0. Consequently, these bacteria are of secondary importance in the maintenance of forest soil fertility. The anaerobic forms (Clostridium or Amylobacter), occur nearly universally in soils, with the possible exception of acid peat bogs, and play an important part in the growth of both forest stands and nursery stock. A reaction not lower than pH 5.5, an adequate supply of organic matter and mineral plant food, and a fairly high temperature are essential for the optimum activity of these organisms.

In the symbiotic fixation of nitrogen, leguminous plants provide nodule bacteria with carbohydrates and in return receive nitrogen compounds. The nitrogen accumulated by nodule bacteria is likely to be directly available and is transferred to the plant at a rather constant rate.

The nodule bacteria (Rhizobium) are usually quite specific in their host requirements. They can withstand about the same pH as their respective hosts. The forms associated with soybeans and lupines can survive at pH 4.0, thus permitting their advantageous use in forest nurseries. In spite of the great tolerance of certain legume bacteria to acidity, the rate of nitrogen fixation is usually increased by the addition of lime. Mineral fertilizers and organic remains are also indirectly effective, due to increased growth of the host plant.

In the great majority of cases inoculation of seeds or soil with the proper culture of bacteria is necessary to obtain satisfactory results with leguminous green manure crops. Some forest trees, such as black locust, are dependent in their nitrogen nutrition upon bacteria and may also require artificial inoculation. Although the bacteria are often present in nursery soils, their viability is greatly influenced by pH, organic matter, moisture, temperature, and toxic agents. Consequently, it may prove wise to inoculate seed with a known effective culture rather than to depend upon the presence of the organism in the soil.

(e) Carbohydrate-Decomposing Bacteria

Carbohydrates comprise the greatest portion of organic matter. They include sugars, starches, cellulose and hemicelluloses. Cellulose is the most abundant constituent and the process of its decomposition has a particularly important bearing upon soil productivity.

The role of cellulose in plant nutrition is of a complex nature as it may exert either beneficial or harmful influences. Cellulose serves directly or indirectly as a source of energy for nitrogen fixing bacteria and other useful organisms, but has no value as a plant nutrient or base exchange material. In large quantities it encourages the growth of organisms capable of utilizing ammonia and nitrates and thus may cause the nitrogen starvation of trees. For this reason, the productivity of soil, as well as the quality of composted fertilizers, may be greatly decreased by an accumulation of undecomposed cellulose.

The bacteria employed in decomposition of cellulose include both aerobic and anaerobic forms; (Cellulomonas, certain Spirochaetes and Clostridia). In compost piles with a high temperature, these organisms may be partly replaced by thermophilic bacteria (Clostridium thermocellum). The mechanism of cellulose decomposition varies depending upon the conditions of environment and the organisms involved. However, the end products usually include: carbon dioxide, methane, hydrogen, other gases, intermediate products such as acids and alcohols, and bacterial cells mixed with other decay-resistant substances.

The aerobic cellulose-decomposing bacteria are very intolerant and of poor aeration and soil acidity. Their activity ceases completely at a reaction low er than pH 5.5. Consequently, they are confined chiefly to ha rdwood mull loams and non-podzolic pine sands. The anaerobic bacteria withstand both strong acidity and deficiency of oxygen and occur abundantly not only in poorly drained and acid forest soils but also in deposits of peat and over-watered compost piles.

The activity of some bacteria in anaerobic media is greatly stimulated by the addition of nitrate salts. Under such conditions, the nitrate is reduced to gaseous nitrogen and the released oxygen is used by organisms in respiration. This relationship may be advantageously used to accelerate the decomposition of raw organic remains in poorly aerated compost pits.

Raw organic remains used in forest practice as fertilizing material usually contain about 40 per cent of carbon and 2 per cent of nitrogen. When such remains are added to a nursery soil, cellulose-decomposing bacteria multiply rapidly, using for their cells both carbon and nitrogen. As the bacterial cells are composed approximately of one part of nitrogen and five parts of carbon the supply of nitrogen present in both soil and organic remains may be soon exhausted. Unless the soil receives a new supply of nitrogen in the form of fertilizers this condition will arrest the process of decomposition and bring about the starvation of nursery stock. Such utilization of nitrogenous compounds by cellulose-decomposing bacteria often takes place in preparation of composted fertilizers and may also be prevented by applications of soluble nitrogen salts, such as ammonium sulfate.

Fortunately, the decomposition of cellulose is accomplished not only by bacteria, but also by fungi which assimilate considerably smaller amounts of nitrogen per unit of carbon and hence work more economically.

A process similar to the micro-biological utilization of nitrogen may affect some other available nutrients, particularly phosphorus and sulfur. Consequently, in the application of peat, raw humus and green manure crops to nursery soils, careful attention should be paid, not only to the carbon-nitrogen ratio, but to the availability of other nutrients as well.

The decomposition of hemicelluloses and other carbohydrates is on the whole similar to that of cellulose, except that it proceeds more rapidly and has a lesser effect upon the fertility of soil.

(f) <u>Sulfur Bacteria</u>

From the standpoint of nutrition, sulfur is closely related to nitrogen and undergoes similar biological transformations. The oxidation of elementary sulfur and sulfides, including hydrogen sulfide, into available sulfates is accomplished primarily by a specific group of sulfur bacteria (<u>Thiobacillus</u>, <u>Beggiatoa</u>, <u>Thiothrix</u>) according to the following reactions:

$$2\ H_2S + O_2 \longrightarrow 2\ H_2O + S_2$$

$$S_2 + 3\ O_2 + 2\ H_2O \longrightarrow 2\ H_2SO_4$$

$$H_2SO_4 + CaCO_3 \longrightarrow CaSO_4 + H_2O + CO_2$$

The accumulation of sulfuric acid or sulfates, resulting from the process of oxidation, is followed by an increase in soil acidity. Since the acidification of nursery soils supporting coniferous stock is often aimed for, the sulfur-oxidizing bacteria and their well-being attain a considerable importance in forestry practice. The activity of these forms is stimulated by additions of sulfur flowers and various organic remains, viz. green manure, peat, duff, or compost.

The oxidation of sulfur is of further benefit in the preparation of composted fertilizers where the sulfuric acid formed converts the insoluble rock phosphates into available mono-calcium phosphate or phosphoric acid.

The process of the reduction of sulfates or other sulfur oxides to hydrogen sulfide is similar in its nature to denitrification and may be accomplished by a wide variety of both autotrophic and heterotrophic organisms capable of carrying on anaerobic respiration. Vibro desulfuricans, a strictly anaerobic spirillum, plays an outstanding part in this transformation. The reduction of sulfates takes place prevailingly in poorly-drained soils, especially peat and muck. The accumulated hydrogen sulfide exerts a toxic affect upon the roots of the trees and is, at least partially, responsible for the development of superficial root systems.

(g) Iron Bacteria

A number of bacterial forms, (Crenothrix, Leptothrix, Gallionella) derive their energy from the oxidation of ferrous iron, thereby converting it into the difficultly-soluble ferric precipitate. This process may play a certain part in the development of iron-rich horizons of forest soils, especially the ortstein in podzols.

Aside from the activity of the iron bacteria proper, a number of other bacteria may cause development of a hardpan or bog-ore by using the organic fraction of soluble iron humates and leaving iron hydroxide as a residue.

Attached drawings, adapted from standard microbiological texts, give a general idea of the more important forms of soil bacteria and other soil organisms.

Fungi

Fungi are multicellular chlorophyll-free lower plants deriving their energy from decomposition of organic matter. They occur in soil either as free molds or as symbiotic fungi forming mycorrhiza on the roots of higher plants. Both of these groups include minute forms with microscopic filaments as well as the higher mushroom fungi.

Fungi tend to dominate raw organic remains, such as the litter and duff horizons of forest soils. At the same time, they are strongly influenced by the supply of available nutrients in striking contrast to bacteria, which are more dependent upon organic matter than mineral salts. Many of the fungi can withstand a greater acidity than bacteria and occur in great numbers in acid forest soils. The number of fungi increases with soil moisture content, provided there is adequate aeration. Although the greatest density of fungal population is found in the upper few inches, fungi occur more or less uniformly distributed in the soil profile to a depth of 4 or 5 feet. Fungi in greater or lesser quantity occur throughout the entire range of soil conditions suitable to forest growth. Aspergillus, Botrytis, Fusarium, Monilia, Mucor, Oidium, Penicilium, Phytophthora, Pythium, Rhizoctonia, Rhizopus, Sclerotium, Trichoderma, Verticillium, Zygorhynchus, Armillaria, Amanita, Boletus, Cortinarius, Merulius, Phoma, and Russula are the most common genera found in soils.

The role of fungi in soils, especially in forest soils cannot be over-emphasized. Fungi are greatly responsible for the decomposition of proteins, cellulose and most of the other carbohydrates.

Under ordinary conditions, the activity of fungi proceeds very efficiently with comparatively little consumption of energy materials and results in the accumulation of a highly nitrogenous residue of fungal mycelia.

The accumulation of large quantities of available nitrogen takes place, because the fungi consume primarily the carbohydrate fraction of the protein compounds and release ammonia as a waste product. In some instances, however, fungi temporarily remove the soluble nitrogen compounds and other mineral nutrients as do bacteria. They release them only after the source of energy i.e. carbohydrate fraction is exhausted and the dead mycelia are decomposed. While the inhibition of nitrogen may have a temporary depressing effect upon the seedlings, it preserves the soluble nitrate and ammonia compounds from leaching by rain or artificial watering.

Fungi may modify considerably the reaction of soil by the liberation or consumption of organic acids and by the formation of ammonia. In some instances they benefit the growth of trees by liberated carbon dioxide. The fixation of atmospheric nitrogen and the possible conversion of difficultly-soluble compounds into available form by mycorrhizal fungi, has an especial significance in the growth of trees and is discussed at length separately.

Some of the fungi do not draw an exact line between the dead and alive organic matter and cause the destruction of tissue of seedlings and older trees. The so-called "damping-off" fungi, Rhizoctonia, Pythium, Fusarium, Phytophthora and a few other genera, attack forest seedlings shortly after germination and are frequently responsible for great losses of nursery stock. In close relation to damping-off forms are root-rot fungi which cause the decay of the older seedlings and transplants. Among the fungi attacking the roots of older trees, black shoestring fungus, Armillaria mellea, and some members of the Polyporaceae, have the most wide and the saddest reputation in both American and European forestry practice.

Mycorrhizae

The roots of forest trees, especially conifers, are often invaded with fungi searching for an available supply of synthesized carbohydrates. The penetration of mycelium, however, is in most instances arrested by the live root either in epidermal cells or in the inner parts of the root. The intrusion of hyphae causes certain differentiation and rearrangement of root tissue and results in the development of permanent root-fungus growths, referred to as mycorrhizae. The mycorrhiza is classified as "ectotrophic" or "endotrophic" depending upon whether the hyphae penetrate only the epidermis or the deeper cortical cells of the root.

In the majority of cases a mycorrhiza is a symbiotic association in which the fungus derives carbohydrates from the root and in exchange supplies the tree with nutrients, particularly nitrogen. The nitrogen supply is accumulated by fungus either through the decomposition of soil organic matter or possibly by fixation from the atmosphere. The root may receive the soluble nitrogen as by-product of fungus metabolism, or may obtain it by digesting the fungus tissue. Since the formation of mycorrhizae often leads to the complete degeneration of root hairs, the entire intake of water and mineral salts may be accomplished via fungal hyphae or the fungal mantle. This in turn may enable trees to utilize difficultly-soluble phosphates, potash, and other nutrients occurring in soil in the form of unweathered minerals.

Mycorrhizae are formed chiefly by Hymenomycetes, such as Boletus, Amanita, Tricholoma, Lactarius, Cortinarius and Russula, and are confined chiefly to acid soils, poor in nutrients. On soils having a fairly high amount of soluble salts, or a reaction higher than pH 6.0, true mycorrhizal fungi degenerate and may be replaced by so-called "pseudo-mycorrhizae", produced by Mucor, Verticillium, and other common soil fungi. Some of the mycorrhizal fungi, like Boletus, invade only a few certain tree species, whereas others, for example Amanita, may associate with a wide variety of tree genera.

The occurrence of mycorrhizae on roots of forest trees, namely on pine, chestnut and hazelnut was first revealed as early as 1856 by Gasparrini. Since that date mycorrhizae have been detected on the majority of forest trees, shrubs, and ground cover plants by Frank, Müller, Gibelli, Roess, Vyssotzky, Sarrauw, Stahl, and others. The most recent studies of this problem were made by Melin in Sweden and Hatch in the United States.

Although the theories advanced by different writers are somewhat contradictory, there is enough factual evidence to consider mycorrhizae as non-pathological developments, often essential for the normal nutrition of forest trees. Particularly convincing evidenc e of this has been obtained from the observation of the tree growth on drained peat soils in Sweden. In such localities the seedlings lacking mycorrhizae showed symptoms of nitrogen starvation and eventually died, while seedlings infected with mycorrhizal fungi grew successfully. Nursery failures in

Australia have been traced to the lack of mycorrhizal fungi, as satisfactory growth of seedlings was obtained by the importation of soil infected with the proper organisms. Likewise, it was recently reported that seedbed inoculations have saved a new nursery from abandonment in Southern Rhodesia. All successful plantations of introduced pine in the Philippines are known to have an abundant infection of mycorrhizal fungi. A striking illustration of mycorrhizal importance has presented itself recently in the U. S. Forest Service Nursery at Licking, Missouri where the growth of shortleaf pine seedlings appears to be ultimately dependent upon the infection of roots with fungi.

The development of mycorrhizae often is associated with the shortening of roots and their branching in a fork-like fashion. In extreme cases, this condition may materially decrease the resistance of nursery stock to drought, and may have to be counteracted by an application of phosphate fertilizers.

Actinomycetes

Actinomycetes are generally classed as fungi although they exhibit characteristics of both fungi and bacteria. The body of these organisms consists of mycelia with branching nonseptate hyphae similar to those of higher fungi. The mycelium is brightly colored and is easily broken into short rods resembling bacteria. Most species produce a typical earthy odor of fresh soil.

Actinomyces occur primarily in forest soils where their main function is the decomposition of lignin-like substances. These substances are resistant to the activity of all the other soil organisms.

In contrast with fungi, actinomycetes are very sensitive to acidity, and disappear almost completely in soils having a reaction of a pH 4.7 or lower. This may have a direct bearing upon the development of the highly ligneous duff layers of so-called "raw humus" forest soils. Some actinomycetes have the ability to reduce nitrates to nitrites and may be detrimental.

Soil Algae

Algae are chlorophyll-bearing organisms generally occurring in filaments or colonies.

The algal flora of the soil is confined to three groups: Cyanophyceae or blue-green algae; Chlorophyceae or green algae, and Bacillariaceae or rod-shaped diatoms.

Algae hasten the solubility of minerals , particularly carbonates, and thus aid in processes of weathering. Being capable of photosynthesis, they utilize carbon dioxide and increase the content of soil organic matter. It is very likely that algae in symbiosis with bacteria promote the fixation of atmospheric nitrogen. A noticeable increase in growth of spruce and pine seedlings in nitrogen-free quartz cultures was observed when algae were allowed to accumulate on the soil surface for a period of 3 years. Lichens which are a symbiotic association of algae and fungi are of great importance in initiating plant succession and development of soil on unweathered rocks and other barren soil parent materials.

Because algae can be readily "invited to life" by an addition of small amounts of mineral salts, several attempts were made to cultivate them in natural ponds and artificial basins as a source of organic matter for humus-deficient forest nurseries. Slight improvement in growth of white spruce seedlings was noted when colloid-free sand cultures received an application of dried green algae grown in dilute solution of potassium phosphate. However, no positive results were reported thus far in regard to large scale applications.

It is possible that the growth of the higher plants on poorly-drained soils is benefited by the oxygen given off by the algae.

Protozoa

Protozoa are one-celled animals, varying in size from a few microns to several centimeters with protoplasm either naked or enclosed in a membrane and containing one or more nuclei.

Soil-inhabiting protozoa are classified into three groups according to their organs of mobility. Sarcina - moving by means of pseudopoda or temporary extensions of the body; Flagellata - provided with one or more permanent flexible whip-like flagella; Ciliata - with numerous short hair-like cilia confined to certain parts of the body or covering the entire organism.

Protozoa participate in the decomposition of organic remains, serve as a source of energy for other soil organisms, and destroy certain parasitic, as well as useful organiams, particularly bacteria. In recent times, a theory has been advanced that protozoa materially decrease the fertility of agricultural soils, or even cause a so-called "soil sickness" by feeding on ammonia and nitrate-forming bacteria. Such a condition may be expected in over-watered heavy nursery soils high in organic matter, i.e. a medium favoring the multiplication of protozoa.

Since protozoa are less resistant to heat than bacteria, a method of partial sterilization was advanced as a means of increasing soil fertility. However, this has not found an application in nursery practice. In several instances partial sterilization promoted the development of parasitic fungi, presumably due to the destruction of hyperparasites.

Rotifers

Rotifera, or "wheel animalcules", are minute animals deriving their name from a ciliated corona at the anterior end of an elongated body. The corona serves for locomotion and obtaining food.

Rotifera occur primarily in poorly-drained soils. Humification is the only function thus far ascribed to these organisms.

Nematodes

Nematodes are transparent, non-segmented, spindle-shaped, worm-like organisms. The soil-inhabiting forms are microscopic or nearly microscopic in size. They occur in great numbers in the humic horizons of forest soils and include parasitic, saprophytic and free-living species (Tylenchus, Iota, Mononchus, Rhabditis and Alaimus).

Nematodes play an important role in decomposition of organic matter and improve soil aeration. They consume bacteria, fungi, protozoa, and other nematodes and may be either injurious or beneficial depending upon the nature of destroyed organisms. By distributing parasitic fungi throughout nursery soil they may increase the extent of damping-off disease. Recent evidence from Wisconsin and New Zealand has shown that some of the nematode species (Rhabditis) invade the tissue of live coniferous seedlings, producing the same effect as damping-off disease, or at least completing the destructive work of fungi.

Earthworms

The worms inhabiting soil include chiefly the members of two families: Oligochaeta-Terricolae, having segmented bodies with four rows of bristles, and Oligochaeta-Limicolae, characterized by whitish color and presence of more than two straight bristles in some of the bundles. Lumbricus, Allolobophora, Eisenia, Helodrillus, Enchytraeus, Fredericia and Anachaeta are the most important species.

With very few exceptions, the occurrence of earthworms is confined to moist soils rich in organic matter and of moderately acid reaction. Loam and silt loam soils, high in bases and supporting hardwood stands, often have especially abundant earthworm population and are sometimes referred to as "earthworm mull soils." The number of specimens per acre in such soils according to Wisconsin studies varies from 500,000 to 1,000,000 per acre.

Earthworms drag fallen leaves into their burrows and use them either as litter or food, thus preventing the accumulation of duff. In the process of nutrition they pass great quantities of soil and organic remains through their bodies, thereby promoting humification and the incorporation of humus with mineral soil. As a result, the upper layer of soil attains a typical crumby structure which increases aeration, diminishes runoff, and to some extent facilitates the root penetration of germinating plants.

Undoubtedly the activity of earthworms has considerable beneficial influence upon the productivity of soils, as was originally stressed by Darwin in his work "Vegetable Mould and Earthworms." However, the presence of earthworms in forest soil is not always an indication of high soil productivity. Very often the abundant population of earthworms is found in soils with a high ground water level, where the growth stagnates due to deficient aeration of the deeper soil layers.

Mollusca

The mollusc population of soil is limited to snails and slugs. These moisture-loving forms occur predominantly in heavy soils with a fairly high ground water level. Both vegetarian and carnivorous molluscs feed largely upon the surface whenever the ground is wet. Their waste products make a certain contribution to the content of soil humus.

Arachinda

Soil-inhabiting Arachinda include mites, ticks, and spiders. They are as a rule confined to the upper one-inch layer. In well-humified mull soils the total number of arachinda may reach several hundred thousands per acre. Being primarily carnivorous, arachinda play certain role in the maintenance of biological equilibrium of the soil population and to some extent contribute to the processes of humification. Recently claims were made that mites are responsible for the injury of young seedlings.

Insects

A great majority of insects spend a certain portion of their life cycle in the soil, and the total insect population of forest soil per acre may be estimated in terms of millions. Some of the insects feed on root systems (Melolontha) or on soil organisms (Carabideae), while others live saprophytically (Collembola) or simply use soil as a shelter (Formicidae). Finally, some insects occur in soil only in the pupal stage (Lepidoptera).

The insects benefit forest soils by addition of organic matter, its humification and improvement of soil structure. Certain forms (Ichneumonidae and Braconidae) destroy cutworms and other parasitic organisms. Among the injurious insects, the white grub, wireworms, cutworms and root borers are of greatest importance. The first two destroy the roots of seedlings and transplants, whereas the latter cut the stems of young plants near the ground and feed upon the exuding sap.

In some tropical forests termites act as a particularly outstanding soil factor by decomposing vast amounts of dead and living plants and by greatly increasing the soil porosity with their numerous passages.

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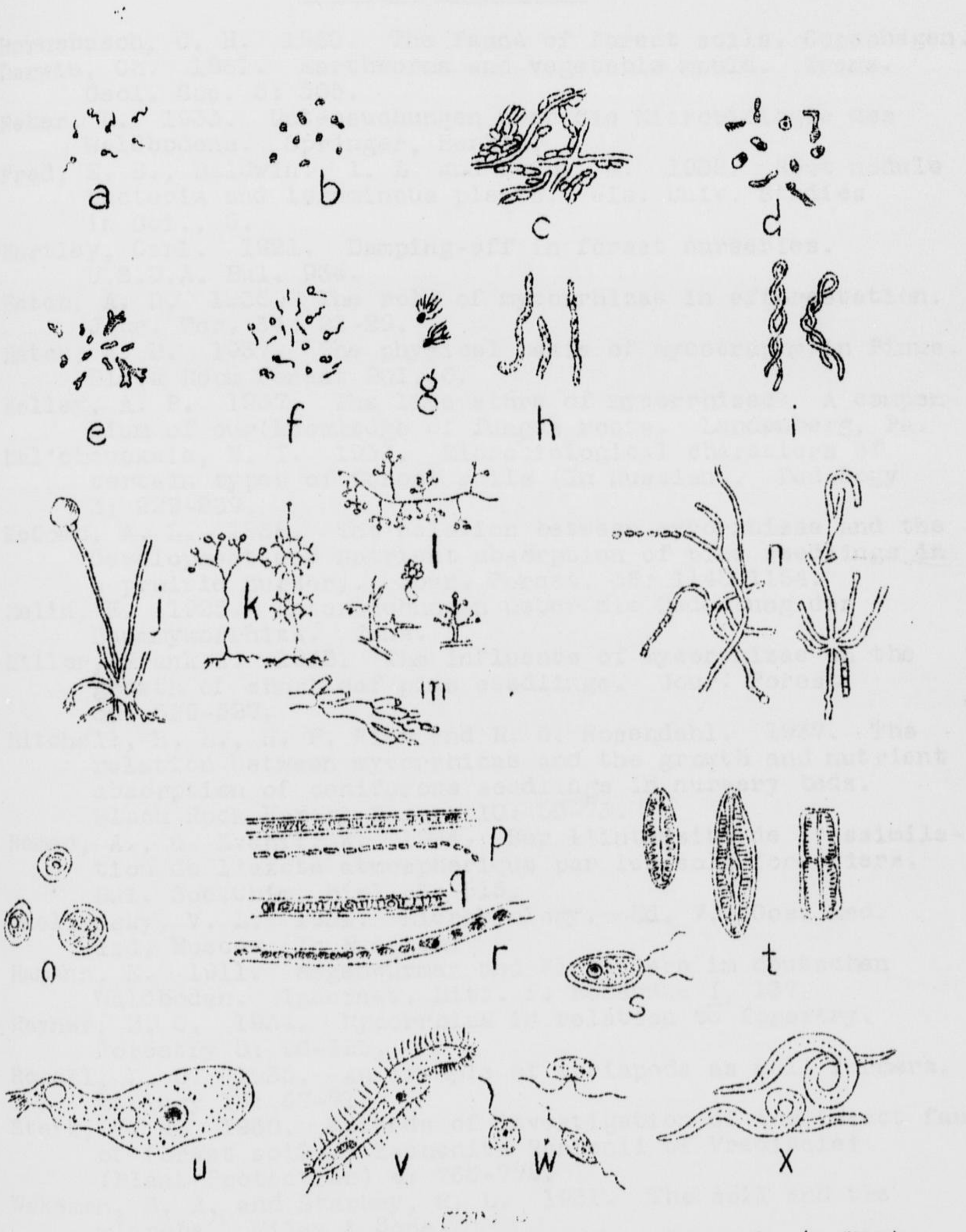

Representative forms of soil organisms. Bacteria (x 700): (a) Nitrosomonas; (b) Nitrobacter; (c) Azotobacter; (d) Clostridium; (e) Rhizobium; (f) Bac. cellulosae; (g) Bact. vulgare; (h) Beggiatoa; (i) Gallionella ferruginea. Fungi: (j) Rhizopus (x 40); (k) Mucor; (l) Trichoderma (x 250); (m) Penicillium (x 600); (n) Actinomycetes. Algae: (o) Pleurococcus; (p) Phormidium; (q) Nodularia; (r) Anabaena; (s) Chlamidomonas (x 1000); (t) Diatoms (x 1000). Protozoa (x 800): (u) Amoeba; (v) Ciliate; (w) Flagellates. (x) Nematodes (x 100).

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CHAPTER XII

HUMUS

(Properties and Silvicultural Importance)

> "So lie the dead leaves; but they and such as they nourish forever that great trunk ... which still sheds forth another crop and another, each as strong and as fair as the last."
> Sir A. Conan Doyle

The term "forest humus", in its broadest sense, refers to the entire organic portion of the soil profile (Waksman). It includes undecomposed leaves, needles and twigs or litter, partly decomposed remains, or duff and the finely-divided decay-resistant residue often incorporated with the mineral soil and referred to as amorphous humus or "leaf mold".

Forest humus is an ecological factor of extensive significance. It is an important agent in the processes of soil development. The leaching of podzols, maintenance of the equilibrium of soluble salts in the melanized soils, and accumulation of sesquioxides in laterites are intimately related to the nature of humus decomposition. Different forms of humus modify the rate of natural reproduction of forest stands and thus influence the technique of selective logging. Forest humus plays an important part in the maintenance of the fertility of permanent forest nurseries, being a source of useful organisms, balanced nutrients, buffering colloids, growth hormones and other substances essential in tree growth.

The first classification of the organic layers of forest soils is accredited to the German forester Emeis who in 1875 described three types of forest humus; one consisting of well-decomposed organic matter largely incorporated with the mineral soil and containing nitrogen in the form of "nitric acid"; the other two being composed of "raw" organic remains. This subdivision has formed the basis for all subsequent schemes of classification.

P. E. Müller of Denmark was the first to look upon forest humus layers as naturally occurring biological units. In 1879 he subdivided the humus la yers of forest soils into two types or groups, mull and mor.

The typical representative of Müller's mull group is the earthworm mull, consisting of an intimate mixture of humus and mineral soil. It has a friable, crumby structure due to the presence of large earthworms, such as *Lumbricus terrestris* and supports a rich flora of nitrophilous geophytes. Müller's mor or raw humus group is characterized by a thick, matted layer of free organic matter, sharply delineated from the mineral soil. The vegetation includes acidophilous plants of saprophytic nature.

Since Müller published his original work, there have been numerous attempts to broaden the classification of humus and adapt it to the needs of silvicultural practice (Ramann, Ebermayer, Hesselman, Leiningen, Vater, Albert, Ekstrom, Frosterus and Tamm, Juncker, Tschermak, Bornebusch, Romell and Heiberg, and Heiberg and Bornebusch). Although these efforts have broadened the knowledge of humus forms, they have resulted in the introduction of several misconceptions and unnecessary complications. The following points summarize the chief discrepancies and omissions common to the existing classifications.

On the basis of observation of isolated cases, several authors declared that the rate of forest grow th depends upon the type of humus. As more extensive studies showed, such a correlation does not hold true universally.

The degree of humification and development of mull or mor types was directly related to the reaction of the organic remains. "Sour" humus and "sweet" humus were used as synonymous for mor and mull humus in Russian, German and English literature. This relationship also proved to be unfounded, as strongly acid mulls with a reaction less than pH 5.0, as well as alkaline mors with a reaction as great as pH 8.0, were described.

Mull humus was presented as a material containing greater amounts of readily available nutrients than mor humus. Analysis of a large number of humus samples, as well as quartz sand culture experiments, proved the direct opposite of this supposition; pure mull types showed considerably less available nutrients per unit weight than the mor types.

The presence of an A_1 horizon with incorporated humus was assumed to be the distinguishing characteristic of mull humus. Actually, a number of varieties of the mor group with a pronounced A_1 horizon was observed.

Classificational schemes of different authors in various countries led to great terminological confusion. An examination of a glossary of the terms would show that almost every expression of international use has two or more meanings and the same material is known under several names.

None of the existing classifications gave sufficient consideration to the thickness and friability of the free organic matter, properties which are directly correlated with the rate of natural reproduction.

As a rule, classifications of humus completely disregarded the nature of the underlying mineral substratum. As recent investigations showed, chemically and to a great extent biologically, the humus layers are dependent upon the properties of the mineral soil.

Considering the outlined criticisms, and the information available at present, a general scheme of forest humus classification is outlined below. This classification recognizes two broad biological groups (mull and mor), eight well-defined and silviculturally important types (barren mull, earth mull, duff mull, podzol mull, crust mor, raw mor, infiltrated mor and rendzina mor), and a number of morphological varieties of secondary practical importance, (crumb mull, grain mull, firm mull, matted mor, fibrous mor, amorphous mor, etc.). The accompanying drawings present schematically the important morphological features of humus types.

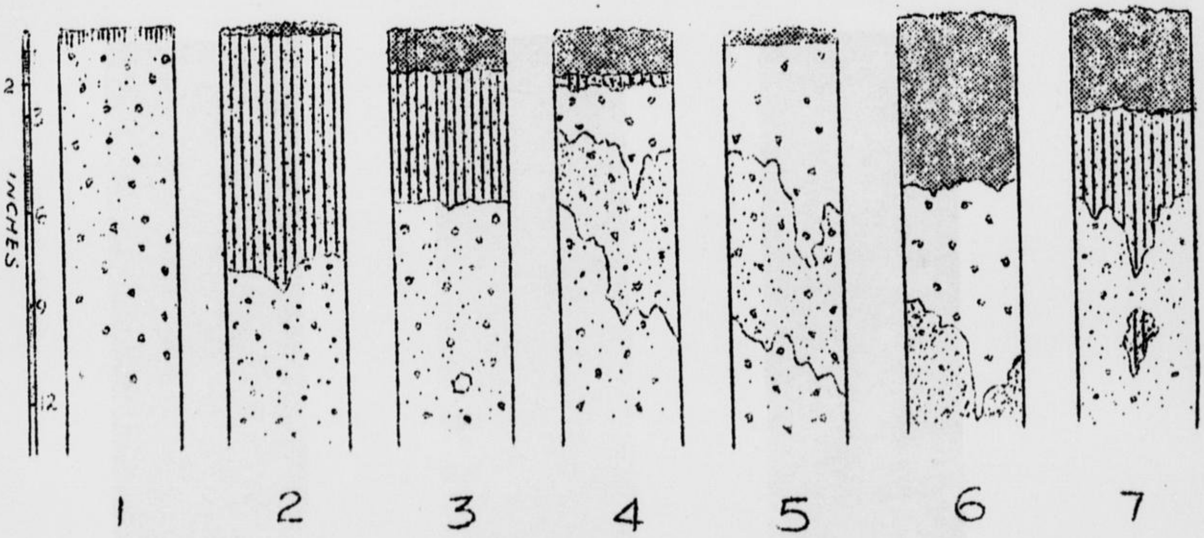

Figure 34

Schematic profiles of humus types (1) Barren mull; (2) Earth mull; (3) Duff mull; (4) Podzol mull; (5) Crust mor; (6) Raw mor; (7) Infiltrated mor.

Vertical lines indicate incorporated humus, whereas solid black indicates raw or free organic matter.

A. Mull Group or Active Humus

1. Barren Mull is formed under conditions promoting extremely rapid decomposition of organic remains. The litter is either entirely absent or is represented by a few scattered remnants of the last year's leaf fall. The mineral soil contains only a negligible amount of incorporated humus, which sometimes is difficult to detect by ocular examination. The humic layer does not exceed a depth of 2 inches. In spite of the rapid decomposition of organic remains, the upper layer of soil may be of very high acidity, approaching pH 4.

The type is confined chiefly to soils of lateritic nature, particularly the red and yellow forest soils. It also occurs in the brownearth region, and in areas adjacent to the hardprairie. This type is found under stands of both pines and hardwoods, oaks being the principal hardwood species.

The possibilities of natural reproduction are high due to exposed mineral soil. In spite of the low content of soil organic matter pine stands on barren mulls may be fairly productive. This is generally true of the lateritic zone where climatic conditions make satisfactory tree growth possible on soils with a minimum content of base exchange material and available nutrients.

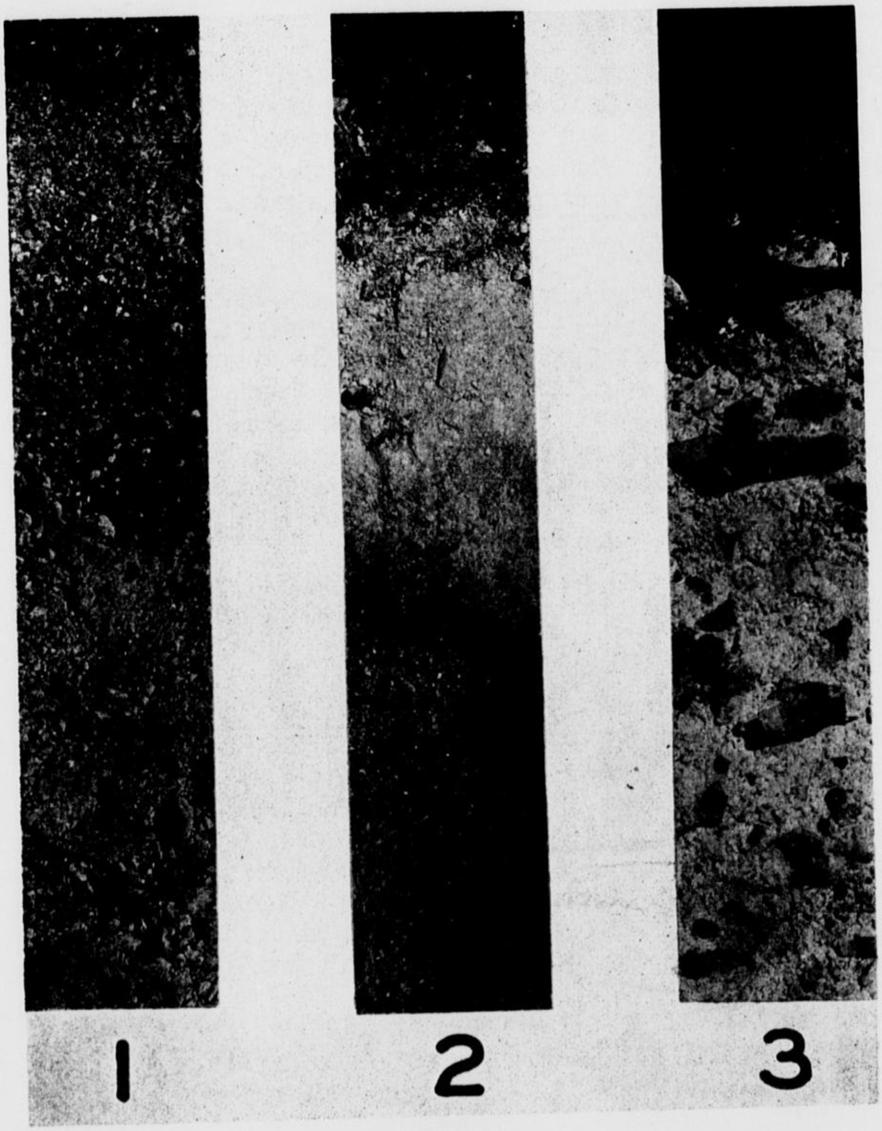

Figure 35. Characteristic profiles of mull and raw humus types: 1. Crumb mull on a slightly podzolized silt loam; 2. Acid raw humus on a podzol sandy loam with ortstein horizon; 3. Alkaline raw humus underlain by limestone bedrock. The monoliths represent sections 20 inches deep.

3. Earth Mull is characterized by a dark A_1 layer with incorporated humus, usually varying in depth from 3 to 8 inches. In some instances the depth of humic layer is even greater. The layer of litter is thin and often interrupted. In many instances the litter is nearly absent. The reaction of the humic layer ranges from pH 5 to pH 8.

This type occurs in the region of brownearths, grey forest soils and podzolic soils, predominantly under hardwood stands. The rate of growth and quality of the stands are extremely variable. The ground cover association is composed of typical mesophytic "mull" plants, such as Mercurialis, Anemone, Hydrophyllum, Thalictrum, and Dicentra.

The conditions for natural reproduction in this type are very favorable. Because of the rapid decomposition of organic remains and the vigor of competing vegetation, thinnings and selective cuttings must be conducted in a very conservative manner. The value of earth mull as a natural fertilizer is low because of the high content of mineral soil. Its inoculating capacity is questionable since the earthworms and bacteria may not survive in the poorly aerated compost pile or in the acid nursery soil.

Depending upon the structure of the A_1 horizon, the earth mull may be divided into a number of morphological varieties, as follows:

(a) Crumb mull. The humic layer is of a coarse crumby structure resulting from the activity of large earthworms. The content of organic matter rarely exceeds 20 per cent. This variety occurs predominantly on heavy soils with a high ground water level. Forest stands are composed chiefly of hardwood species. A high percentage of cull material is common. The ground cover includes several species of ferns, and moisture-loving plants in addition to typical mull vegetation. The reaction of the humic layer varies from pH 5.5 to pH 8.0.

(b) Grain mull. This variety is characterized by a fine grained structure and the absence of large earthworms. The content of organic matter may be higher than in crumb mull. The ground cover consists of typical mull plants. Grain mull occurs on well drained soils of loam texture, often under stands of a high productivity. The reaction is about pH 6, or higher.

(c) Firm mull. The humic layer is structureless, of dense or firm nature and has a low content of organic matter, as a rule not exceeding 10 per cent. The reaction varies from pH 5.0 to 6.0. It is confined to heavy upland soils.

(d) Bor mull. The humic layer is of single-grained structure and reaches a depth of 8 inches. The content of organic matter usually does not exceed 6 per cent. The reaction varies from 5.0 to 6.5. The variety is confined to unleached sands, and occurs chiefly under pine and oak stands.

3. Duff Mull. This type is characterized by the presence of a substantial layer of friable litter and duff, varying in thickness from 1 to 2½ inches. The infiltrated horizon may be structur-

ed or structureless. The depth of the humic layer seldom exceeds 8 inches. The reaction of the organic portion usually varies from pH 5.0 to 7.0.

Duff mull occurs predominantly on well drained podzolic and grey forest soils supporting either pure hardwoods or mixed hardwood-coniferous stands. The conditions for natural regeneration of the stand are somewhat less favorable than are found on the true mull type and selective logging may be carried on with a somewhat greater intensity. The duff portion as a rule has a high content of nutrients, and can be advantageously used as a fertilizer or inoculating medium.

Duff crumb mull, duff grain mull, duff bor mull and duff firm mull are morphological varieties of this type separated on the basis of the nature of the A_1 horizon. With the exception of the duff layer, these varieties are essentially similar to those of the earth mull type.

4. Podzol Mull. This type is a peculiar transition between mull and mor forms. The entire absence or slight development of the infiltrated A_1 layer as encountered in podzol soils, is the outstanding characteristic. The litter and duff layers are of a distinctly friable structure and their thickness does not exceed $2\frac{1}{2}$ inches. The reaction of organic horizons varies from about pH 5.0 to 6.0. This type occurs on podzolized soils supporting hardwood-coniferous or pure coniferous stands. The ground cover is largely composed of raw humus plants and several species of Liliaceae.

The duff layer has, as a rule, a very high content of available nutrients, and is characterized by the presence of very active organisms, both fungi and bacteria. It is an ideal fertilizer and inoculating medium for most species.

This type is very favorable for natural reproduction of conifers, particularly spruce, fir, hemlock and white pine. Selective logging should be carried on in a very conservative manner, as the rapid decomposition of the duff layer will result in a drastic reduction of soil fertility. The danger of soil deterioration is due to the absence of incorporated humus and the exposure of the sterile podzolic layer following the rapid decomposition of the free organic remains. The silvicultural importance of this type has been overlooked and the type itself usually confused with "raw humus."

B. Mor Group or Inert Humus

1. Crust Mor. This type is primarily confined to the boreal region of the North American and Eurasian continents, particularly to barren sandy soils, too poor to support heath shrubs. The organic remains assume the form of a thin, but firm, crust-like layer of lichens, xerophytic mosses and needles. This crust has an extremely acid reaction, approaching pH 3.0. Crust mor and its adverse influences upon forest growth are well known from the descriptions of the "Yag" type of the Russians and the "Cladina" type of the Finnish foresters.

2. Raw Mor. Duff layer consists of partly decomposed remains of vegetation, particularly wood, interwoven by the mycelia of fungi and often by the roots. It is of a compact or tough consistency, ordinarily varying in thickness from 3 to 5 inches, but in places reaching a depth of 1 foot. It rests directly upon leached mineral soil. The reaction varies from pH 3.5 to 5.5.

This type is confined to true podzols and occurs predominantly under the dense stands of conifers. The ground cover is composed exclusively of acidophilous raw humus plants of saprophytic nature, such as Vaccinium, Lycopodium, Maianthemum, Cornus canadensis, and Linneae.

The raw mor is noted for its unfavorable influence upon natural regeneration. In order to promote the decomposition of the thick mat of organic remains, stands must be opened by heavy selective logging. Sometimes the duff layer is broken up mechanically. As fertilizing and inoculating material it is considerably more valuable than earth mull, but is inferior to podzol mull and some varieties of duff mull.

A description of the main morphological varieties follows:

(a) Matted mor: Duff layer appears as a tough, compacted brown mat of leaves, needles and wood remains approximately 4 inches in thickness. It is the most common variety found on podzol soils of America and Europe.

(b) Amorphous mor: Duff layer is compacted but not tough, composed chiefly of dark brown, nearly black wood remains. The lower portion is highly dispersed and has a greasy feel when wet. The thickness of duff layer may be as great as 12 inches. This variety occurs in cool regions of high humidity, and is associated with very strongly podzolized soils.

(c) Fibrous mor: Duff layer is of a considerable thickness, firmly bound by interwoven roots of heath plants, but not compact. Occurs on soils with a ground cover of Hypnum and Vaccinium spp. Widely distributed in Scandinavia, and northern Russia, chiefly on soils of sandy texture.

3. Infiltrated Mor. The thick duff layer is quite similar to the duff layer of the matted mor. However, it is underlain by an infiltrated A_1 horizon with incorporated or rather "washed in" humus, which is the distinguishing characteristic of this type. The tongues of the infiltrated horizon extend to a depth of one foot or more, and often occurs as dark spots.

Infiltrated mor is confined chiefly to podzol soils with impeded drainage. The forest cover is composed predominantly of mixed hardwood-coniferous stands. The ground cover includes mosses, ferns, sedges and other water-loving plants. The understory includes a considerably higher amount of tall shrub species than is found on the raw mor type. Natural reproduction proceeds rapidly, but may be easily suppressed by weed species if the stand is cut too heavily.

On wet gley soils of heavy texture, the A_1 horizon is black, or nearly black, plastic, and of muck-like or sapropel nature (Stebutt). This variety may be referred to as sapropel mor. The plastic sapropel layer has a tendency to cement the soil and, therefore, is undesirable as fertilizer.

4. Rendzina Mor. This type is found on exposed limestone outcrops and calcareous deposits in the podzol region. The dark brown duff layer is approximately 4 inches thick and consists of partly decomposed wood remains. It grades into a nearly black, finely divided humic layer, varying in thickness from 2 to 4 inches. The reaction of the duff and humic horizons varies from pH 6.5 to pH 8.0. The forest stands are inferior and composed chiefly of conifers. Northern white cedar is the predominant species in the United States. The ground cover includes typical saprophytic plants occurring on strongly acid soils.

As the organic layers rest upon highly calcareous strata, their destruction through fire, logging, or erosion converts the land into unproductive barrens. The use of the duff layer as fertilizer is objectionable because of its high content of calcium and magnesium carbonates.

The lime-bearing substrata of high mountains develop so-called "Alpine humus" which is closely related to rendzina mor.

Figure 36 shows characteristic profiles of mull and raw humus types.

Chemical and Biological Properties of Humus in Relation to Its Morphology or Degree of Decomposition

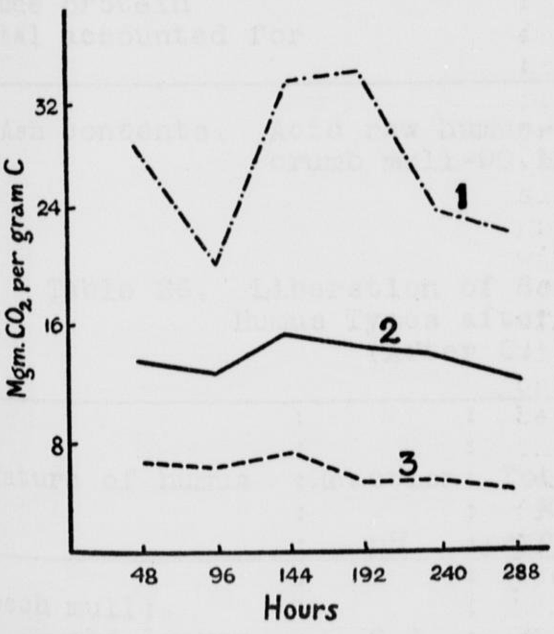

Figure 36. Relative biological activity of different humus types as determined by carbon dioxide evolution: 1, Mull; 2, Alkaline raw humus; 3, Acid raw humus. (After H. M. Galloway).

Because of differences in degree of decomposition, humus types are characterized by the specific proportions of lignin, carbohydrates, proteins, fats, resins, and similar groups of constituents. The most significant fractions of these groups may be isolated by extraction with water, ether, alcohol, strong acids and other reagents, and determined quantitatively. The relative distribution of these fractions brings out not only the differences between the types of humus, but also the differences between a certain humus type and the original residue from which it was derived. Table 25 illustrates proximate chemical composition of the three types of forest humus occurring in the podzol belt of the Lake States.

The rate of organic matter decomposition is broadly correlated with the activity of microorganisms as manifested by the liberation of carbon dioxide, the consumption of oxygen, the heat of fermentation, or release of soluble nitrogen. A quantitative recording of these processes may serve to indicate the general nature of organic remains. Diagram 36 shows the differences in the evolution of carbon dioxide by mull and mor types of humus (Galloway). Table 26 presents the amounts of ammonia and nitrates released during incubation of old beech leaves from mull and raw humus types (Bornebusch).

It should be noted that natural environment is an extremely important factor in the activity of organisms and, hence, the results of biological investigations of humus under optimum laboratory conditions have but relative significance. In particular, it is difficult to judge on the basis of laboratory trials the inoculating value of different humus deposits; the organisms which are very active in a fertile natural soil or in laboratory environment may rapidly degenerate upon the transplanting into composting medium or nursery soil.

Table 25. Proximate Chemical Composition of Different Types of Forest Humus
(After H. M. Galloway and W. E. Patzer)

Constituents	Acid raw humus	Alkaline raw humus	Crumb mull
	Per cent of dry material on ash-free basis*		
Ether soluble fraction	3.42	0.26	0.46
Hot water soluble fraction	5.22	2.42	1.83
Alcohol soluble fraction	4.65	2.12	3.17
Hemicelluloses	6.84	7.82	2.94
Cellulose	6.08	2.21	1.69
Lignin	41.51	32.72	31.16
Crude protein	11.11	12.41	19.02
Total accounted for	78.83	59.96	60.27

* Ash contents: Acid raw humus-4.55; alkaline raw humus-14.46%; crumb mull-90.12%.

Table 26. Liberation of Soluble Nitrogen in Mull and Raw Humus Types after Six Weeks Incubation
(After C. H. Bornebusch)

Nature of humus	Reaction pH	Total N percent	Nitrogen liberated from 1 kg. of dry humus: NH_3	NO_3	Total
			grams		
Beech mull; old leaves	6.1	1.70	0.084	1.200	1.284
Beech raw humus; old leaves	5.6	1.97	0.252	0.020	0.272

Nutrient Content and Exchange Properties of Humus

The nutrient content of humus is a function of three variables: type of humus, nature of underlying substratum, and composition of forest stand. Mull types having a high volume weight show considerably lower concentration of nutrients than mor or raw humus types. Heavy soils derived from parent materials rich in minerals, as a rule produce humus with a high content of nutrients, whereas sandy or siliceous soils, produce humus poor in nutrients. Light demanding species, particularly pines, tend to accumulate less nutrients in their litter than do tolerant trees, such as spruce, maple and basswood. Table 27 includes average values of different fertility factors for a number of humus types found on granitic deposits of the Lake States region. Diagram 37 facilitates a comparison of the nutrient contents present in various types of humus. Although humus is a factor of great complexity, involving physico-chemical, biological and catalytic aspects, a close correlation was shown to exist between the nutrient content of humus and the growth of forest seedlings under controlled conditions (Fig. 38).

Base exchange capacity is closely related to the content of lignin-like substances, and may serve as an indicator of the degree of humus decomposition. The base exchange capacity of raw humus ranges between 40 and 100 m.e. per 100 g. The base exchange capacity of mull humus is seldom greater than 30 m.e. per 100 g. because of the high content of mineral matter; however, the exchange capacity of the organic fraction itself may exceed 200 m.e. per 100 g.

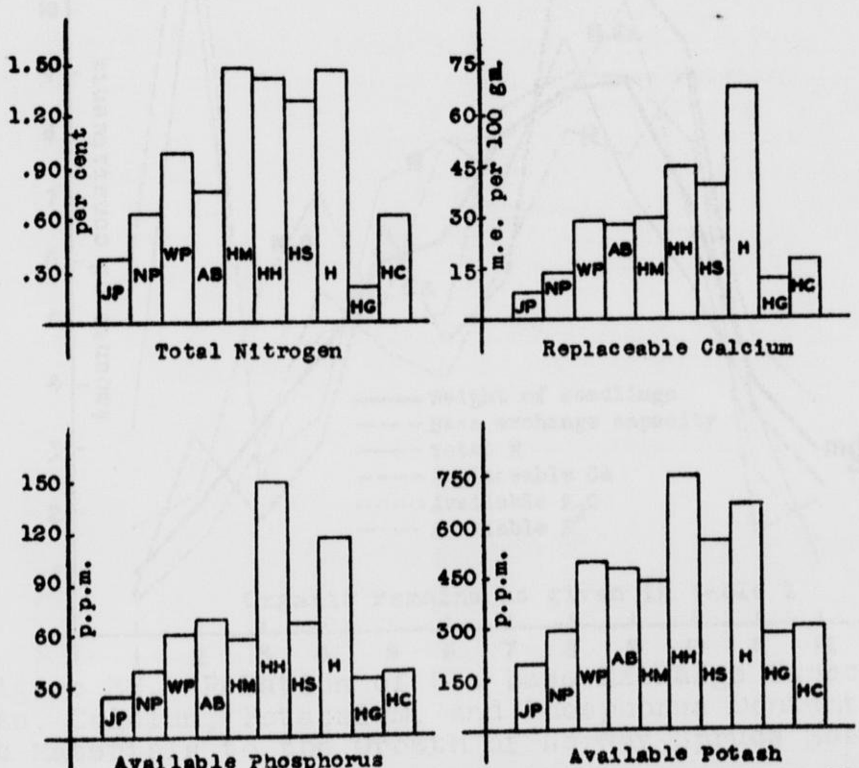

Figure 37. Contents of Nitrogen, Calcium, Phosphorus, and Potash in Different Types of Organic Remains from Upland Forest. JP--jack pine duff; NP--Norway pine duff; WP--white pine duff; AB--aspen-birch duff; HM--hemlock duff; HH-hardwood-hemlock duff; HS--hardwood-spruce-fir duff; H--hardwood duff; HG--hardwood grain mull humus; HC--hardwood crumb mull humus.

Table 27. Fertilizing Value of Organic Remains of Upland Forest Vegetation, as Determined by Chemical Analysis

Type of organic remains	Reaction	Base Exch. (per 100 g)	Total N	Avail. P	Avail. K_2O	Repl. Ca (per 100 gm.)	Repl. Mg (per 100 gm.)
	pH	m.e.	percent	p.p.m.	p.p.m.	m.e.	m.e.
Jack pine duff	5.6	13.3	0.372	24	186	7.5	1.8
Norway pine duff	5.4	29.3	0.653	38	287	12.9	3.2
White pine duff	5.4	47.1	0.976	60	483	28.2	5.6
Aspen-birch duff	5.7	39.3	0.775	69	471	27.3	4.8
Hemlock duff	4.8	73.2	1.490	57	432	29.4	6.5
Hardwood-hemlock duff	5.4	72.5	1.430	148	741	44.1	8.7
Hardwood-spruce-fir duff	5.5	65.8	1.290	66	545	38.6	8.0
Hardwood leaf mull	6.5	90.5	1.460	115	660	66.6	9.5
Hardwood grain mull	6.4	15.5	0.227	35	282	11.2	2.8
Hardwood crumb mull	5.3	27.6	0.610	37	296	16.5	3.3

Average standard errors: pH ±.02; B.Ex. ±4.4; Tot. N ±.074; Avail. P ±6.7; Avail. K_2O ±25.1; Repl. Ca ±3.4; Repl.Mg ±1.0.

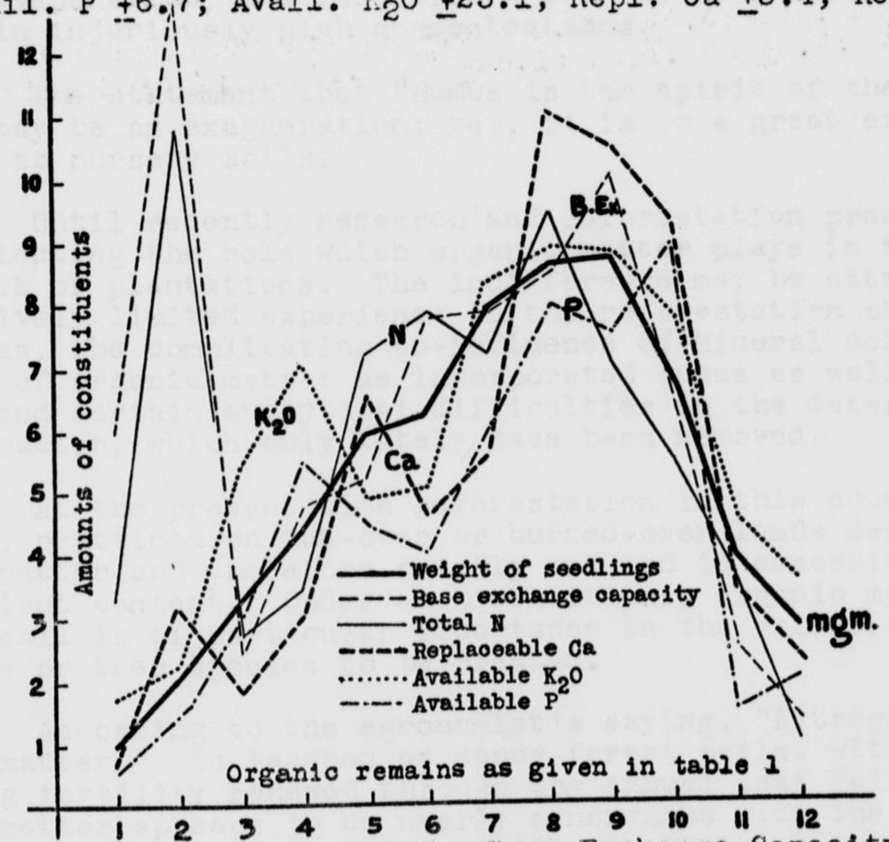

Figure 38. Relation of the Base Exchange Capacity and of the Nitrogen, Calcium, Potassium, and Phosphorus Contents of Different Organic Materials to the Growth of Norway Spruce Seedlings.

Each unit of the ordinate represents the following values: 100 mgm. of the dry weight of seedlings; 10 m.e. per 100 gm. of base exchange capacity; 0.2 per cent of total nitrogen; 0.1 per cent of replaceable calcium; 0.01 per cent of available potash; and 0.002 per cent of available phosphorus.

Significance of Humus in Nursery Practice and Reforestation

Regardless of the origin or morphological form, humus fulfills in the soil four important functions; it improves physical properties of the soil, provides nitrogen and other plant food, absorbs mineral salts, and increases the availability of nutrients through its exchange and catalytic effects.

In no other branch of plant production is a deficiency of humus manifested with such sharpness as it is in forest nurseries. Forest trees, especially conifers, develop in their youth on a purely organic layer of forest debris, and thus acquire more or less pronounced saprophytic tendencies. No crop residues are left in the soil of the nursery because even the root systems of seedlings are removed. Continuous weeding and cultivation, artificial irrigation, and additions of commercial fertilizers promote biological activity and rapid decomposition of organic matter. Under these conditions, the maintenance of an adequate supply of humus may require regular additions of organic remains to the soil.

If fertilizers are applied to a nursery soil having a low content of humus, mineral colloids are likely to be insufficient to prevent the loss of salts by leaching. In times of drought, the moisture content of humus-deficient soils rapidly decreases through evaporation, and fertilizers tend to accumulate on the soil surface in injuriously high concentrations.

The statement that "Humus is the spirit of the soil" (Knox), may be an exaggeration; yet, it is to a great extent applicable to nursery soils.

Until recently research and reforestation practice have been neglecting the role which organic matter plays in the survival and growth of plantations. The indifference may be attributed to comparatively limited experience in the reforestation of old cut-over areas, the complicating co-influence of mineral colloids, occurrence of organic matter as incorporated humus as well as surface litter, and certain analytical difficulties in the determination of organic matter, which only lately have been removed.

At the present time reforestation in this country is, in the main, practiced on cut-over or burned-over lands depleted of organic matter and therefore greatly reduced in absorbing capacity and nutrient content. Under such conditions, organic matter content of soil is of particular importance in the selection of planting sites or tree species to be planted.

According to the agronomist's saying, "Nitrogen spells organic matter." In leached or sandy forest soils, with their revolving fertility renewed through the annual leaf fall, the organic matter appears to be nearly synonymous with the content of all nutrients. Diagrams 39 and 40 illustrate the relationships found in cut-over sandy soils of Wisconsin granitic outwash (7-inch surface layer).

Organic matter retains considerable amounts of water and soils rich in humus are likely to be less subject to drought injury than humus-deficient soils.

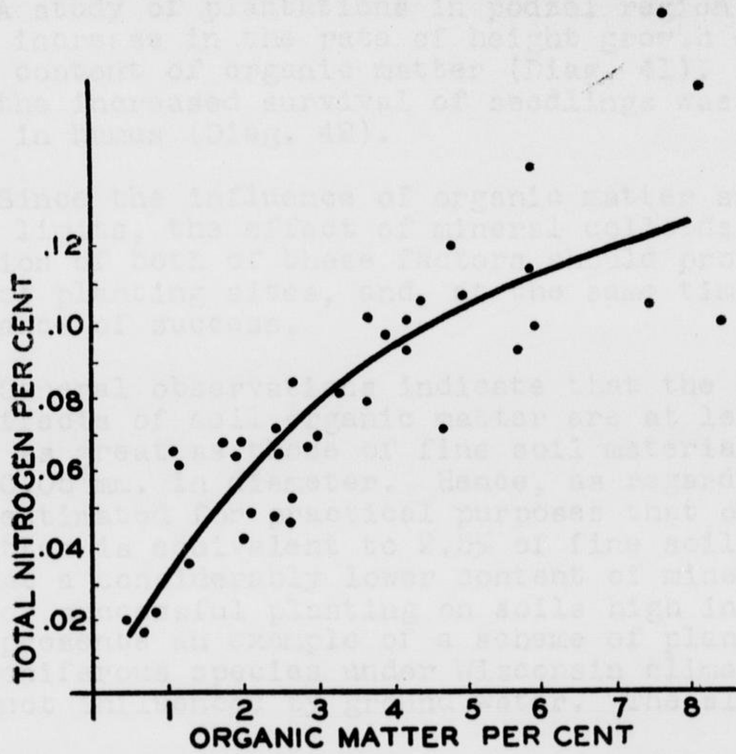

Figure 39. Relation of total nitrogen to organic matter in cut-over sandy soils of Wiscons in (Plainfield and Vilas series)

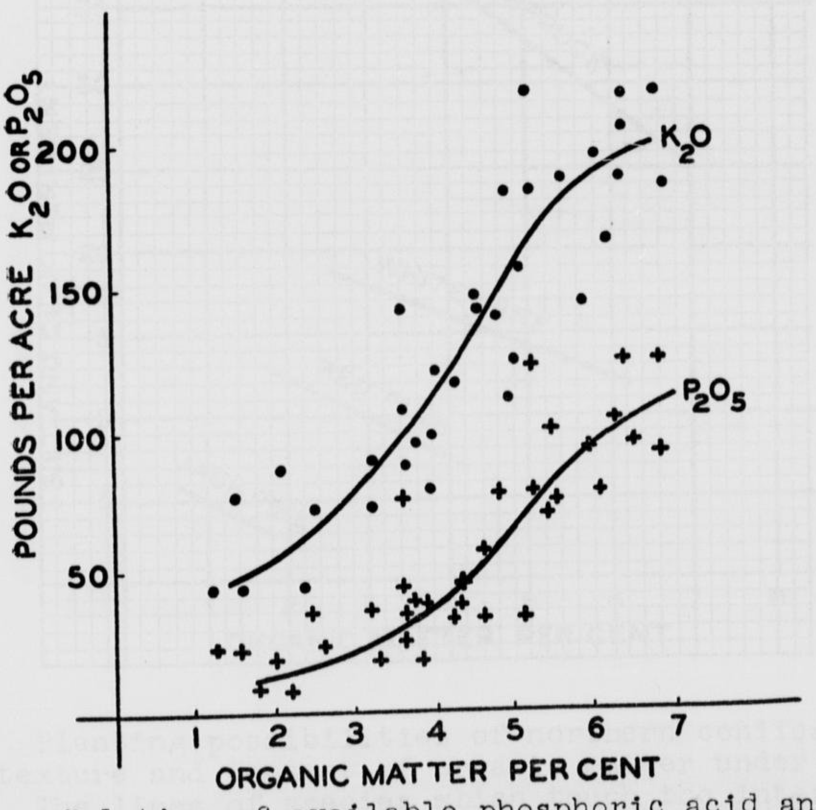

Figure 40. Relation of available phosphoric acid and available potash to organic matter in cut-over sandy soils of Wisconsin (Plainfield and Vilas series)

A study of plantations in podzol region has indicated a pronounced increase in the rate of height growth of trees due to the higher content of organic matter (Diag. 41). A general tendency for the increased survival of seedlings was also observed on soils high in humus (Diag. 42).

Since the influence of organic matter supplements, within certain limits, the effect of mineral colloids, a coordinated consideration of both of these factors should provide a wider selection of planting sites, and, at the same time, would give more assurance of success.

General observations indicate that the absorbing or base exchange effects of soil organic matter are at least two and one-half times as great as those of fine soil material, i.e., material less than 0.05 mm. in diameter. Hence, as regards these effects, it may be estimated for practical purposes that one per cent of organic matter is equivalent to 2.5% of fine soil material. This implies that a considerably lower content of mineral colloids is adequate for successful planting on soils high in organic matter. Figure 43 presents an example of a scheme of planting possibilities for four coniferous species under Wisconsin climatic conditions and for soils not influenced by ground water. The slanted lines re-

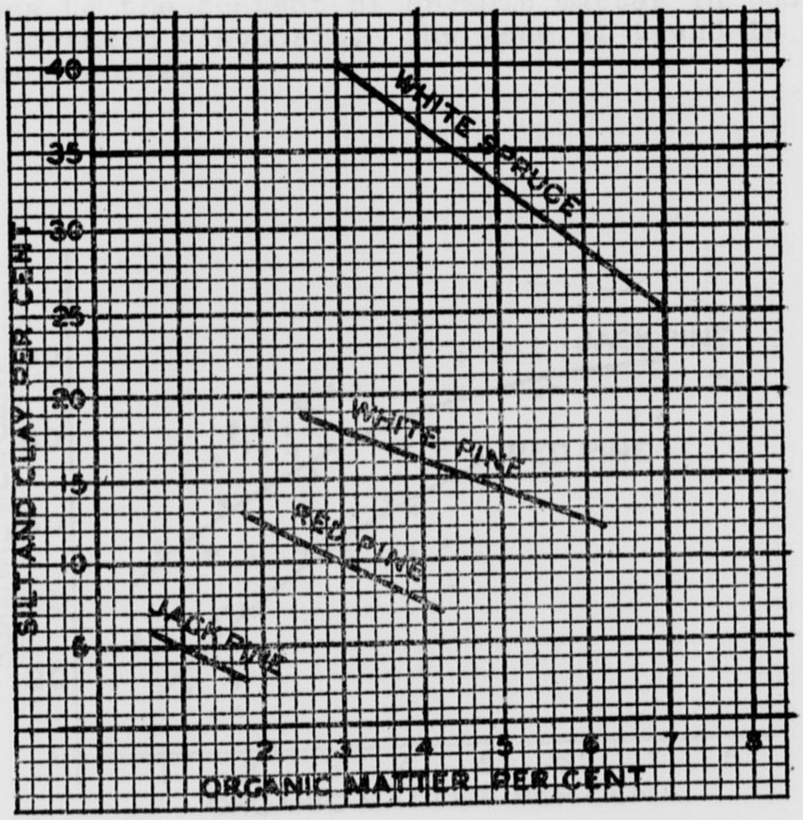

Figure 43. Planting possibilities of northern conifers in relation to soil texture and content of organic matter under Wisconsin conditions. The lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question.

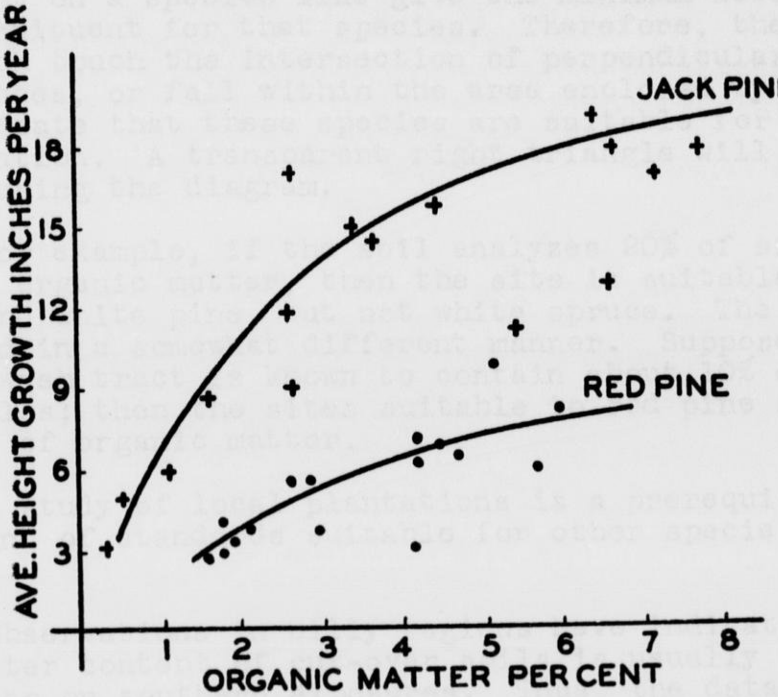

Figure 41. Relation of height growth of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves

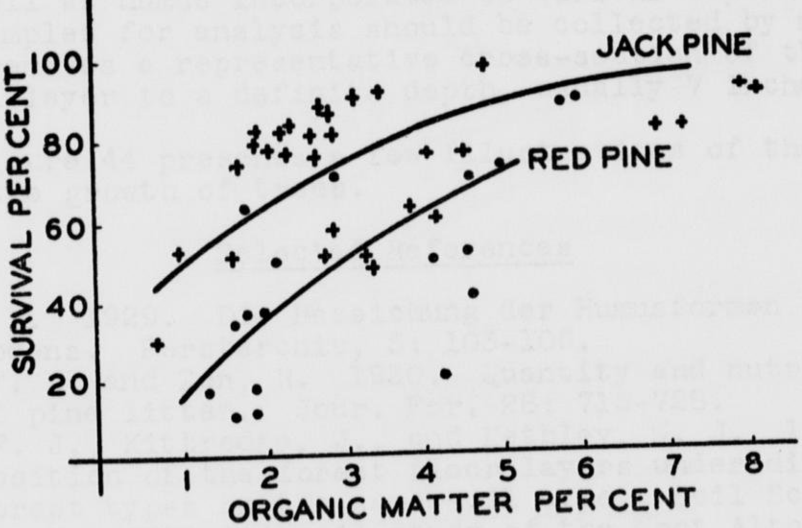

Figure 42. Relation of survival of jack pine and red pine plantations to the content of organic matter in podzolic sandy soils of northern Wisconsin. The general trend is indicated by free-hand curves.

present the minimum acceptable ranges of fine soil material and organic matter for each species. The ordinate and abscissa values for any point on a species line give the minimum acceptable values of each constituent for that species. Therefore, the lines of species which touch the intersection of perpendiculars erected from the coordinates, or fall within the area enclosed by the perpendiculars, indicate that these species are suitable for planting on the soil in question. A transparent right triangle will be found helpful in using the diagram.

For example, if the soil analyzes 20% of silt and clay and 2.7% of organic matter, then the site is suitable to jack pine, red pine, and white pine, but not white spruce. The graphs may also be used in a somewhat different manner. Suppose the soil of a large outwash tract is known to contain about 10% of silt and clay particles; then the sites suitable to red pine should have at least 3% of organic matter.

A study of local plantations is a prerequisite for the establishment of standards suitable for other species and climatic conditions..

Observations in hilly regions have indicated that the organic matter content of cut-over soils is usually greater on northern than on southern exposures. Thus, the data from soil organic matter determinations tend to express the influence of temperature, moisture, and other site factors common to various topographical aspects.

The determination of organic matter content may serve as an index of soil depletion resulting from grazing, burning, removal of litter, or erosion, and may be very useful in the management of woodlot soils.

Because soil organic matter occurs in the form of surface debris as well as humus incorporated to various depths with the soil, the samples for analysis should be collected by means of a tube which removes a representative cross-section of the entire surface soil layer to a definite depth, usually 7 inches.

Figure 44 presents a few illustrations of the effect of humus upon the growth of trees.

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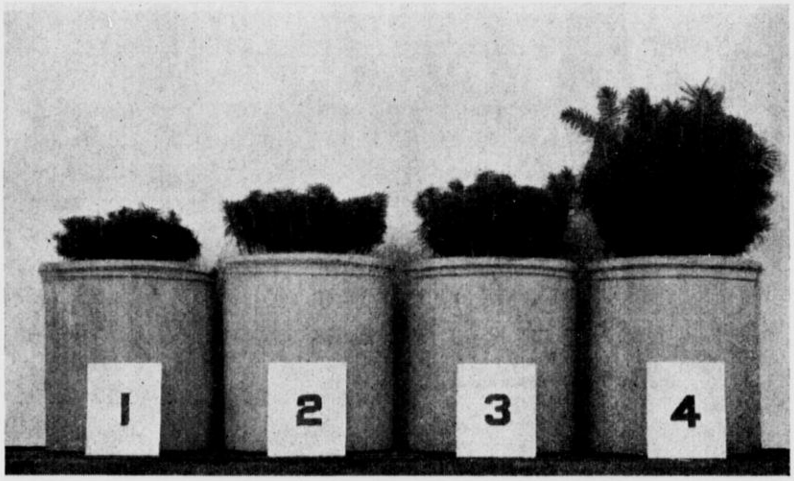

Figure 44. Effect of humus upon the growth of trees. Top: Fourteen-year old red pine on sand deficient in organic matter; average height 6 feet. Plantations of the same age ordinarily attain an average height of 15 feet. Bottom: Two-year old Norway spruce raised in quartz sand cultures with addition of various organic remains: 1. Check; 2. Sedge peat; 3. Hardwood crumb mull; 4. Hardwood-hemlock duff.

PART IV

SOIL-FOREST TYPES

> The distribution of vegetation is influenced by climate and governed by the soil.
>
> G. F. Morozov

Introduction

The following outline includes a number of sketches of soil-forest associations found in different geographical regions. The areas described were selected from the different parts of the world. An attempt was made to cover a sufficiently wide range of physiographic conditions. The descriptions were shortened to the allowable minimum which would demonstrate the most essential features of the correlation between the environmental factors and forest growth. It is assumed that the reader has a sufficient knowledge of soils and tree habits to appreciate that a great number of soil properties, and characteristics of trees are often implied by a single term such as "podzolic loam" or "tolerant conifers."

The relationships described for different areas were not established upon equivalent amounts of analytical work. Some of the correlations are based upon examinations of thousands of soil profiles, numerous chemical analyses, detailed mensuration studies and extensive surveys of the ground vegetation. Others were compiled from fragmental information scattered in soil survey bulletins, botanical reports and silvicultural publications.

The descriptions of the individual areas were combined into several groups, characterized by a comparative similarity of conditions. Such arrangement allows one to observe the parallelism in the development of geographically distant biocenotic units, particularly those of the Eurasian and American continents. The designation of ecotypes is given in terms of soil morphology, topographical features, composition of the main forest stand or characteristic ground cover vegetation, as different writers considered most suitable.

The specific objectives of this compendium are to show the varying effect of soil properties under different climatic conditions; to demonstrate, on a large scale, the adaptability of tree species, and thereby to provide a foundation for a better understanding of silvicultural principles.

Among the broader a ims of this outline, is to illustrate, by means of concrete examples, the universal applicability of the fundamental laws governing the distribution and growth of vegetation. These basic laws form the essentials of not only silvicultural practice, but the entire science of plant ecology.

Neither tundra, desert nor prairie has the multitude of life forms and species, and ability to manifest the effect of environmental factors as does the forest. Two conditions, in particular, make a forest stand an unexcelled indicator of the outside influences: first, the development of the three independent, and yet interrelated, layers of vegetation, composed of trees, shrubs and ground plants; second, the permanent record of the rate of stand growth provided by the diameter, height and annual rings of the trees.

CHAPTER XIII

SUBARCTIC FORESTS

Finno-Scandian Shield

> "The long road over the moors, and up into the forest....the road through the great Almenning--the common tracts without an owner; no man's land."
>
> Knut Hamsun. Growth of the Soil.

The region described includes the northern-most parts of Norway and Finland and the entire Kola peninsula bordered by the Arctic Ocean and the White Sea. The total area comprises about 150,000 square miles. In general it is an undulating or rolling plateau, not exceeding 500 feet above sea level with a number of rivers and with numerous lakes. The climate is strongly affected by the warm current of the Gulf Stream, and the Arctic Ocean remains free of ice and is open for navigation the entire year. The mean winter temperature ranges from 10 to 18 degrees F. and the mean summer temperature from 46 to 50 degrees F. In spite of relatively moderate winter temperature, the climate is extremely severe, due to strong winds. The precipitation averages about 10 inches per year, being somewhat higher on the shore of the ocean and along the southern boundary. The greatest part of the precipitation is in the form of snow, in places reaching a depth of 15 to 20 feet. In mid-winter there are but a few hours of daylight whereas in June the sun does not disappear from the sky.

The Finno-Scandian range is composed of gneiss, granite, schists, diorite, diabase, and gabbro. In places are found volcanic tufa, dolomite, and limestone. In the majority of cases, the rocks are covered with a thick layer of glacial deposits.

The northern part is occupied by tundra or muskeg; the southern by taibola or forest. The boundary between these two formations ranges between 66 to 69 degrees north latitude, following closely the isothermal line of 56 degrees F. for the month of July.

Tundra is a treeless, swampy plain, supporting mosses, lichens, species of Ledum, Vaccinium, and other heath plants. The surface soil is formed by a layer of peat of varying thickness. The mineral substratum remains, in many cases, permanently frozen below a depth of a few inches.

Along the forest boundary of the tundra occur small groups of dwarfed spruce, with some birch, swamp birch, and crowberry. Alder and willows are also found along the rivers and creeks.

The development of forest stands is strongly influenced by the conditions of climate. Because of this, the soils of the same origin and texture in different latitudes and on different exposures support stands of different composition. Thus, for example, in the proximity of tundra and on exposed sites, stands of larch occupy sandy soils which otherwise support stands of Scotch pine. In general, the stands of better quality are confined to narrow strips along the rivers. Such strips do not exceed 7 miles in width. The stands of plateaus, as well as the stands on poorly drained lands, have but low productivity. A brief description of the most important forest types of the range and adjacent islands is given below.

Well-drained Soils

1. Pine and birch on granitic rock outcrops. The northern and eastern slopes of granitic rock outcrops or "sheep-backs" are usually bare, whereas the western and southern slopes covered with Scotch pine stands. The roots of Scotch pine on such sites show an amazing ability to penetrate small cracks and gain a foothold on practically barren surfaces. Curiously, the growth of pine on these locations is considerably better than on the coarse sandy soils of the region. With increasing age the pine suffers from windfall. However, even after the stems are blown down they continue to grow, with the branches forming new upright stems. The ground cover consists of lichens and heath plants, and the remains of these together with the pine needles form a peat-like layer which rests directly upon unweathered granite and can be easily removed in large sheets. In the understory are found Juniperus communis and Betula pubescens (var. tortuosa). On the exposed tops of outcrops Betula tortuosa takes the place of the Scotch pine. In such localities the ground cover is characterized by a number of arctic plants. This type is especially common along the shore of the White Sea.

2. Birch on skeletal soils. The soils of this type are confined to islands and extreme northern part of the region. They consist of boulders of different sizes, largely of granitic origin. Severe climatic conditions of these localities ordinarily do not allow the growth of either pine or spruce, and birch (B. tortuosa) is the only occupant of these sites. The stands are dwarfed in form and do not reach more than 3 or 4 feet in height. Nephoma arcticum is the most important species among the lichens, and Vaccinium myrtillus the most important of the woody plants which form the sparse ground cover.

3. Pine on podzolic soils. The sandy and sandy loam soils of outwash and pitted outwash in the interior of the peninsula are occupied predominantly by the stands of Scotch pine. The spruce is commonly associated with pine on these localities, but remains as a suppressed and dwarfed member of the understory. The productivity of pine stands in general is low, but it varies somewhat, depending on texture of soil and degree of podzolization. The differentiation of pine stands into a number of distinctly pronounced types takes place only in the southern portion of the region. These latter types belong rather to the temperate zone, and their description is given in the proper outline. The ground cover is characterized by the presence of lichens, mosses, Ledum palustre, Empetrum nigrum, Calluna vulgaris, Arcostaphylos uva-

ursi, Vaccinium ulliginosum, V. myrtillus, V. vitis idaea, Linnaea borealis, and Andromeda polyfolia.

4. Larch on sandy podzols. This soil-forest type occurs only on exposed sites, in most northern "sub-alpine" areas, beyond the region of natural distribution of Scotch pine. The soil is strongly leached and cemented and supports larch stands of inferior quality, with an understory of spruce and birch. With age the larch suffers greatly from heart rot and loses its top foliage. The ground cover vegetation is closely related to that of pine stands occurring on podzolic sandy soils.

5. Mixed coniferous-hardwood stands on slightly podzolized loams. The soils of this type are largely derived from limestone, gypsum, or calcareous shales. The podzolic horizon is only slightly pronounced or may be entirely absent. The leaf litter does not accumulate in layers of any great thickness. This type of soil may be regarded as the most northerly variety of the mull type. The stands are composed of larch, spruce, pine, aspen, and birch, with either spruce or larch predominating. In some instances these soils support a mixture of all the tree species occurring in the north. These are the most productive stands of the entire region, but unfortunately they have only limited distribution, being confined to a certain type of soil and to narrow areas along the rivers.

The ground cover vegetation includes practically no lichens or mosses, except some of Hylocomium species. Among the rather rich ground cover association the following species are outstanding: Rubus saxatilis, Lycopodium annotinum, Geranium silvaticum, Vicia silvatica, Orobus vernus, Oxalis acetosella, Maianthemum bifolium, Pyrola secunda, Equisetum silvaticum, Trientalis europea, Phegopteris dryopteris, Carex digitata, Luzula pilosa, Calamagrostis epigeios, Deschampsia flexuosa, Epilobium and Solidago. The shrub story is made up of Salix caprea, Sorbus aucuparia, Juniperus communis, Rosa acicularis, Rubus idaeus, and Daphne mesereum.

Periodically Wet Alluvial Soils

1. Mixed stands of flood plains. Soils of the lower terraces, subject to overflow, are usually of sandy loam texture and have a considerable percentage of calcareous particles. In the southern part of the region and along larger rivers such lands are usually cleared and utilized as meadows. The virgin forest stands are composed of spruce, pine, larch, birch, aspen, white alder, and cherry. Spruce commonly is the predominant species. Pine is confined to the drier, sandier islands. The understory is formed by several species of shrubs and shrub-like trees, particularly alder, willows, gooseberries, honeysuckles, and spiraea. The ground cover is characterized by numerous grasses. Stands of this type are of low density and occur in patches as park-like formations. The main reason for the local distribution of forest stands is the destructive action of spring floods. Toward the north this type of forest degenerates into dwarfed stands of birch and willows.

2. Willow stands on stream-bottom deposits. The narrow stream bottoms give rise to half-mineral and half-organic muck-like soils

which remain wet during most of the growing season. The stands on these sites are composed of different species of willow. The ground cover consists of grasses.

Poorly Drained Soils

1. Pine on swamp-border sands or sandy gley podzols. These soils are of a coarse sandy texture, strongly leached, and with a close gley horizon. The stands are composed of pine, of less than average productivity, with spruce and birch in the understory. The ground cover vegetation includes Sphagnum and other mosses as well as lichens. Rubus hammaemorus is the most typical species of the herbaceous plants. The shrub layer is formed exclusively by swamp birch.

2. Spruce on loam gley podzols. These soils occupy extensive flats deficient in drainage. The profile is characterized by a thick layer of raw humus, a wide leached horizon of loam texture, and a mottled gley layer which grades into the permanently frozen substratum; the upper layers of soil become free of ice only in June. The sparse forest stands are composed of spruce, usually associated with birch of sprout origin. Both species are of poor form and very slow growth. Ground cover vegetation includes Polytrichum, Sphagnum, and other mosses, ferns, horsetail, sedges, Labrador tea, and blueberries. In the understory are found willows, mountain ash, juniper, and swamp birch.

3. Pine on peat soils. The peat consists of the remains of Sphagnum mosses, sedges, and heath plants. The stands are composed of struggling Scotch pine. The ground association includes species of Sphagnum, Ledum palustre, Calluna vulgaris, Empetrum nigrum, Vaccinium uliginosum, V. vitis idaea, Andromeda polyfolia, Cassandra calyculata, Oxicoccos palustris, Rubus hammaemorus, Scirpus and Carex spp. In the understory occurs Betula nana.

The subarctic forests preserve their characteristic features in the entire circum-polar region, including Siberia, Alaska, and northern Canada. These forests may not have a far-reaching silvicultural or economic importance. Yet, the simplicity of the physiographic conditions and the scarcity of species composing forest cover place them in the key position of all the studies of soil-forest relationship.

A highly instructive picture of the relation between the composition of forest associations and the rate of forest grow th is presented in works of Cajander and his associates embracing the whole of Finland. The results of exhaustive investigations of Finnish foresters have been summarized in a series of excellent papers in English. An attempt to remold these publications in an abbreviated form would hardly be justifiable (Lit. cit).

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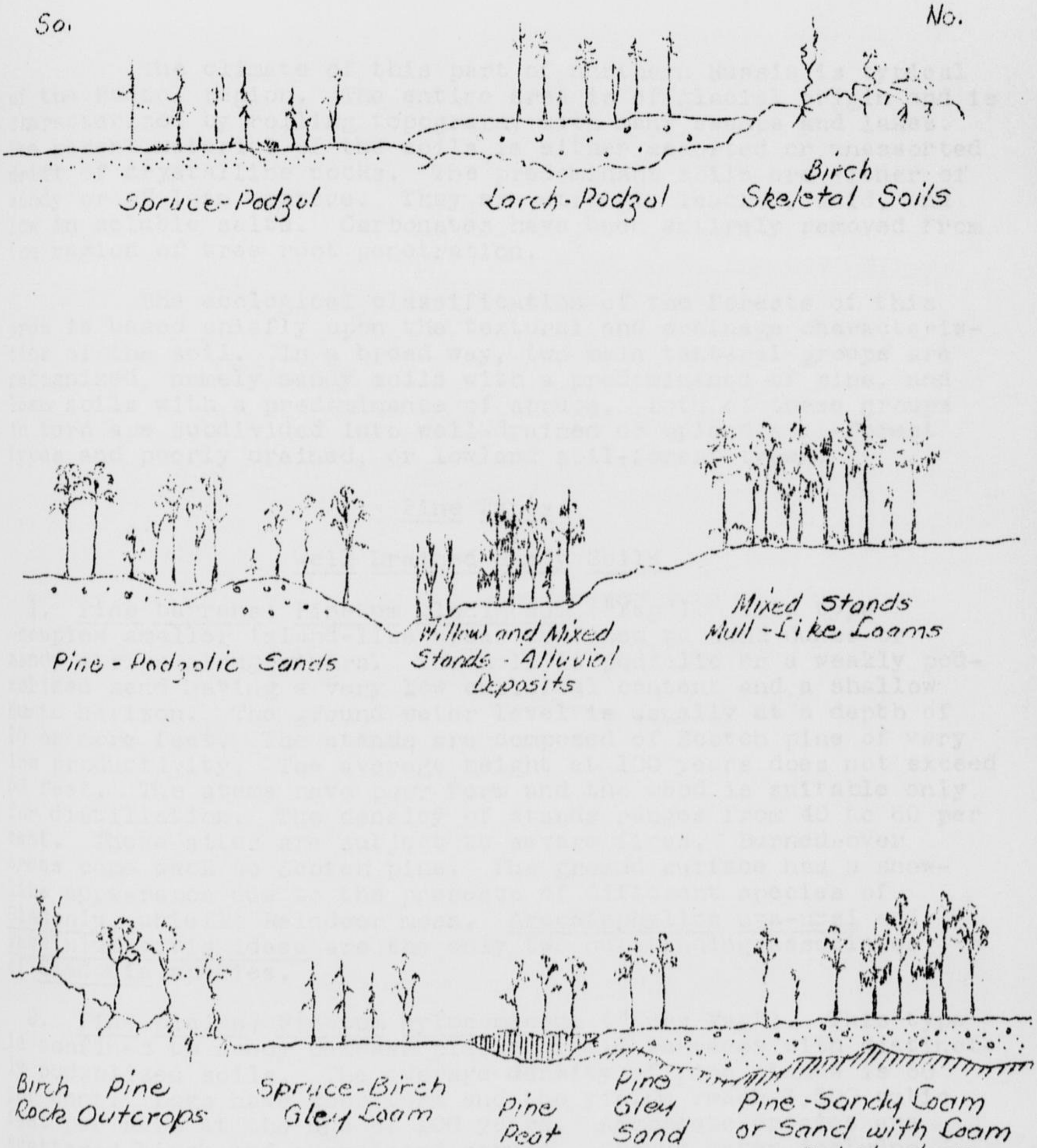
Figure 45

Soil-Forest Types of Finno-Scandian Shield and Adjacent Islands



CHAPTER XIV

FORESTS OF THE PODZOL REGION

A. Upper Volga Basin, Russia

"The stately aspens are whispering high overhead; the long pendent branches of the birch are barely stirring; a mighty oak stands, like a warrior, by the side of a handsome linden."
I. S. Turgenieff, Forest and Steppe in "Memoirs of a Sportsman".

The climate of this part of northern Russia is typical of the Podzol region. The entire area is of glacial origin and is characterized by rolling topography with many swamps and lakes. The parent material of the soils is either assorted or unassorted drift of crystalline rocks. The predominant soils are either of sandy or of loam texture. They are strongly leached, acid, and low in soluble salts. Carbonates have been entirely removed from the region of tree root penetration.

The ecological classification of the forests of this area is based chiefly upon the textural and drainage characteristics of the soil. In a broad way, two main textural groups are recognized, namely sandy soils with a predominance of pine, and loam soils with a predominance of spruce. Both of these groups in turn are subdivided into well-drained or upland soil-forest types and poorly drained, or lowland soil-forest types.

Pine Types

Well Drained Sandy Soils

1. Pine barrens; Pinetum cladinosum ("Yag"). This type occupies smaller island-like areas confined to sand dunes or sandy strips along rivers. The soil is podzolic or a weakly podzolized sand having a very low colloidal content and a shallow humic horizon. The ground water level is usually at a depth of 10 or more feet. The stands are composed of Scotch pine of very low productivity. The average height at 100 years does not exceed 50 feet. The stems have poor form and the wood is suitable only for distillation. The density of stands ranges from 40 to 60 per cent. These sites are subject to severe fires. Burned-over areas come back to Scotch pine. The ground surface has a snow-like appearance due to the presence of different species of Cladonia, chiefly Reindeer moss. Arcostaphyllos uva-ursi and Vaccinium vitis idaea are the only two outstanding associates of Cladonia species.

2. Pine plains; Pinetum hylocomiosum ("Moss Yag"). This type is confined to sandy outwash plains of old terraces with distinctly podzolized soils. The average density of pine stands is 60 per cent. Logs have good form and the yields reach 3,500 cubic feet per acre at the age of 100 years. Associate species are scattered birch and suppressed spruce. Ground cover includes predominantly Hylocomium, other mosses, and species of Vaccinium.

3. Larch terraces; Pinetum laricetum ("Nia Yag"). This association occurs on fairly fertile, podzolic sandy loams of the young terraces. The forest is composed of larch with some pine, white birch and spruce. The yields of the stands of higher density (80 per cent) reach 4,000 cubic feet at 100 years. The shrub layer consists of mountain ash, honeysuckle, and juniper. The ground cover vegetation includes chiefly species of Vaccinium and mosses.

4. Pine-spruce on heavier sandy soils; Pinetum oxalidosum ("Soobor"). This type occupies the slopes of sandy loam ridges or transitional areas on which outwash sands cover heavy morainic deposits as a more or less thin blanket. The stands are composed of pine and spruce. The latter seldom exceeds 30 per cent of the total stand and largely remains in the understory. The pine is of excellent form and high rate of growth for this region, reaching a height of 80 feet at 100 years. The ground cover is composed of the vegetation of both pine and spruce sites. The representatives of the pine flora include Hypnum, Hylocomium, Polytrichum, and Vaccinium myrtillus, whereas the spruce flora is represented by Oxalis acetosella, Linnaea borealis, Trientalis europea, Maianthemum bifolium, Paris quadrifolia, and Orobus vernus.

Poorly Drained Sandy Soils

1. Wet pine plains; Pinetum ledetum ("Kercha Yag"). This type is found between closely adjacent rivers on flat plateaus with a high water level. The soils are podzolic with a well-developed humic horizon and high gley layer. The stands consist of almost pure, slow growing pine, and are striking in appearance because of the beard-like lichens hanging from the branches. The maximum height of mature trees is only 50 feet. The occurrence of sporadic white birch and suppressed spruce offers the only variation in the depressing monotony of this type. The ground cover is composed of mosses, largely Sphagnum, and abundant Ledum palustre.

2. Pine bogs; Pinetum sphagnetum ("Nur"). The moss peat formed predominantly from species of Sphagnum is extremely acid and reaches a depth of 15 feet or more. The pine stands on this formation have a very low productivity reaching a height of only 30 feet in 100 years. The density seldom exceeds 20 per cent. Swamp birch is the only associate. Ground cover is composed of Sphagnum, Andromeda polifolia, Cassandra calyculata, Empetrum nigrum, Rubus chamaemorus, Ledum palustre, Oxycoccus palustris, Eriophorum vaginatum, Luzula pilosa, Carex caespitosa, Menyanthes trifoliata, and Equisetum limosum.

Spruce Types

Well Drained Loam Soils

1. Light loams of morainic hills and ridges; Picetum vaccinIosum ("Kholm"). On such sites, the well drained, light loam soils of light brown or chocolate color are often underlain by iron-bearing or glauconitic heavy substrata. From 70 to 90 per cent of the stand is made up of spruce; the remainder being white

birchwith sporadic pine and aspen. The spruce reaches 85 feet in height and 15 inches in diameter at the age of 150 to 200 years. The wood is of excellent quality and is not subject to heart-rot diseases. Juniper and wild rose occur in the understory. Ground cover vegetation is sparse and includes Hypnum, Vaccinium spp., Oxalis, Maianthemum, Trientalis, Polypodium dryopteris, Aspidium Filix mas, with some Lycopodium, Linneae borealis, and Rubus saxatilis.

2. Podzolic loams of plateaus; Picetum polytrichosum ("Rovniad") The soils of this type are of light loam texture, rather shallow, strongly podzolized and acid. They are underlain by a heavy clay loam subsoil of morainic origin. At a rather shallow depth the subsoil is water-logged and exhibits the mottling and poor aeration typical of a gley horizon. These plateaus occupy large areas forming a transition between well-drained morainic soils and swamps.

The forest stands are composed of spruce with the sporadic occurrence of single white birches. The stems are short with a low form factor and are covered with lichens. The root systems are superficial, the roots being often above the ground as a result of frost and wind. The usual density of the stands is 60 per cent. The height and diameter are 55 feet and 8 inches, respectively, at 150 years. Half of the stand is usually infested with heart-rot diseases. After fire this type becomes waste land and it is commonly 10 or 15 years before a few clumps or brushy birch, aspen, willow and mountain ash begin to appear.

The ground cover is composed of Polytrichum, Hypnum, and Sphagnum among which are scattered Equisetum silvaticum and Vaccinium spp.

Poorly Drained Loam Soils

1. Alluvial soils of stream valleys; Filipendulatum ("Log"). This type occurs in narrow strips along the shallow rivers and creeks. The muck soils of these areas are usually saturated with water; nevertheless, the steep gradient of the watercourse is responsible for rapid exchange of water and consequent high oxidation. Hence, the stands of these localities do not show the stagnation of growth common on poorly aerated swamp soils. The high content of nutrients, accumulated during periods of inundation, materially contributes to the satisfactory growth of the trees of these sites.

The forest cover is composed chiefly of the spruce with some birch. These stands provide a considerable amount of saw-timber with wide annual rings but rather high specific weight. The density of the stands seldom exceeds 60 per cent.

The ground cover includes Aconitum septentrionalis, Filipendula ulmaria, Circium oleraceum, Angelica silvestris, Aegopodium podagraria, Urtica dioica, Geranium Robertianum, Thalictrum aquilegifolium, Veratrum nigrum, Festuca silvatica, Comarum palustre, and Equisetum silvaticum. There is a luxuriant layer of creeping fir, honeysuckle, black currant, juniper and numerous species of willow.

Because of the good growth of grass on these sites, the forest is often cleared to convert the land into meadow.

2. Spruce flat; Picetum-Caricetum ("Sogra"). This type occurs on level or basin-like low areas covered with sedge hummocks. The ground water is close to the surface and forms pools between the hummocks. The soils are strongly podzolized loams covered with a thick layer of raw humus, which grades in places into shallow peat.

The forest cover is composed of spruce with some birch and alder. Growth is generally poor, and the areas particularly deficient in drainage are considered to be entirely unproductive, since they support stands of only 20 to 30 per cent density. Sedges and mosses are the predominant members of the ground cover.

Most of the types above described may be found on the attached drawings (after A. A. von Kruedener), presenting schematically the relation of soils and forest in entire northern Russia. The detailed description of Kruedener's classification constitutes an extensive volume and cannot be outlined here because of limited space. Nevertheless, many essential features of correlation can be readily understood from his excellent diagrams.

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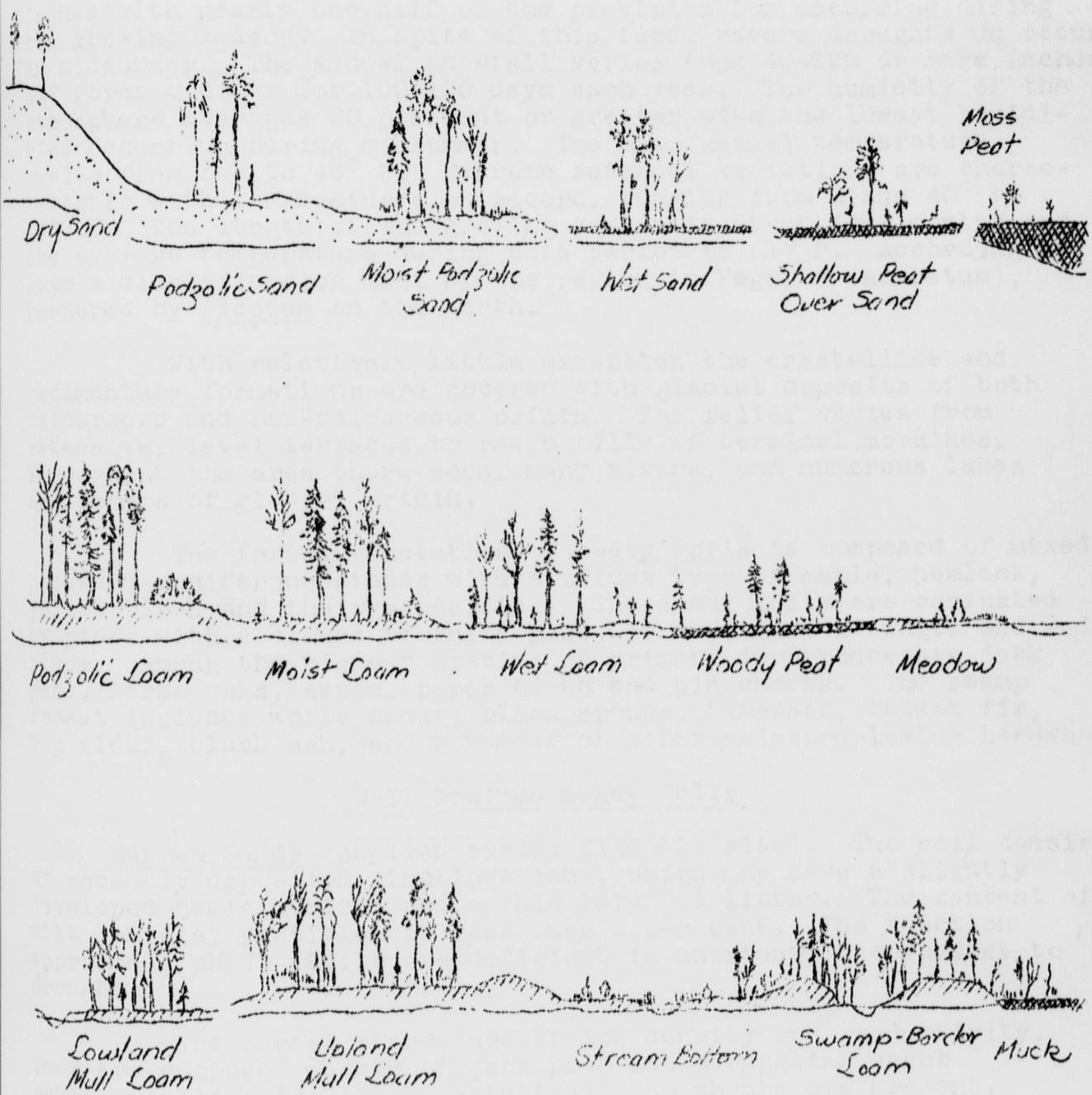
Figure 46

Relation of Soils and Forest in Podzol Region of Russia

(After A. v. Kruedener)



B. Great Lakes Upland, United States

On the shores of Gitche Gumee,
Of the shining Big-Sea-Water...
From the great lakes of the Northland
From the mountains, moors, and fenlands
Where the heron, the Shuh-shuh-gah,
Feeds among the reeds and rushes.
The Song of Hiawatha.

The Podzol belt of this region includes northern Minnesota, Wisconsin and Michigan, and comprises an area of approximately 50,000 square miles. The average annual precipitation is about 30 inches with nearly one-half of the precipitation occurring during the growing season. In spite of this fact, severe droughts do occur in midsummer. The annual snowfall varies from 40-120 or more inches and forms a cover for 100-120 days each year. The humidity of the atmosphere averages 60 per cent or greater with the lowest humidities occurring during midsummer. The mean annual temperature varies from 35° to 46° F. Extreme seasonal variations are characteristic with temperatures on record, ranging from minus 40° to 100° F. The length of the growing season is about four months and the average temperature during this period is 61° F. According to Mayr's classification most of the region is Fagetum (Aceretum), bordered by Picetum on the north.

With relatively little exception the crystalline and sedimentary formations are covered with glacial deposits of both calcareous and non-calcareous origin. The relief varies from extensive, level terraces to rough hills of terminal moraines. Throughout the area there occur many rivers, and numerous lakes and swamps of glacial origin.

The forest vegetation of heavy soils is composed of mixed hardwood-coniferous stands with a climax type of maple, hemlock, yellow birch and their associates. The sandy soils are cominated by pines with a climax of white pine, or a mixture of white and red pines. Among the pioneer species of primary importance are jack pine, scrub oaks, aspen, paper birch and pin cherry. The swamp forest includes white cedar, black spruce, tamarack, balsam fir, tag alder, black ash, and a number of other moisture-loving hardwoods

Well Drained Sandy Soils

1. Barren Sands (Aeolian sands; Cladonia site). The soil consists of recently deposited windblown sand, which may have a slightly developed humic horizon and a thin layer of litter. The content of silt and clay particles is less than 5 per cent. The reaction approaches pH 7. Soils are deficient in nutrients and subject to drought.

The forest stands are of low density and productivity. They are composed mainly of jack pine and struggling scrub oaks (Q. ellipsoidalis, Q. velutina). No shrubs are present. The ground cover consists of sporadia Cladonia species and xerophytic mosses and grasses. The possibilities for natural reproduction are negligible. Artificial reforestation on this type is not profitable, but may be necessary to check wind erosion.

The above described type should not be confused with old sand dunes which have been invaded by forests for a long period of time and have developed a normal profile. The Ortstein dunes, found along the border of Lake Michigan, are a striking example of this latter type.

2. Outwash Sands (Mull sands; Arctostaphylos-Ceanothus site). This type is confined to level or pitted outwash plains of recent glaciation. The soil is characterized by a thin layer of litter and a well developed humic horizon extending, in places, as deep as 8 inches from the surface. The layer is underlain by yellowish-brown sand or gravelly sand, derived largely from granitic rocks. The percentage of silt and clay varies from 7 to 12 per cent and the reaction from pH 5 to 6.5. The base exchange capacity of the upper soil layer approaches 5 m.e. per 100 grams. The soil has a fairly high content of all the essential nutrients. Ground water occurs at a depth inaccessible to trees.

The virgin forest is composed of Norway pine, jack pine and some white pine. Both jack pine and Norway pine attain a fairly high productivity. Following fire or logging, the area is invaded by jack pine and scrub oaks. Neither birch nor aspen occurs on these soils. The shrub layer consists chiefly of dwarfed hazel, Corylus americana. The ground cover presents an example of a very stable floristic associa tion, including New Jersey tea, Ceanothus ovatus, bearberry, Arcostaphylos uva-ursi, low blueberry, Vaccinium pennsylvanicim, sporadic ground pine, Lycopodium complanatum, and xcrophytic grasses. Along the edges of stands and in openings some sweet fern, Myrica asplenifolia may be found.

This type covers extensive areas and is of great importance in commercial reforestation. The level topography and freedom from stones allow forest planting at a minimum cost.

3. Podzolic Sands (Leached sands; Gaultheria-Maianthemum Site). These sands are characterized by the presence of a light grey leached layer and slightly compacted, but not cemented, brown accumulative horizon. Due to the accumulation of colloids in the B horizon, the soil has a fairly high water holding capacity. The reaction of the soil is seldom higher than pH 5.5.

The virgin stands are composed of white and Norway pine of high productivity. Aspen and paper birch dominate the second growth stands. Hazel, raspberry, blackberry, and a few other shrubs occur in considerable quantity. Ground cover includes wintergreen, Gaultheria procumbens, dwarf Solomon's seal, Mainathemum canadense, sweet fern, Myrica asplenifolia, shin leaf, Pyrola americans, trailing arbutus, Epigaea repens and bracken fern, Pteridium latiusculum.

Leached sands are, on the whole, the most productive type of sandy soil, They are adapted for planting of both Norway and white pine, the latter species being best suited to the moister, more podzolized localities, supporting some pioneer species.

4. Sandy Podzols (Ferruginous, or hardpan sands; Vaccinium-Cornus Site). The profile consists of a thick layer of raw humus, or mor, underlain by a strongly leached, almost white podzol horizon and a reddish-brown, compacted and often cemented accumulative layer. The humic A_1 horizon is entirely absent. Because of the translocation of mineral, as well as organic colloids, the texture of the surface layer is of minor importance. The reaction of soil ranges from pH 4.0 to 5.5.

The virgin forest consists chiefly of white pine with some balsam fir. The second growth includes aspen, birch, pin cherry and occasionally red maple. Among the shrubs and herbaceous vegetation the following species are common: dogwood, bush honeysuckle, fly honeysuckle, high bush cranberry, hazel, cherries, blackberry, blueberry, V. canadensis, low blueberry, V. pennsylvanicum, dwarf Solomon's seal, Maianthemum canadense, bunchberry, Cornus canadensis, wintergreen, Gaultheria procumbens, trailing arbutus, Epigaea repens, partridge berry, Mitchella repens, and in places, twin flower, Linnaea borealis, dew berry, Rubus hispidus, club mosses, Lycopodium spp. and mosses, mainly Polytrichum and Hypnum species.

White pine is the only species of commercial value which is suitable for planting on these soils. However, even planting of this species on cut-over lands is difficult because the raw humus layer is burned or decomposed and the properties of the mineral soil are unfavorable to tree growth. For these reasons it is usually advisable to limit reforestation to the encouragement of natural reproduction by means of carefully conducted thinnings and release cuttings. In carrying on silvicultural cuttings, a considerable percentage of the area should be left to deciduous trees, particularly aspen and soft maple. In case planting is desirable for some particular reason, plowing should not be attempted as it will expose the toxic hardpan layer.

5. Wet Sands (Swamp-border sands; Rubus Site). Wet sandy soils are confined to swamp borders or areas underlain by impervious substrata. The morphology of these soils varies considerably, depending upon their location, and proximity of the water table. However, the outstanding characteristic of this type is the water logged horizon of gley nature, occurring at a depth of 4 feet or less.

The forest growth consists of jack, Norway and white pines, aspen, birch, red maple and oaks, occurring usually in mixed stands. Balsam fir is a rather common associate. On some sites hemlock, tag alder and willows are found. The ground cover is characterized by the presence of mosses, bunchberry, Cornus canadensis, dwarf raspberry, Rubus pubescens, dew berry, Rubus hispidus, species of Ribes, and many other shrubs.

The productivity of stands fluctuates from fair to low, depending chiefly upon the depth of sufficiently aerated surface layer and content of available nutrients. Artificial reforestation on this soil is often difficult because of the competition of weed species and the periodic wetness of the soil. Fortunately, however, these soils provide fair conditions for the establishment of natural reproduction.

Heavy Soils

1. Mull Loams (Weakly podzolized loams: Adiantum-Osmorhiza-Thalictrum Site). These soils are formed on loess-like silt loam outwash or on heavy unassorted morainic deposits. The profile consists of a thin layer of litter, a deep humic horizon of mull type and a brownish or grayish brown parent material. The content of silt and clay exceeds 35 per cent. The reaction of the soil fluctuates between pH 5.0 and 7.0. Podzolization occurs only in a very mild form and the plant nutrient content is high. The roots are distributed throughout the soil profile.

The virgin forest is composed of sugar maple, basswood, white ash, red and white oaks, elm, beech, other hardwoods and white pine in some places. Blue beech, hackberry, ironwood, honeysuckle, dogwood, Juneberry, pin cherry, chokecherry, highbush cranberry and leatherwood make up the understory. Soil conditions are very favorable for the natural reproduction of hardwoods, especially sugar maple. The ground cover is characterized by a rich association of mesophytic plants, mainly maidenhair fern, Adiantum pedatum, sweet Cicely, Osmorhiza claytoni, meadow rue, Thalictrum dioicum, wild sarsaparilla, Aralia nudicaulis, waterleaf, Hydrophyllum, and green briar, Smilax rotundifolia.

Because of high productivity, mull soils are extensively used for agriculture, and forestry is confined to the rough or stony areas. The silviculture is largely limited to selective cuttings, conducted in a very careful manner, so as to prevent excessively rapid decomposition of organic remains and the invasion of light-demanding sprouts. The older forest of this type may be gradually converted into mixed hardwood-spruce or hardwood white pine stands, by means of thinnings and underplantings.

2. Leached Loams (Podzolic loams; Liliaceae Site). The soils of this type occupy extensive areas of heavy outwash and morainic deposits. The profile consists of a layer of litter, about 2 inches thick, a thin humic layer, and a grayish leached loam which grades into a coffee brown accumulative horizon of somewhat heavier texture. This is underlain either by unassorted glacial till or stratified sand and gravel. The soil is a transition between a mull loam and a true podzol.

The forest cover consists of sugar maple, basswood, elm, yellow birch and hemlock. Pioneer stands are composed of aspen, paper birch and pin cherry with a reproduction of sugar maple, basswood and elms. The shrubs are fairly abundant. The ground cover is characterized by several members of the lily family, such as bellwort, Uvularia grandiflora, Solomon's seal, Polygonatum pubescens, false Solomon's seal, Smilacina racemosa, twisted stalk, Streptopus longipes, birthroot, Trillium grandiflorum, and dwarf Solomon's seal, Maianthemum canadense.

These soils are well suited for the planting of spruce. The planting of white pine may not be advisable because of the presence of Ribes species. Careful thinnings are required to free the plantation from the suppression of vigorous hardwood sprouts. In thinnings, better hardwood species should be left so that a mixed hardwood-coniferous stand will result.

3. Loam Podzol (Rusty loams, or hardpan loams; Clintonia-Lycopodium Site). This type of soil is formed chiefly on unassorted morainic deposits. A raw humus layer about 4 inches thick is sharply delimited by a leached layer, grading into a rusty coffee brown compacted or firmly cemented accumulative horizon. The reaction of the soil is strongly acid. The available nutrients are concentrated in the surface organic layer. The bulk of the roots are found in the upper six inches.

The virgin forest is composed of hemlock, yellow birch, and some balsam fir. Sugar maple, red maple and other hardwood species occur incidentally. Old stands have no understory of shrubs. Burned or cut-over areas are occupied by aspen, white birch, and pin cherry. Ground cover forms a typical association of saprophytic or "raw humus" plants, namely Clintonia borealis, dwarf Solomon's seal, Maianthemum canadense, twin flower, Linnaea borealis, numerous species of club moss, Lycopodium, ground hemlock or yew, Taxus canadensis, and in places wood sorrel, Oxalis montana.

These soils are unsuitable for agriculture because of their high acidity and low content of available nutrients. Artificial reforestation of this type involves difficulties. Hemlock, which is adapted to this soil, is an extremely tolerant and slow growing tree. The other conifers, including spruce, are not well suited to this soil and their planting may lead to the further development of the hardpan layer. Yellow birch is the only valuable deciduous tree which may be considered for artificial reforestation; however, little information is available on the planting technique of this species. For this reason selective cutting must be practiced wherever possible. The natural reproduction of hardwood species, particularly of sugar maple, should be protected in cuttings as hardwood litter improves the quality of humus, decreases the acidity of the soil, and furnishes available mineral nutrients. The stands of loam podzols require a fairly heavy selective cutting, in order to obtain a more rapid decomposition of the raw humus.

4. Wet Loams (Mottled loams; Fern Site and Moss Site). Poorly drained soils of heavy texture include a number of morphological varieties, classified on the basis of the depth at which the well aerated surface soil grades into a wet, sticky and mottled gley horizon. The crumb-mull loams, with a deep mottled subsoil, and wet loams, with a gley layer near the surface, are the two extremes of this broad soil group.

In spite of the morphological difference, the forest cover of these soils maintains a rather uniform composition, including largely water-loving hardwoods, such as American elm, rock elm, red maple, black ash, aspen, birch, mountain ash, and conifers, chiefly white spruce, balsam fir, and less commonly, hemlock and white pine. Sugar maple often makes up the greatest portion of the stand but it deteriorates on these sites with advanced age.

The shrubs are numerous and their growth is vigorous. Abundance of currant and gooseberry is of a special importance. Ground cover is characterized by the presence of hydrophytic species, particularly bedstraw, Gallium spp., horsetail Equisetum silvaticum, Jack-in-the-pulpit, Arisaema triphyllum, touch-me-not, Impatiens spp., numerous ferns, Onoclea struthiopteris, O. sensibiles, Aspidium spinulosum, Asplenium filix fermina, Asp. filix mass, Osmunda cinnamomea, O. regalis, Polystichum archostycohoides, and mosses of Polytrichum, Mnium, Hylocomium, Leucobryum, and sometimes Sphagnum genera.

The productivity of forest stands varies with the species and degree of soil aeration. As a general rule, conifers better endure the stagnation and produce higher yields than hardwoods. Soils of this type are subject to early and late frosts, which greatly interfere with the success of planting. Also, the competition of shrubs and ground vegetation presents a serious obstacle to artificial reforestation. In many instances, therefore, the silvicultural practices are limited to gradual elimination of inferior trees by improvement cuttings and underplanting of desirable species, particularly spruce. On wetter sites mound planting is necessary.

Calcareous Soils

1. Immature Rendzinas. At some locations in the humid belt, along the shores of Lake Michigan, recent glaciation has exposed strata of limestone. The climatic conditions of these localities caused only slight weathering of calcareous parent material and led to the development of peat-like raw humus, consisting chiefly of wood remains and having a reaction from pH 6.7 to pH 8.0. The ordinary depth of organic layer on the upland does not exceed 5 inches, but reaches a depth of a foot in depressions, where it may be compared with true woody peat.

The vegetation of these sites includes white cedar, balsam fir, aspen, paper birch and in places even such pronounced acidophilous species as hemlock. The ground cover associations consist largely of saprophytic, raw humus plants. The presence of juniper in the shrub layer is very characteristic.

2. Lacustrine clays. Lacustrine clays occur as bottom deposits of receded lakes and are particularly common in the proximity of the Great Lakes.

Soils of this origin have a number of morphological varieties, differing in type of humus, content of basic material in the upper horizons, degree of leaching and structural features, The strongly podzolized varieties are characterized by the absence of structural aggregates, a high water-holding capacity, periodic excessive saturation and poor aeration of soil. The weakly podzolized varieties, on the other hand, are rich in calcareous material and have a peculiar prismatic structure, which provides good aeration throughout the profile.

The forest cover of structureless clays is similar to that of loam podzols or gley podzols, consisting chiefly of white spruce, balsam fir, and acid tolerant deciduous trees. Saprophytic and hydrophytic species of strongly leached and mottled heavy soils are predominant in the ground cover.

The structured clays support an association which could hardly be expected on the soil of this textural class, namely, stands with a predominance of Norway and jack pine, and ground cover common on soils of sandy or sandy loam texture. Among the herbaceous plants, the presence of strawberry and clover is of particular significance.

As may be expected, between the two described extremes there are a number of transitional forms of lacustrine clays supporting mixed hardwood-coniferous stands, in which white pine is often prominent.

The planting of clay soils of all morphological varieties presents a difficult problem because of frost heaving, and difficulty of eliminating air spaces in the planting hole.

Organic Soils

1. Muck (Urtica-Gallium Site). Muck soils are formed partly by the decomposition of plants in situ, and partly by the deposition of both mineral and organic material during inundation. The forest cover of muck soils is composed of water-loving hardwoods and conifers, tag alder, willow, dogwood, elder, other shrubs, and herbaceous vegetation of nettles, *Urtica dioica*, wood nettle, *Laportea canadensis*, bed straw *Gallium spp.*, tall meadow rue, *Thalictrum dasicarpum*, grasses and sedges. The stands have little merchantable value, nevertheless the protection of forest cover on these soils is essential from the conservation standpoint. The stands of this site furnish cover for game and aid in stream protection.

2. Woody Peat (Oxalis-Coptis Site). Woody peat is formed under conditions of excessive moisture where there is a permanent slow drainage. The upper layer includes partly decomposed remains of wood and minor vegetation. The topsoil is strongly acid, the mineral substratum often alkaline. Forest cover contains chiefly white cedar, some balsam fir, spruce, tamarack, black ash, red maple and swamp maple; along the border of this type is found tag alder. The ground cover includes woodsorrel, *Oxalis montana*, goldthread, *Coptis trifolia*, dwarf raspberry, *Rubus pubescens*, dwarf Solomon's seal, *Maianthemum canadense*, bunchberry, *Cornus canadensis*, Clintonia, *C. borealis*, twinflower, *Linnaea borealis*, ferns, mosses and, sometimes, yew, *Taxus canadensis*. The commercial value of the forest cover is in direct proportion to the amount of conifers, particularly to white spruce, balsam fir, and white cedar.

3. Moss Peat (Ledum-Chamaedaphne Site). Moss peat is formed under conditions of excessive moisture and complete stagnation of water. The upper layer includes slightly decomposed mosses of Sphagnum and Polytrichum genera. The layer of mosses in some instances is underlain by sedges and other remains of aquatic vegetation. The peat is extremely acid, the reaction of the top soil being as low as pH 3.5. The only species of forest trees occurring on this site are black spruce and tamarack. They form either pure or mixed stands. Ground cover consists of *Sphagnum* and *Polytrichum* species, leather leaf, *Chamaedaphne calyculata*,

Labrador tea, Ledum groenlandicum, pale laurel, Kalmia polifolia, bog rosemary, Andromeda glaucophylla, twin flower, Linnaea borealis, creeping snowberry, Chiogenes hispidula, cranberry, Vaccinium macrocarpon, pitcher plant, Sarracenia purpurea, blueberry and other plants common on dry sandy soils, such as sweet fern, wintergreen and reindeer moss. The silviculture is limited to the cutting of pulp and Christmas trees wherever these are available. In logging some healthy older trees are usually left all over the area in order to secure natural reproduction. Attempts to increase the growth of black spruce and tamarack by means of artificial drainage have not been successful.

4. Sedge Peat (Carex Site). This type is confined to marshes and quagmires. The peat consists of remains of aquatic vegetation, sedges, rushes, and other marsh plants.

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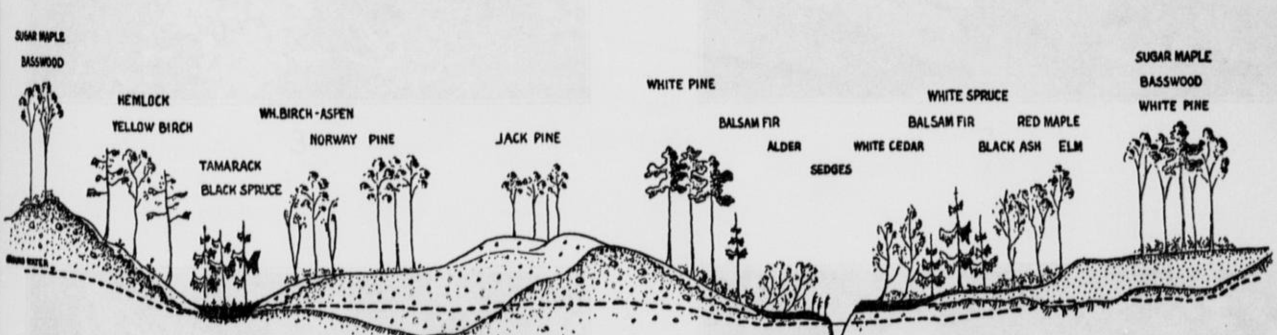

Figure 47

Distribution of forest species in relation to the water table, texture of the soil and podzolization in the glaciated area of the podzol region of the Lake States.

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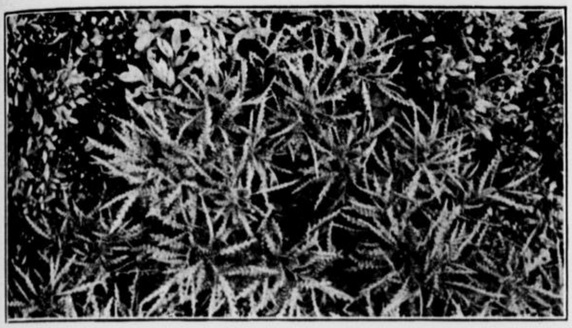

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Characteristic ground-cover vegetation of Wisconsin forest soils:

(1) Loose, outwash sand; (2) Gravelly, moranic sand; (3) Light sandy loam; (4) Leached sandy loam; (5) Ferruginous sandy loam; (6) Swamp-border ferruginous sand; (7) Ferruginous loam; (8) Leached loam.

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Characteristic ground-cover vegetation of Wisconsin forest soils:

(9) Mull loam; (10) Mottled loam; (11) Muck; (12) Wet loam; (13) Coarse woody peat; (14) Fine woody peat; (15) Moss peat; (16) Sedge peat.

CHAPTER XV

PRAIRIE FOREST

Black Forest of Dnieper Watershed, Southern Russia

"It was ever the same boundless, waving, beautiful steppe. Only at intervals the summits of distant forests shone blue, stretching along the banks of the Dnieper." N. V. Gogol "Taras Bulba."

The Black Forest is of particular interest because it presents, with remarkable clearness, the picture of the struggle between forest and prairie.

The climatic conditions of this region are characterized by the following data. Mean temperature of the coldest month (January) 18° F. Mean temperature of the hottest month (July) 71°F. Average annual precipitation 20 inches. Average relative humidity 75 per cent. Distribution of precipitation is very irregular.

The geological substratum is formed by granites and gneisses of the Pre-Cambrian age, for the most part, covered by deposits of the Tertiary and Post-Tertiary periods. The entire formation is capped by a deep layer of loess. Due to the processes of erosion, the surface geological formation presents a mottled appearance. On upland areas the depth of ground water ranges from 50 to 60 feet.

The genetic properties of the soils, as well as the distribution of forest growth, are closely related to the topographic features of the area. As a result of this, four distinct topo-ecological units are recognized, as follows: plateau prairie-forest type, gentle slope forest type, steep slope forest type, and cove forest type. (Fig. 50).

Plateau Prairie-Forest. The soil is a slightly degraded chernozem derived from loess. The sporadic forest stands extend into the prairie. They are composed chiefly of summer oak, Q. pedunculata, and have an understory of maple and basswood.

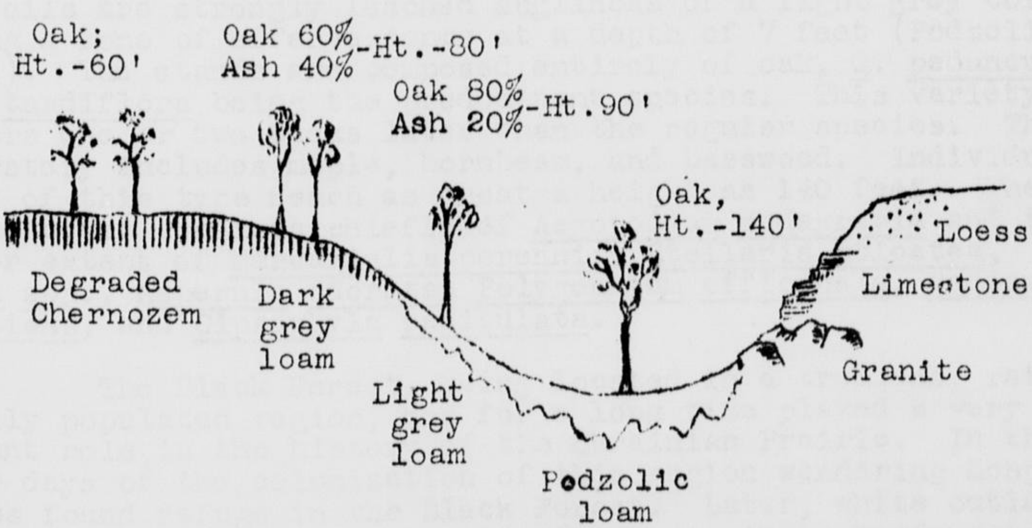

Figure 50

The productivity of these stands is extremely low; the dominant height of oak is approximately 60 feet. Ground cover is characterized by abundant Sisymbrium alliaria, and this association is classed as Quercetum sisymbrianum.

As distance from the prairie increases, degradation of the soil becomes more pronounced and the forest growth improves to such an extent that individual trees reach a height of 80 feet.

Gentle Slope Forest. The soil is a dark colored suglinok characterized by a dark brown color and nut-like structure (Dark grey forest soil). The parent loessial material is impoverished in carbonates to a depth of about 4 to 4½ feet. The principal forest stand is composed of oak and ash, with ash making up about 40 per cent of it. The understory includes chiefly basswood and some maple, hornbeam, and elm. The shrub story is formed by Acer campestris. The ground cover is composed of Stellaria holostea, Sisymbrium alliaria, and Carex spp. Floristically, this type is classed as Quercetum stellarianum.

Steep Slope Forest. The slopes of this type are subject to gulley erosion and are characterized by an intersected relief. The soils are light colored suglinoks having nut-like structure (Light grey forest soil). The zone of effervescence occurs at a depth of from 3½ to 5½ feet. Podzolization follows root channels and structural cracks to a considerable depth. The forest stands are composed chiefly of oak and ash. The latter, however, makes up not more than 20 per cent of the total stand. The understory includes hornbeam, maple, and basswood. The shrub layer consists of hazelnut. Individual oak trees in these stands reach a height of 93 feet. Ground cover consists predominantly of Carex pilosa and C. digitata with some Stellaria holostea, Asarum europeum, Viola spp., and Geum urbanum. This type is referred to as Quercetum caricianum.

Cove Forest. This type is confined to the nearly flat portion of the valley or cove bottoms. These localities receive considerable amounts of run-off water. Some of the water from melting snow accumulates locally in depressions and remains to saturate the soil through a greater part of the growing season. The soils are strongly leached suglinoks of a light grey color, having a zone of effervescence at a depth of 7 feet (Podzolic soils). The stands are composed entirely of oak, Q. pedunculata var. tardiflora being the predominant species. This variety flowers one or two weeks later than the regular species. The understory includes maple, hornbeam, and basswood. Individual trees of this type reach as great a height as 140 feet. The ground cover consists chiefly of Aegopodium podagraria and to lesser extent of Mercurialis perennis, Stellaria holostea, Viola spp., Asperula odorata, Polygonatum officinale, Gardamine impatiens, and Gipsophyla paniculata.

The Black Forest, being located in a treeless, rather heavily populated region, has for a long time played a very important role in the history of the Ukrainian Prairie. In the early days of the colonization of this region wandering Mongolian tribes found refuge in the Black Forest. Later, white outlaws from the Great Russian Plain made this area their headquarters and spied from here upon their prey in the surrounding extensive prairies. Ukrainian Kosaks camped here during their numerous marches to and from battle. Finally, a monastery of the Greek-Orthodox order was established upon the grounds of the forest.

During the course of this manifold history the forest has been subjected to several loggings, made partly for firewood and partly for building protection against enemies. A considerable number of stands of sprout origin bear witness to these early cuttings. Also, the absence of an understory and the presence of weeds in some stands indicate another form of man's interference, namely, pasturing.

Up to 1840 the best materials had been cut selectively without regard to any system of cutting. As a result of such cuttings, three-story stands were formed with a considerable percentage of sprouts. However, on a whole, the regeneration of the forest was very satisfactory. In 1840 the forest was placed under systematic management. The original management plan for the elimina tion of all species of secondary importance and the encouragement of the highly merchantable oak and ash by means of selective cutting. This method of management led to the development of two-story stands, and was not found satisfactory. The practice of clear cutting and leaving seed trees was recommended. This latter method failed completely since sprout competition eliminated the seed reproduction. From 1863 to 1871 clear cutting in strips was practiced, using a 500 foot width of cut strips. Because of the heavy seed of oak, which prevented its dissemination, this practice led to the reproduction of light seed species of secondary importance, particularly hornbeam. Sprouting of secondary species after clear cutting on such wide strips also tended to eliminate the slow-growing seed reproduction of oak. Finally, on the drier sites, the oak and ash in the remaining strips began to die from drought. In 1871 the hornbeam occupied so much ground that it w as found desirable to subdivide the entire forest into two separate management units; one with a predominance of oak, and the other with a predominance of hornbeam. In 1886 the revision of the management found it unwise to continue the maintenance of hornbeam as a principal species and began a sy stem of clear cutting followed by artificial reforestation by planting and seeding of oak. The results of this method left much to be desired, due again to the competition of sprouts.

Thus, for nearly a half century the experiments in management of the Black Forest brought more disastrous than beneficial results. Only recently, after all differences in soils and other growth factors were explained, the management of this forest was placed on a sound basis of careful selective cuttings adapted to the ecological requirements of the stands.

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CHAPTER XVI

FORESTS OF THE LATERITIC REGION

Southern Coastal Plain, USA

"It was a savagely red land, blood-colored after rains, brick dust in droughts...the virgin forests, dark and cool even in the hottest noons, mysterious, a little sinister, the soughing pines seeming to wait with an age-old patience..." M. Mitchell: "Gone with the Wind."

The coastal plain is bordered by the Atlantic Ocean and the Gulf of Mexico. This great area of marine deposits slopes gently oceanward and near the coast is broken by long tidal marshes and inlets, reaching far up the shallow estuaries.

The parent material is made up of clay, sand, and gravel, eroded from the Older Appalachians and laid down during the Tertiary and Cretaceous periods. The sea has covered this region and receded several times during the formation of the sediments.

The climate is mild and humid. The season without killing frost varies from six months in the north to 12 months in the south. The mean annual temperature ranges from 60° F. to 75° F. The annual precipitation is 40 to 60 inches and occurs almost entirely in the form of rain. The precipitation is rather evenly distributed throughout the year, but drought and serious fire hazard sometimes occur in the winter.

The soils are of a lateritic nature, frequently showing evidence of superimposed podzolization. They are usually classified into "Red" and "Yellow" soils depending on the color of the laterized substratum, and, further, on the basis of textural composition of the surface layer. Neither of these features has an outstanding ecological importance as the distribution and the rate of growth of vegetation are correlated primarily with the degree of soil leaching, amount of incorporated humus, reaction of soil, content of nutrients, especially lime, structure of soil profile, and the depth of the ground water table.

Because of the low elevation above sea level and the frequent presence of an impervious clay substratum, the occurrence of poorly drained soils is extensive.

The dominant forest cover of uplands is made up largely of longleaf pine, loblolly pine, slash pine, shortleaf pine, and inferior oaks. More fertile soils support sturdy oaks, walnuts, hickories, tulip poplar, sweet gum, ash, beech, and magnolia. Southern cypress, tupelo gum, red gum, and several other hardwoods are found on alluvial bottoms.

The coastal plain region, because of its size, location near the centers of consumption, ease of logging, and generally a rapid forest growth, is an important timber-producing area.

In the following outline, the soil-forest types are designated according to the expressive folk terminology of the "Deep South", as quoted by Hilgard.

Upland Soils

"Pine Lands" or "Pine Hills." This type occupies extensive areas of rolling or undulating plains with podzolized soils of a lateritic substratum. The soil profile is usually composed of a greyish to light brown sand or quartzose residue grading into a porous clay. The soils are acid, have a low content of organic matter and nutrients, and are subject to drought. The deficiency of humus is partly due to repeated burning. In the opinion of some local foresters only few tracts of this type have escaped forest fire.

In spite of the low state of soil fertility, the growth of pine species is fairly rapid because of the long growing season, high temperature, and abundant rainfall; the high light requirements of the southern pines, their abundant infestation with mycorrhizal fungi, and the low density of stands appear to be other factors counteracting the deficiency of nutrients.

The forest cover consists of longleaf, loblolly, slash, and shortleaf pines; oak species are found in groups or as interspersed associates. On the poorest sites, the forest cover is almost entirely formed by either longleaf pine and palmetto, or shortleaf pine and struggling oaks; the latter condition is confined to the northern boundary of the region.

The poorer sites are characterized by a ground cover of *Aristida stricta*, *Stipulicida sitacea*, *Lupinus perennis* and *Cladonia silvatica*. The ground vegetation of the more productive sites includes *Tephrosia virginiana*, *Phaseolus spp.*, *Cassia nictitans*, *Kuhnistera pinnata*, *Pteris aquilina*, *Clitoria mariana*, *Centrosema virginiana*, *Liatris spicata*, *Aster* and *Silphium spp*.

"Table Lands." Wide plateaus with soils of medium heavy loam texture constitute a productive type of land from both agricultural and forestry viewpoints. The soils are of a yellowish-brown or brown color imparted by incorporated humus; they have a moderately acid reaction and a fair supply of nutrients. The forest cover consists of oaks with a high percentage of hickory. White, red, black, and Spanish oaks are prominent; post oak and jack oak or pines occur rather as an exception. The presence of some mesophytic members of the Carolinian flora characterizes the ground cover.

"Bluff Soils." This name refers to the rolling or hilly deposits of loess adjacent to the Mississippi valley. The loessal silt loams are high in lime and other nutrients; they have ideal physical properties, and support valuable stands of oaks, black walnut, tulip poplar, ash, and other exacting hardwoods which are ordinarily confined to the rich alluvial bottoms. In places where hardwoods have been destroyed by fire, loblolly pine and other pine species occur as pioneers and show a remarkably rapid growth.

"Limestone Ridges." The ridges or hills in the region of the eroded deposits of soft limestone are covered with deep red loams or silt loams. These mellow unleached soils with incorporated humus have but slightly acid reaction and a high content of available nutrients, especially calcium. They bear mixed stands of the better oaks, hickory, black walnuts, umbrella tree, and tulip poplar. The ground cover consists of calciphilous species.

The red or reddish brown loams of calcareous substrata, together with the loess deposits, form the most productive soils of the region.

"Lime Prairies." This name applies in northern Mississippi to level lands with black clays or clay loams formed on weathered or "rotten" cretaceous limestone. These rendzina-like soils are highly productive agriculturally, but support only sparse growth of trees, namely post oak and jack oak; red cedar, clumps of crab apple, and thickets of Chickasaw plum are found occasionally. The oaks, although sporadically distributed, attain considerable dimensions.

Lowland Soils

"Flatwoods." Extensive level tracts of poorly drained non-calcareous soils form the least productive type of the region, comparable to the Russian "Kercha Yag." The surface soil layer is strongly leached, low in humus and nutrients, and often extremely acid; at a shallow depth the surface soil grades into water-logged clay of a grey or mottled appearance. In places, the substratum attains characteristics of an ortstein layer of true podzol soils. The areas of this type remain under water for a considerable period after heavy rains.

The forest cover is composed of pines and struggling oaks; shortleaf pine in the north and longleaf pine in the rest of the region are the leading species. The characteristic ground cover includes sedges, rushes, orchids, Ctenium aromaticum, Sarracenia flava, Dichromena latifolia, Polygala lutea, Calopogon pulchellus, Aletris lutea, and a number of other swamp plants.

Near the sea coast flatwoods grade into "pine meadows", a closely related soil-forest association.

"Sand Hammocks." In the proximity of the ocean, the impervious clay substratum occurs at a greater depth and the surface deposit of sand is well aerated. As the result of this, the stands of longleaf pine show a greatly improved growth and a higher percentage of slash pine; a few other associates include pond pine, loblolly pine, red gum, and Ilex and Persea in the understory. The stands are park-like and have a subtropical appearance imparted by the cabbage palmetto. The ground cover includes only incidental intrusions of the swamp vegetation.

"Shell Mounds." The narrow strip along the sea coast is often covered by the calcareous residue of shells. The surface layer of these deposits consists of black or dark grey humus sand having a high content of lime. The vegetative cover includes live oak, grape vines, Aralia spinosa, Verbesina, and numerous leguminous plants.

"Coastal Peat." The deposits of peat along the Atlantic coast, called "Pocosins", are formed by dark remains of wood underlain by either sand or clay. Where the substratum is sandy, the southern white cedar usually occurs as a pure, even-aged type, but is sometimes mixed with pond pine, southern cypress, swamp black gum, and slash pine. On peat underlain by clays, hardwoods make up the larger portion of the stand. The associate vegetation includes

Ilex glabra, Myrica carolinensis, Leucothoe acuminata, Lyonia nitida, Baccharis halimifolia, Vaccinium spp., and the shrubby grass, Arundinaria tecta.

Alluvial Sands. Intermittently flooded areas in the flatwoods country are commonly occupied by a dense growth of cypress with some swamp black gum, slash pine, black willow, and swamp ironwood. In the southern portion of the region some sub-tropical hardwoods may also be found on these sites. Mosses, ferns, orchids, and particularly Spanish moss, Tillandsia usneoides, growing on the trunks and branches of the trees, are distinctive characteristics of this type.

Heavy Alluvial Soils. These soils vary in texture from silt loams to clays. They support a variety of hardwood species, particularly southern oaks, hickory, bitter pecan, red gum, willows, elms, green and white ash, beech, red maple, tupelo gum, swamp black gum and southern cypress. The stands have a heavy undergrowth of small trees, shrubs and vines, namely: Staphylea trifolia, Asimina triloba, Crataegus marshalli, Cephalanthus occidentalis, Sabal glabra, Rubus spp., Myrica cerifera, Ilex virginica, Smilax spp., Tecoma radicans, Cissus arborea, Psedera quinquefolia and Vitis spp. The ground cover is characterized by the presence of Phlox divaricata, Arisaema triphyllum and Habenaria ciliaris.

Hardwood stands produce high yields of valuable timber on heavy alluvial soils, although the conditions of forest growth vary considerably depending upon the distance from the stream, and degree of water stagnation.

"Bayous." The localities under water during the greater part of the year are occupied by a nearly pure type of southern cypress. Associate species when present are tupelo gum, swamp black gum, red maple, water oak and other swamp hardwoods. The wetter the site, the higher the percentage of cypress and fewer associated species. The stands are very dense and produce fairly high yields of timber. Typical minor associates are palmetto, thornapple, cane, Saururus cernuus, Penthorum sedoides, Lippia lanceolata, Commelina hirtella, and Hypericum spp.

The soil conditions exert in the Coastal Plain region a striking influence upon the form of trees, as has been pointed out by Hilgard. Figure 51 presents morphological varieties of post oak (Q. minor) characteristic of four different soil types. Careful observations and especially mensurational stem analyses prove that the same effect of soil conditions in a less pronounced degree is common in other regions.

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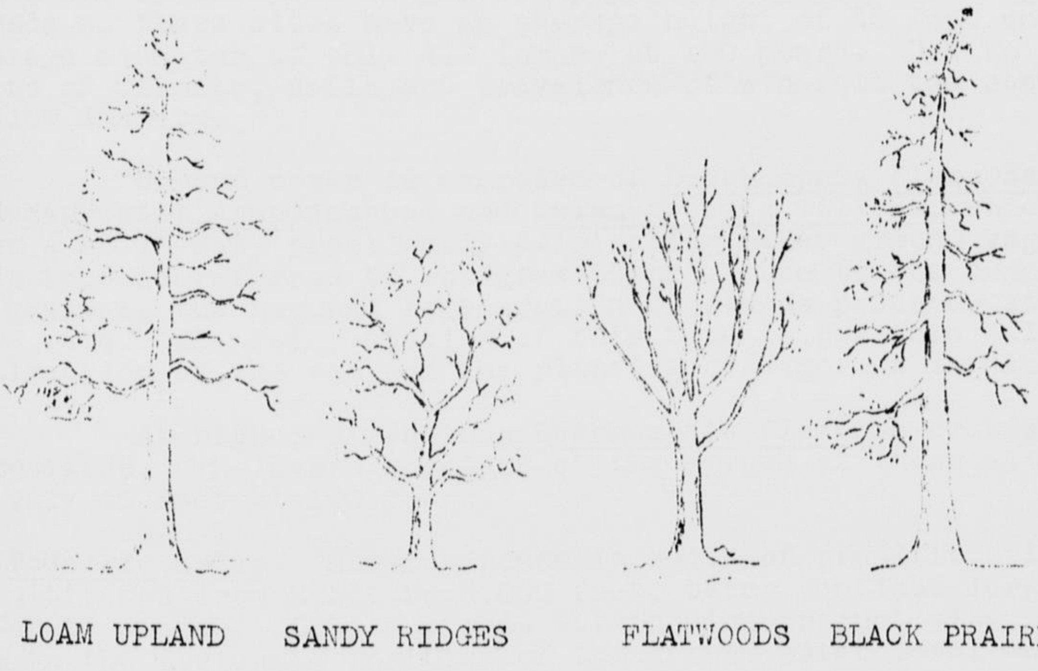

Figure 51. Extreme Forms of Post Oak
(After Hilgard)

CHAPTER XVII

MOUNTAIN FORESTS

A. Iser Mountains, Bohemia

"Rauschender Strom, brausender Wald,
Starender Fels, mein Aufenthalt..."
Fr. Schubert, "My Abode."

The Iser Mountains form a natural boundary separating northeastern Bohemia from German Silesia. The silviculturally important portion of these mountains belongs to the Picetum region. The mean temperature for the growing season is 54° F. and the mean annual temperature is as low in places as 40° F. The precipitation is 22 inches for the growing season and 56 inches for the entire year. The climate is characterized by strong, destructive winds, frequent glaze storms, and heavy snowfall. The altitude of the mountain range does not exceed 4,000 feet.

The geological substratum is composed of gneiss and coarse grained, easily weathered granite, locally grading into syenite. The forest cover consists predominantly of Norway spruce and a sparse ground cover vegetation of acidophilous low shrubs and herbs.

Sod Soils. This type occurs at altitudes from 2,500 to 3,500 feet and is confined to the well-drained, steeper slopes and ridges. The moderately acid, slightly podzolized sod soils of moderate depth are interrupted in places by protruding rock outcrops. Spruce stands on these sites have an average height of 65 feet and an average diameter of only 4.8 inches at 100 years. Due to conditions of climate, soils and prevalence of windfall the stands are of low density.

Ground cover is composed of *Deschampsia flexuosa*, *Calamagrostis arundinacea*, and *Calamagrostis villosa*, which grasses form a solid mat, practically eliminating other ground vegetation. This type is referred to as "grass type". Due to the competition of grasses, the natural regeneration of stands proceeds at a very slow rate. The reforestation of this type is possible only by the destruction of the sod and the planting of vigorous transplants.

At higher elevations *Deschampsia flexuosa* crowds out its associates. The average height of the spruce at these altitudes is only 40 feet at 100 years.

Podzolic Soils. Shallow podzolic soils of granitic origin occur at altitudes from 2,500 to 3,000 feet, being confined largely to moderate slopes. Spruce stands attain high productivity, chiefly due to the fortunate position of the ground water level which allows for a supply of capillary water and sufficient aeration. The average height and diameter at 100 years are 75 feet and 16 inches, respectively.

Ground cover is composed mainly of Dicranum scoparium, Polytrichum commune, P. Strictum, Hylocomium splendens, Sphagnum spp., some other mosses, Calamagrostis villosa, C. arundinacea and Deschampsia flexuosa. Oxalis acetosells and Vaccinium myrtillus occur sporadically. The grasses do not form a solid cover but are found scatteringly. The site may be called "Moss grass type".

Although the stands of this type regenerate fairly well naturally, reproduction cuttings should be carried on in a very conservative manner. A considerable opening of the stand may result in a rise of the ground water level, decreased aeration of soil, and development of Sphagnum mosses. These conditions will depress the rate of forest growth and retard the process of natural reproduction. The underplanting of mature stands, followed by release cuttings, is often a safer method of reforestation.

Podzols. Smaller areas of podzol soils having a deep layer of raw humus, are usually formed as a transition between swamp and upland forest types. The average height of spruce stands on these soils at 100 years is 52 feet. The ground cover consists predominantly of Vaccinium myrtillus with some Vaccinium vitis-idaea. This type is known as the "Blueberry type". Stands of advanced age commonly have an understory of saplings and seedlings. Natural reproduction is secured most successfully by group selection cuttings which encourage the decomposition of the raw humus layer.

This forest type occupies only a small total area in the Iser region.

Swamp Border Soils. The soil consists predominantly of a strongly acid peat-like raw humus, underlain by a leached layer of weathered granite or gneiss. Soil aeration is poor and the temperature is extremely low because of the insulating effect of the organic remains and the moss cover. The stands of spruce are characterized by shallow root systems and are usually uneven-aged, of poor form, and very low productivity. The average height and diameter at 100 years are 40 feet and 8 inches, respectively.

This type is hardly suitable for management on a commercial basis because of low productivity. The incidental reforestation is accomplished by planting spruce, with some white birch and mountain ash. Best success is obtained by planting on mounds with balled stock. The average accomplishment of a planter is about 35 seedlings per day.

The ground cover is composed chiefly of Sphagnum and Vaccinium vitis-idaea with some Vaccinium uliginosum, Vaccinium oxycoccus, and Calluna vulgaris. Polytrichum and Dicranum mosses associate with Sphagnum to a limited extent. This association is referred to as "Foxberry type". While the foxberry ground cover association occurs in northern Europe on dry sandy soils of morainic or outwash origin, in the Iser Mountains it is found on the borders of Sphagnum bogs, including those which have been drained. It appears that the actual dryness of sandy soils corresponds closely to the physiological dryness of the peat layer, and thus conditions are created which are responsible for the similar development of forest stands and composition of the ground cover.

Alluvial Soils. This type is located in stream valleys with deeper, well aerated, but sufficiently moist soils. The spruce stands have excellent form and a very high productivity, reaching an average height of 100 feet at 100 years. The ground cover is characterized by the abundant occurrence of *Oxalis acetosella* and of the mesophytic vegetation. The other conditions are similar to those of the "Oxalis type" described by the various authors.

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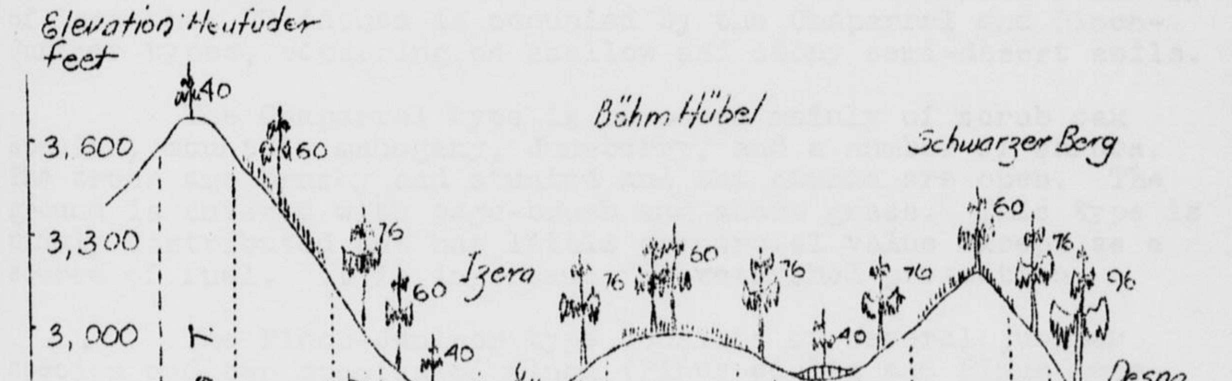

Figure 52. Types of Iser Mountains

(After Jar. Müller)

The numbers indicate the average height of trees at 100 years.

B. Southern Rocky Mountains

The Southern Rocky Mountain region covers an area of approximately 250,000 square miles, confined chiefly to Colorado, New Mexico and Arizona. The entire system is young in geological sense and the mountains are steep and sharply dissected. The ranges tend to be aligned in a north and south direction. Some peaks attain an elevation of 14,000 feet.

The Southern Rocky Mountains present a striking example of parallelism between altitude, climate, soils and vegetation. Progressing upward from the desert soils of low elevations is encountered a series of soil groups, including prairie soils, podzolic forest soils, mountain meadow soils, and skeletal barrens. Because of the direction of the moisture-bearing winds, the southern and especially the eastern exposures are much drier and support xerophytic vegetation at higher altitudes.

The forested portion includes a great number of types adapted to different altitudes, soils and exposures. However, little information is thus far available on the relation of soil and forest vegetation in the entire West, except some general descriptions of broad divisions. Thus, the following outline contains only a brief description of the principal forest zones of the region.

Dry Woodland Types

The lowest of the timber zones with an annual rainfall of less than 20 inches is occupied by the Chaparral and Pinon-Juniper types, occurring on shallow and stony semi-desert soils.

The Chaparral type is composed mainly of scrub oak species, mountain mahogany, Juneberry, and a number of shrubs. The trees are brushy and stunted and the stands are open. The ground is covered with sage-brush and short grass. This type is widely distributed but has little commercial value except as a source of fuel. It is important for watershed protection.

The Pinon-Juniper type consists of several juniper species and two species of pinon (*Pinus edulis* and *Pinus monophylla*). At the higher altitudes, dwarf forms of Douglas fir, western yellow pine and scrub oaks are found. This type is open in character and is associated with a considerable amount of herbaceous vegetation and small woody plants. The stands are usually uneven-aged, of small size and poor form. The Pinon-Juniper type covers a large area and is a source of fuel, posts and mine timber.

Yellow Pine Type

This type borders the dry woodland zone, occurring at elevations from 6,000 to approximately 8,000 feet.

The rainfall in this zone fluctuates between 20 and 25 inches. The growing season is short and dry. Temperatures of 110° F. occur quite frequently. The brown or grayish-brown soils are often shallow and stony, very low in organic matter and of neutral or alkaline reaction. The surface layers usually are of sandy texture grading into heavier B horizons. The forest litter as a rule is absent. In places piles of dry cones accumulate at the bases of trees.

The stands of lower elevations are composed of pure western yellow pine. At higher altitudes a certain portion of the stand is made up of Douglas fir. The stands are open and park-like with a ground cover of grazing grass and other herbaceous vegetation. They resemble somewhat the longleaf forest of the Atlantic Coastal Plain. The trees attain fairly good form and considerable size. After forest fire or logging the area is usually reoccupied by the western yellow pine, which acts as both pioneer and climax species. Because of the wide distribution, value of wood and accessibility, this type is of high commercial importance.

Douglas Fir Type

This type occurs above the yellow pine belt at elevations from 8,000 to 9,500 feet. Precipitation ranges from 25 to 30 inches, occurring mostly as snow in winter. Prolonged periods of high temperature and drought occur in the spring and fall. The soils are characterized by a rapid decomposition of organic remains, development of mull humus forms, and absence of pronounced podzolization. The water-holding capacity of these soils is often very low.

Douglas fir is usually associated with western yellow pine, and limber pine at lower altitudes, and Engelmann spruce and white fir in the upper portions of the zone. The dominant trees are 3 to 4 feet in diameter and over 100 feet in height. Burned-over areas are often invaded by aspen or lodgepole pine, which form temporary types.

Lodgepole Pine Type

Lodgepole pine has extremely wide ecological amplitude. It tolerates great extremes of temperature, is fairly resistant to drought and has moderate nutrient requirements. The altitudinal range of this species extends from the yellow pine zone almost to the timber line. At the lower elevations, the distribution is limited by a rainfall of less than 18 inches. As a rule, lodgepole pine forms temporary types, succeeded by either Douglas fir or Engelmann spruce.

Fire, by opening the cones of lodgepole pine, is largely responsible for the occurrence of extremely dense, even-aged pioneer stands on large burned-over areas on a great variety of soil types.

Spruce-Fir Type

This is the timber line type, extending from an elevation of 9,500 to 11,500 feet, where it grades into the alpine meadows. The annual precipitation averages 30 inches. The average growing season temperature is about 50° F. The length of growing season may be less than three months.

The shallow and stony soils of mountain podzol type are covered with a layer of raw humus. The soil profile shows a podzolized zone up to three inches in thickness and a slightly developed horizon of deposition.

The forest is composed of Engelmann spruce with varying amounts of lodgepole pine, limber pine, bristle-cone pine, Douglas fir, cork-bark fir, and alpine fir. The latter two species are the chief associates. The cooler and more moist sites support a higher percentage of fir species. The forest stands are well stocked and uneven aged. The mature trees reach a diameter of 30 inches d.b.h. On level areas along the streams the forest cover is usually replaced by mountain meadows.

As has been pointed out by Shantz and Zon, there is a close similarity in the development of forests in the western and eastern portions of North America. Figure 53 shows, in a greatly simplified, diagrammatic form, the relative position of the major types of forest cover.

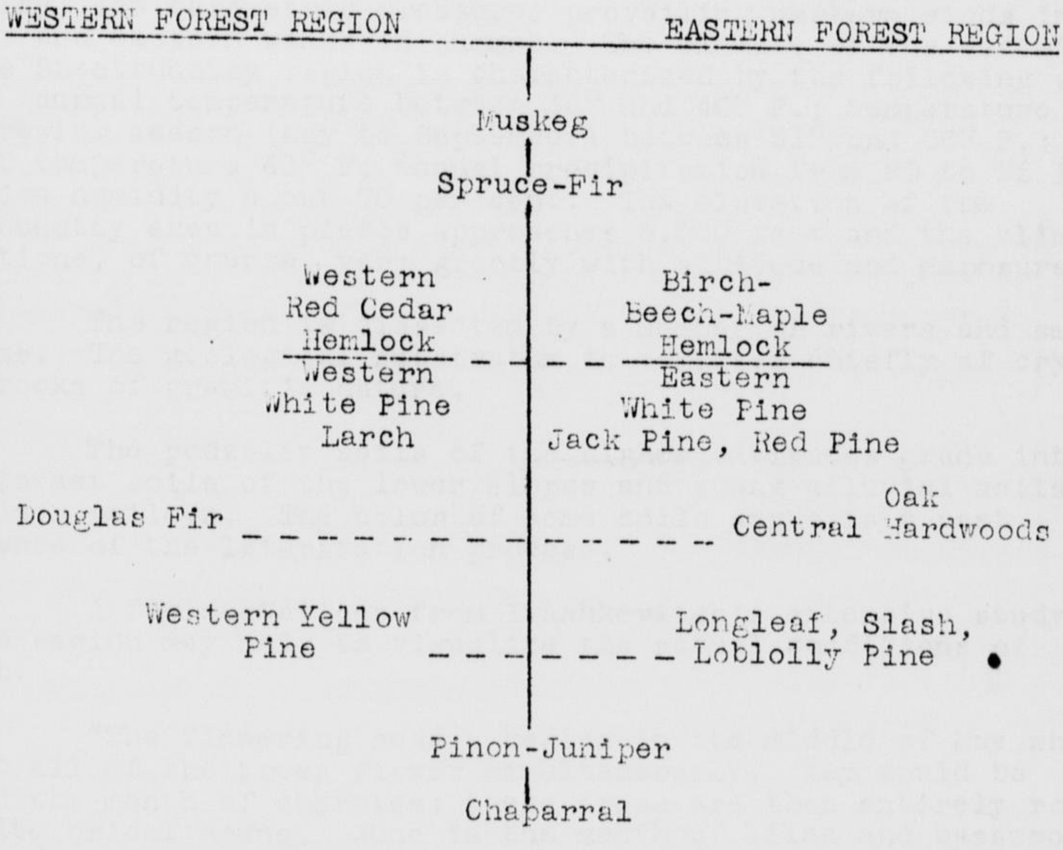

Figure 53. A diagrammatic presentation of the relationship between the major types of forest cover in the western and eastern portions of North America.

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C. Sheetouhetzy Mountains, Eastern Manchuria

The forests of Manchuria are peculiar in many respects and present considerable interest from the geo-botanical standpoint. Although they are composed entirely of indigenous species, there is a close genetical and ecological relationship between the forest cover of this area and that of Eurasia and North America. Aside from this, the region includes many unusual combinations of northern and subtropical flora. An American forester, in particular, is likely to detect a remarkable resemblance between some ecological conditions of the Sheetouhetzy Range and those found either on the podzols of the Great Lake region or on the lateritic soils of the Atlantic Coastal Plain.

The climate of Manchuria, as a whole, may be considered as a transition between continental and oceanic types. The outstanding characteristics of the region are: cold winters with little snow, warm summers with abundant rainfall, high relative humidity, low barometric pressure, prevailing western winds in winter and eastern winds in summer. The climate of the vicinity of the Sheetouhetzy region is characterized by the following average data: annual temperature between 35° and 40° F.; temperature of the growing season (May to September) between 51° and 66° F.; the lowest temperature 43° F; annual precipitation from 20 to 25 inches; relative humidity about 70 per cent. The elevation of the Sheetouhetzy area in places approaches 5,000 feet and the climatic conditions, of course, vary greatly with altitude and exposure.

The region is dissected by a number of rivers and smaller streams. The geological substratum is composed chiefly of crystalline rocks of granitic nature.

The podzolic soils of the higher altitudes grade into grey forest soils of the lower slopes and young alluvial soils of the river valleys. The color of some soils suggests a past influence of the laterization process.

A few quotations from Ivashkevitch's extensive study of the region may help to visualize the actual conditions of growth.

"The flowering season begins in the middle of May when almost all of the trees flower simultaneously. May could be called the month of cherries; these trees are then entirely robed in white bridal gowns. June is the month of lilac and basswood. In the forest, at this time, one's head swims with the intoxicating aroma of flowers and the rich spring odors of the warmed-up earth. The shortness of the growing season here is fully compensated for by abundant precipitation and high temperature. A summer day in Manchuria reminds one of the atmosphere of a greenhouse. Under such conditions everything grows luxuriantly. In June the grass reaches the height of a man and the forest at this time appears to be a solid green wall, impassable without the help of an axe. The enormous trunks of Siberian pine and spruce are entwined to the very top with lianas which, as they drape downward, are interwoven with the branches of basswood, lilac, hazel, cherry, locust, jasmine, and the extremely thorny devil's wood. Among the dark green color of the conifers your eyes are caressed by the lighter foliage of ash, walnut and other deciduous species. And below, the ground is covered with a bright carpet of flowers and large soft leaves."

Forest of the Mountains

1. Coniferous-hardwood type of high elevations. This type occurs at altitudes from 2500 to 4200 feet above sea level on little weathered stony soils, derived from crystalline rocks. The humic horizon varies in thickness from 2 to 5 inches and often grades into a somewhat leached horizon underlain by unweathered parent material. The stands are composed chiefly of *Picea ajanensis* and *Abies nephrolepis* mixed with *Betula plotyphylla*, *Acer manshuricum*, *Tilia manshurica* and *Ulmus montana*. *Pinus manshurica* occurs sporadically. The stands are abnormally dense, but the height of the trees usually does not exceed 60 feet. The fir commonly forms a second story. Ground cover consists of mosses and *Oxalis acetosella*.

2. Coniferous-hardwood slope type is adapted to the altitudes lower than 2500 feet, and is best developed on slopes not exceeding 15° gradient. The soils of loam texture are largely of deluvial nature and are somewhat podzolized. The humic A_1 horizon reaches a thickness of 8 inches and is underlain by a little-differentiated A_2B horizon, characterized by a yellowish-gray color. The dominant species of the forest cover is *Picea ajanensis*. This is mixed with broad-leaved species already mentioned and *Pinus manshurica*. The stands have a fairly high productivity. The understory includes *Corylus manshurica*, *Acer manshuricum* and *Tilia manshurica*, The ground cover is characterized by *Oxalis acetosella*, *Maianthemum bifolium* and *Lycopodium spp*.

3. Pine-hardwood slope type. This type is distributed on sandy loam soils at elevations under 2500 feet above sea level. The residual podzolic soils of the upper portion of the slopes usually grade into deluvial, slightly leached and somewhat structured soil of the lower situations. *Pinus manshurica* is the dominant species. *Fraxinus manshurica*, *Juglans manshurica* and *Phellodendron amurense* are the most important associates. The shrub layer is composed of dense *Corylus manshurica*. The stands are penetrated by abundant lianas particularly *Vitis amurensis*, *Schezandra Chinensis*, and *Actinidia spp*. The ground cover includes numerous species, among which the following are particularly prominent: *Alcrophora lilifolia*, *Paris obovata*, *Arena Schelliana*, and *Vicia baicalensis*.

Forest of the Valleys

The stands of these types are confined to the wide, open valleys with an altitude of less than 2000 feet. The valley forest includes the following types.

1. Coniferous-hardwood valley type. This type occurs on deep, well drained, deluvial, dark gray forest soils of loam texture. It is confined to the gentle outward slopes of the valley, and

gradually grades into the slope type of the mountains. A thin layer of friable litter of needles and leaves is underlain by a two inch A_1 humic horizon of fine crumby structure. The leached, A_2 horizon is of a very dark gray color and fine grain structure. The soil is very often moist and ground water usually occurs at a depth of about four feet. The forest association is very complex and includes pine, spruce, fir and practically all of the hardwoods of this region. The outstanding characteristic of this type is the presence of apple, cherry, alder, rock elm, and the replacement of Ulmus montana by Ulmus campestris. The understory is dense and lianas reach their greatest development, so this type may be truly called impassable. The herbaceous vegetation is also luxuriant and includes Paris obovata, Mainthemum bifolium, Convollaria maialis, Polygonatum multiflorum, Filipendula purpurea, Impatiens noli tangere, Aquilegia oxysepala, Thalictrum spp., Aconitum spp., Viola spp., Angelica dahurica, Solidago virga aurea, Dianthus chinensis, Equisetum and Lycopodium spp., Adiantum pedatum and numerous other ferns. Because of the high percentage of hardwood species, the total yields are somewhat lower than in similar types of the mountains. The percentage of cull pine is rather high.

2. River bottom hardwoods. This type is confined to areas subject to inundation. The deep alluvial soils support chiefly elm, walnut, and Phellodendron. Pine and other conifers occur sporadically as single specimens. The understory and shrub layer are of considerable density and Syringa amurensis is prominent. The stands seldom reach a height of more than 60 feet and most of the trees are infested with heart rot. The ground cover is characterized by the presence of ferns and numerous other plants common on alluvial soils.

3. Larch type of swamps. This type occurs on Sphagnum bogs. The stands are ordinarily composed of 70 per cent of larch, 20 per cent Siberian spruce and 10 per cent of pine and birch. The understory is composed of spruce, birch and suppressed larch. The density of the stands seldom exceeds 70 per cent. Virgin stands reach a height of 80 feet and the total yields are comparatively high. The ground cover is composed of Sphagnum, Eriophorum and Equisetum. The presence of larch in these stagnant bogs of w arm valleys is rather puzzling since this species ordinarily occurs on the rocky ridges of Asiatic mountains at elevations as high as 5000 feet. Apparently the low temperature of the Sphagnum peat accounts for the fact that none of the other species can compete with larch on these sites.

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PART V

ANALYSIS OF FOREST SOILS

Introduction

Much has been done in recent times by soil chemists to simplify and abbreviate the analytical determinations of various soil constituents. In spite of this, soil analysis still remains a time consuming procedure, too costly to be employed indiscriminately. The obtaining of worthwhile results requires a knowledge of analytical technique, certain laboratory skill, and careful collection of reliable samples.

The skill in laboratory determinations may be acquired, in many instances, without a profound theoretical background; sampling of soils, especially forest soils, calls for a thorough understanding of soil conditions and plant requirements. This is one phase of work in which the "savoir fair", or, to translate freely, the "horse sense" of a forester cannot be replaced by any written instruction.

In the selection of planting sites, the analysis may well be limited to a few of the more important factors such as reaction, texture, and content of organic matter; in case the soil is formed on a uniform geological deposit, for instance, outwash sand, five samples per forty acres may give sufficient information. In the work with nursery soils, it is necessary to make a more complete analysis of the basic fertility factors as well as the available nutrients; in this type of investigation, as many as five samples per acre may be needed to obtain a true picture of the soil fertility.

In dealing with young nursery stock, the analysis may be confined to the surface 7-inch layer of soil. In studies of soil drainage or soil texture, the analysis of the substrata may be of much greater importance than the analysis of the surface layers. In most cases, the investigation of forest soils involves the analysis of the entire soil profile, i.e. three to five separate horizons.

For some determinations, sampling may be accomplished by means of a tube which removes a representative cross-section of the surface layer. In other determinations, samples should be taken from the individual soil layers. Sometimes both methods may be combined.

The mixing of soil from different parts of the field, so commonly used in agricultural analyses, is rarely permissible in forestry practice. Because of uneven distribution of fertilizer within the same nursery block, the amount of available potash may vary as much as 50 to 400 pounds per acre. The composite sample from such a block may give an ideal content of about 200 pounds per acre, whereas actually potash occurs in the soil in either deficient or excessive amounts. The same may be true in regard to all other fertility factors.

Mistakes in soil sampling, which lead to the drawing of erroneous conclusions are often made because of the outmoded assumption that the soil is a static and homogenous surface layer. Actually, the soil is a dynamic and heterogenous sequence of several horizons.

Determination of Soil Texture

(Hydrometer Method)

Add 50 g. of fine-textured soil or 100 g. of sand, based on oven-dry condition, to the dispersing cup. Fill the cup with distilled water to about 1½ inches of the top. Add to the contents 5 cc. of a solution of sodium silicate (water glass) having a hydrometer reading of 36, at 67° F., and 5 ml. of saturated and filtered sodium oxalate. It is well to allow all soils to soak for about 15 minutes before they are dispersed. Start the stirring motor, and stir the contents for 5 minutes for sands and 10 minutes for all other soils.

Pour and wash the contents into the special cylinder. If 50 g. of soil are used, fill the cylinder to the lower mark with the hydrometer in it. If 100 g. of soil are used, fill the cup to the upper mark with the hydrometer in it. Take the hydrometer out, place the palm of one hand on the mouth of the cylinder, and shake the contents vigorously, turning the cylinder upside down several times. Place the cylinder quickly on a table and note the time immediately. At the desired period put the hydrometer in the suspension column, record the reading at the top of the meniscus, and take it out. Since there is a tendency for slight amounts of soil material to settle on the shoulder of the hydrometer, it is better not to leave it in continuously for all readings.

At every hydrometer reading, the temperature of the suspension should be measured. Great care must be taken, however, not to disturb the suspension column too much in putting in and taking out the hydrometer and the thermometer. For every 1° F. above or below 67° F., apply a temperature correction of 0.2 graduation on the hydrometer. For temperatures above 67° F., the corresponding amount of correction is added to the hydrometer reading, and for temperatures below 67° F., the corresponding amount is subtracted. This temperature correction, however, is only an approximation, as it tends to vary somewhat with extreme concentrations of soil suspensions and also with extreme variations of temperature. The most accurate hydrometer readings are taken near the temperature of 67° F., which is the temperature at which the hydrometer was calibrated in actual soil suspensions. Extreme temperatures such as 100° F. and 50° F. should be avoided. If possible, temperatures should be above 67° rather than below. The corrected hydrometer reading is then divided by the dry weight of soil taken and multiplied by 100, the result being the percentage of material still in suspension.

Some organic soils have a tendency to produce froth at the top of the column after being shaken, in which case a correct hydrometer reading is not always possible.

This difficulty may be overcome by adding a drop or two of amyl alcohol after shaking.

To calculate the amount of combined sand (1.0-0.05 mm. in diameter), silt (0.05-0.005 mm.), and clay (less than 0.005 mm.) as determined by the hydrometer method, the procedure is as follows: The corrected hydrometer reading at the end of 40 seconds is divided by the amount of absolute dry soil taken and is multiplied by 100. The result is percentage of material still in suspension at the end of 40 seconds. This percentage is subtracted from 100, and the result is the percentage of material that settled out at the end of 40 seconds, which is supposed to represent all the sand in the soil. The corrected hydrometer reading at the end of 1 hour is also divided by the weight of soil sample and multiplied by 100. The result is percentage of material still in suspension, or clay (less than 0.005 mm.). The percentage of silt is obtained by subtracting from 100 percentages of sand and clay.

By taking hydrometer readings continuously or every so often, a complete distribution curve of size particles of soil and their respective amounts can be obtained.

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The Determination of Moisture and Air Content

(Modified Kopecky Method)

The apparatus for the determination of soil moisture and aeration consists of a steel tube, ground to a sharp edge on one end. Sizes in common use are 100, 250, and 1000 cc. The proportion of height to diameter is 2:3. The tube is provided with fitted covers to prevent damage to the sample during transportation. Sampling tubes are permanently numbered.

In taking soil samples, a pit is dug with benches at the levels from which samples are desired. A bench is carefully leveled with a spade, and the sampling tube gently pressed vertically downwards into the soil, avoiding any twisting motion. This is facilitated by using a larger cylinder which fits over the sampling tube. The filled sampling tube is dug out with a generous block of the surrounding soil. The excess is carefully cut away and the surfaces leveled with a knife. The lids are put in place and fastened on with rubber bands.

In the laboratory, the lids are removed and one is replaced by a coarse copper screen. The sample is weighed to an accuracy of 0.1 gram. It is placed in a shallow dish filled with water and allowed to become saturated. Saturation takes several hours, and is complete when the surface of the sample becomes shiny, due to a film of water. The saturated sample is placed on four thicknesses of rough filter paper on a flat glass plate, under a bell jar to prevent evaporation. The filter paper is replaced by fresh sheets after the first half hour. After draining twenty-four hours, the sample is again weighed. The soil is removed from the sampling tube, pulverized, and dried at 110-115° C. till constant weight, cooled in a desiccator, and weighed.

The difference between the original and oven-dry weight of soil gives the actual amount of water present in the soil at the time of sampling. The difference between weights of saturated and of oven-dry soil gives the amount of water the soil retains during twenty-four hours. This is the absolute, or maximum, water-holding capacity of the soil. Both moisture content at the time of sampling and absolute water-holding capacity are expressed as volume per cent of oven-dry soil.

In order to determine the air content of a soil, it is necessary to determine first its volume weight, specific gravity, and porosity. The volume weight of soil is its weight per unit volume. Specific gravity is determined by a pycnometer. This is a small flask with a tightly fitting stopper having a hole in it. Precisely 20 grams of oven-dry soil are boiled for three minutes in a porcelain dish with 20 to 30 cc. of water. When cool, the contents of the dish are transferred to the pycnometer, using a funnel, a fine stream of water from a wash bottle, and a wire to prevent clogging the funnel. Enough water is added to fill the pycnometer, the latter allowed to come to standard temperature, stoppered, the overflow of liquid wiped off the outside with a piece of filter paper, and the pycnometer weighed. The weight of the pycnometer filled with water alone is also determined. The weight of the pycnometer filled with water, plus the weight of the soil sample, minus the weight of the pycnometer filled with soil and water, is equal to the weight of water displaced by the soil. The weight of soil, divided by the weight of the displaced water, gives the specific gravity. Soil porosity in per cent by volume is equal to the difference between specific gravity and volume weight, divided by the specific gravity and multiplied by 100. The aeration of soil is the difference between porosity and moisture content.

Example of the Determination of the Water-holding Capacity of Soil and Soil Aeration

Sampling tubes 100 cc. being used

Soil and sampling tube immediately after sampling...	198.8 g.
Sampling tube...	50.3
Weight of soil..	148.5

Saturated soil and sampling tube......................	206.5
Sampling tube...	50.3
Saturated weight of soil................................	156.2

Oven-dry soil...	125.1

Moisture content at time of sampling: 148.5 - 125.1 = 23.4 g. per 100 cc. sample, or 23.4% by volume.
Absolute water-holding capacity: 156.2 - 125.1 = 31.1 g. or 31.1% by volume.
Percentage of saturation: 23.4 ÷ 31.1 x 100 = 75.2%.
Volume weight: 125.1 ÷ 100 = 1.251 g. per cc.

Specific gravity:

Pycnometer filled with water..........................	140.52
Soil sample (oven-dry).................................	+ 20.00
Pycnometer filled with water plus weight of soil...	160.52
Pycnometer filled with soil and water..............	-153.01
Weight of displaced water..............................	7.51

Specific gravity: 20.0 ÷ 7.51 = 2.663. Porosity: (2.663 - 1.251) x 100 ÷ 2.663 = 53.0%.
Aeration at the time of sampling: 53.0 - 23.4 = 29.6%.
Absolute air capacity: 53.0 - 31.1 = 21.9%.

Precautions

In the case of a gravelly soil, or soil penetrated by roots, the sample should be sieved through 2 mm. mesh. The volume of gravel and roots is calculated from their dry weights and specific gravity. The volume as well as the weight of the gravel and roots is then subtracted from the saturated and oven-dry weights of the soil sample.

Highly colloidal soils expand upon saturation. In such cases the excess of soil should again be cut away with a knife, and the weight of the surplus soil considered only in the determination of moisture and aeration at the time of sampling. If the excess of soil is not removed, a negative result for aeration may be obtained.

Determination of physical properties of soil by the described method find their chief application in work with forest nursery soils.

Kopecky, Jos. "Die physikalische Eigenschaften des Bodens", Prag 1914; Burger, Hans, "Physikalische Eigenschaften der Wald--und Freilandboden" Mitteilungen schweiz. Centralbl. f. d. forstl. Versuchswesen, 1922 and 1926; Wilde, S. "Untersuchungen des Standorts und die physikalischen Eigenschaften des Waldbodens". Les Prace, 10, 1929.

Determination of the Moisture Equivalent

(Bouyoucos Method)

Take a small Buechner funnel, 5 cm. in diameter and $2\frac{1}{2}$ cm. in depth, and fill it with air-dry soil that has been passed through a 2 mm. sieve. Compact the soil by gently tapping the lower end of the funnel against the table. It is important to maintain a uniform depth of soil. The depth used will give a weight of 40 to 85 grams, depending on the soil. Place the filled funnel in a beaker into which water is poured until it almost reaches the upper surface of the soil. After the soil has been soaked for 24 hours, place the funnel on a suction flask, and apply suction, either from a filter pump or from a vacuum pump, for 15 minutes after all the free or excess water on the upper surface of the soil has disappeared. Cover the soil with a tumbler containing a moist cloth to prevent evaporation during the time suction is applied. If the soaked soil swells above the edges of the funnel, level it off after suction has been applied for one minute by removing enough soil to make the upper surface even with the top of the funnel.

At the end of 15 minutes disconnect the suction flask, remove the funnel, and scrape the soil into a weighed receptacle. Weigh the soil before and after drying at 105° C. to determine the moisture content. The amount of water present, expressed in per cent, is the moisture equivalent.

The moisture equivalent is considered one of the most accurate indirect methods of determining the wilting coefficient of soils,--that is, the percentage of water present when plants wilt permanently. The following formula was found to express the relationship for a wide range of soils:

$$\text{Wilting coefficient} = \frac{\text{Moisture equivalent}}{1.84}$$

Briggs and Shantz have also suggested the following formula for the relation of the moisture equivalent to the moisture holding capacity of soils obtained by the Hilgard method:

$$\text{Moisture holding capacity} = (\text{Moisture equivalent} \times 1.57) + 21$$

Figure 54 illustrates some phases of the physical analysis of soils.

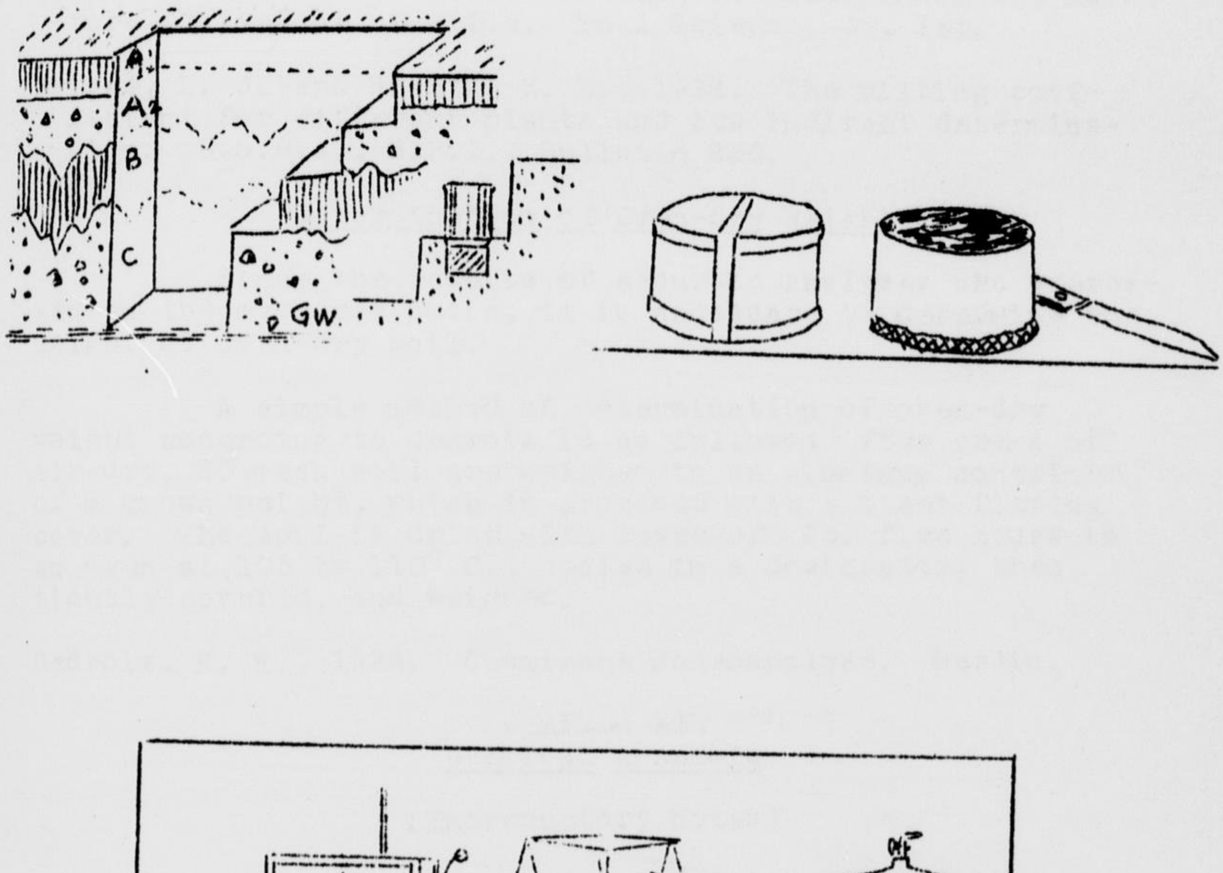

Figure 54. Profile trench used in sampling of soil for physical analysis; Kopecky's steel cylinders for determination of moisture, porosity, and aeration of soil; and apparatus for determination of specific gravity (Adapted from Kopecky).

Bouyoucos, G. J., 1929. A new, simple and rapid method for determining the moisture equivalent of soils, and the role of soil colloids in this moisture equivalent. Soil Science, 27, 233.

Bouyoucos, G. J. 1935. Comparison between the suction method and the centrifuge method for determining the moisture equivalent of soils. Soil Science, 40, 165.

Briggs, L. J. and Shantz, H. L. 1912. The wilting coefficient for different plants and its indirect determination. U.S.D.A., B.P.I., Bulletin 230.

Determination of Oven-dry Weight

Since the results of accurate analyses are expressed on the oven-dry basis, it is necessary to determine the weight of oven-dry soil.

A simple method of determination of oven-dry weight according to Gedroiz is as follows: five grams of air-dry, 20-mesh soil are weighed in an aluminum container of a known weight, which is provided with a tight fitting cover. The soil is dried with cover off for five hours in an oven at 105 to 110° C., cooled in a desiccator, then tightly covered, and weighed.

Gedroiz, K. K., 1926. Chemische Bodenanalyse. Berlin.

CHAPTER XIX
CHEMICAL ANALYSIS

(Introductory Notes)

Distribution of Plant Nutrients in Forest Soil

A careful examination of a fresh cut of forest soil shows that it consists of several layers, varying in color and composition. Some are well decomposed, or weathered, and contain an abundance of available nutrients, whereas in other layers the chemical compounds are unavailable to the trees due to insufficient decomposition or excessive saturation with water. Finally, some of the soil layers are leached and depleted of plant food, while in others the mineral substances have accumulated in excessive quantities. The study of these layers shows that the roots occur in abundance only in strata which contain easily soluble or available compounds. On the other hand, the layers in which leaching, excessive concentration of salts, or reduction processes render nutrients unavailable are practically free of feeding roots.

If we mix the soil of different layers together and analyze this mixture, obviously we shall not obtain a true picture of the distribution of the available plant food, or of the highly concentrated, toxic compounds. Therefore, for a reliable analysis of forest soils, the separate soil layers as they occur in nature should be analyzed.

The upper and lower limits of soil layers seldom follow a horizontal or straight line; rather, they have an undulating or even a zigzagging contour. Therefore, the samples of forest soil taken from a certain depth may not always represent the same layers. It may easily happen that one sample, for example, from the depth of 8 inches may include entirely leached material, whereas another sample taken nearby from the same depth will include a mixture of leached and precipitated material. In such a case the analyses will show different amounts of nutrients in the samples, while the soil in both cases is actually the same. For this reason, it is necessary in taking soil samples to dig a hole, to clean one of its sides, and to take the samples with great care from the separate soil layers.

In cases where soil material from separate horizons differs in volume weight, the total content of nutrients is calculated on the basis of the average thickness of each layer and content of its nutrients in per cent or in parts per million.

Example: A layer of duff 2 inches in thickness contained 120 p.p.m. of available phosphorus, whereas the 5 inch layer of mineral soil underlying the duff contained 10 p.p.m. of available phosphorus. The weight per acre of a 7 inch layer of a mineral loam soil is 2,000,000 pounds. Hence, the weight of the 5 inch layer of mineral soil is 2,000,000 lbs. x 5 ÷ 7, or about 1,500,000 pounds per acre. Consequently, the content of phosphorus in this layer is 1,500,000 x 10 ÷ 1,000,000, or 15 pounds per acre. The weight of the 2 inch duff layer, which is 2½ times as light as mineral soil, is (2,000,000 x 2) ÷ (7 x 2.5), or about 240,000 pounds per acre. The content of phosphorus in this layer is 240,000 x 120 ÷ 1,000,000, or 29 pounds per acre. Hence, the total amount of available phosphorus in a soil layer 7 inches deep is 29 + 15 or 44 pounds per acre, or per 1,740,000 pounds of soil. This corresponds to 44 x 1,000,000 ÷ 1,740,000, or 25 parts per million. This is the content of phosphorus which will be found in the top 7 inches of nursery soil after the analyzed layers have been mixed by plowing and disking.

Similarly, the content of total nitrogen of the same soil, providing the duff layer analyzed 1.2 per cent and the mineral soil 0.02 per cent of total nitrogen, would be 240,000 x 1.2 ÷ 100, or 2880 pounds, and 1,500,000 x 0.02 ÷ 100, or 300 pounds, which totals 3180 pounds per 1,740,000 pounds, or 0.18 per cent.

Methods of Chemical Analysis

The analysis of soils is accomplished chiefly by four principal modes of procedure, namely, (a) gravimetric methods; (b) volumetric methods; (c) colorimetric methods; and (d) turbidity methods.

Gravimetric methods include two kinds of determinations. In one, the unknown constituent is precipitated, purified, and weighed. In another a volatile constituent is driven off and its content is determined as the difference of two weighings of the sample.

Volumetric methods, or titration methods, determine the desired constituent by allowing it to react with a measured volume of reagent.

Colorimetric methods depend upon a comparison of the color of the solution containing the desired constituent with the color of a standard solution containing a known amount of the constituent.

Turbidity methods depend upon a comparison of the turbidity of the suspension containing the desired constituent with the turbidity of a standard suspension containing a known amount of the constituent.

Gravimetric methods are employed in modern soil analysis only in a few cases, such as in the determination of calcium carbonate, loss on ignition, and content of total salts. Volumetric methods find application in most determinations in soil analysis, particularly in those for replaceable bases and total nitrogen. Colorimetric methods are chiefly confined to the determinations of nitrates, ammonia, and available phosphorus. Turbidity methods serve in the rapid determinations of potash and calcium.

The Calculations of Gravimetric Analysis

Since the weights of reacting substances are proportional to their atomic or molecular weights, or to simple multiples of these weights, the amount of unknown constituent is determined from the following ratio:

$$Ax = \frac{Mx.Ap}{Mp}$$

where Ax is actual weight of constituent sought, Mx is molecular or atomic weight of constituent sought, Ap is actual weight of precipitate, and Mp is molecular weight of precipitate.

Thus, the weight of Ca contained in 0.72 g. of $CaCO_3$ will be:

$$Ax = \frac{40.07 \cdot 0.72}{40.07 + 12.0 + 48.0} = 0.288 \text{ g.}$$

The same may be obtained from modified ratio:

$$\frac{Ca}{CaCO_3} = \frac{x}{0.72}; \text{ or } \frac{40.07}{100.07} = \frac{x}{0.72} \text{ from which } 0.4 = \frac{x}{0.72}$$

$$\text{and } x = 0.4 \cdot 0.72 = 0.288 \text{ g.}$$

The ratio of the molecular or atomic weight sought to the molecular weight of the given substance, in our case $Ca:CaCO_3$, is called a <u>chemical</u> or <u>gravimetric factor</u>. Gravimetric factors for the principal compounds are calculated and presented in tabular form in chemical handbooks. The use of gravimetric factor greatly facilitates the calculation of results.

Table 28

<u>Atomic Weights of Elements</u>

Element	Symbol	Atomic Weight	Element	Symbol	Atomic Weight
Aluminum	Al	26.97	Manganese	Mn	54.93
Arsenic	As	74.96	Mercury	Hg	200.61
Barium	Ba	137.36	Molybdenum	Mo	96.0
Boron	B	10.82	Nitrogen	N	14.008
Calcium	Ca	40.07	Oxygen	O	16.000
Carbon	C	12.000	Phosphorus	P	31.02
Chlorine	Cl	35.457	Platinum	Pt	195.23
Chromium	Cr	52.01	Potassium	L	39.10
Cobalt	Co	58.94	Radium	Ra	225.97
Copper	Cu	63.57	Silicon	Si	28.06
Fluorine	F	19.00	Silver	Ag	107.880
Hydrogen	H	1.0078	Sodium	Na	22.997
Iodine	I	126.932	Sulfur	S	32.06
Iron	Fe	55.84	Tin	Sn	118.70
Lead	Pb	207.22	Titanium	Ti	47.90
Magnesium	Mg	24.32	Zinc	Zn	65.38

<u>Equivalent Weights and Normal Solutions</u>

In volumetric analysis the solution of unknown strength is brought into reaction with a solution of accurately known concentration. The formation of a precipitate, change in color of the solution, or of an added indicator, shows when the reaction is complete. The amount of the analyzed constituent is then calculated from the quantity of known normality solution used.

A one normal solution contains one gram equivalent weight of substance in one liter of solution. The term N means a one normal solution, 5N means a solution five times as strong, and 0.1N or N/10 refers to a concentration of one-tenth of an equivalent weight per liter.

An equivalent weight of a salt as precipitant is the molecular weight divided by the valence of the precipitating ion. Thus, the equivalent weight of AgCl, $AgNO_3$, and KCNS is equal to the molecular weight. The equivalent weight of $BaCl_2$, $(NH_4)_2CO_3$, and $CaCl_2$ is one-half the molecular weight. A liter of one normal $CaCl_2$ contains $(40 + 35.5 + 35.5) \div 2 = 55.5$ grams, and a liter of N/20 contains $55.5 \div 20 = 2.78$ grams.

An equivalent weight of acid is the molecular weight divided by the number of replaceable hydrogen ions; an equivalent of base is the molecular weight divided by the number of replaceable hydroxyl ions. The equivalent weight of HCl, HNO_3, NH_4OH is equal to the molecular weight. The equivalent weight of H_2SO_4, $Ba(OH)_2$ is equal to one-half the molecular weight. A liter of 1N H_2SO_4 contains 49 grams of acid; a liter of N/5 acid contains 9.8 grams. Since the specific gravity of concentrated H_2SO_4 is 1.80, it is necessary to dilute 49:1.80 or 27.2 ml. to 1 liter to make a 1N solution of H_2SO_4.

The equivalent weight of an oxidant or reductant is equal to the molecular weight divided by the change in valence of the active constituent. For instance, ferrous salts are oxidized by potassium permanganate in acid solution to ferric salts:

$$2\ KMnO_4 + 10\ FeSO_4 + 8\ H_2SO_4 = 2\ MnSO_4 + 5Fe_2(SO_4)_3 + K_2SO_4 + 8H_2O$$

The same equation may be written ionically:

$$MnO_4^- + 5\ Fe^{++} + 8\ H^+ = Mn^{++} + 5\ Fe^{+++} + 4\ H_2O$$

In the above reaction the manganese is reduced from a valence of plus seven to plus two, a change of five; the iron is oxidized from plus two to plus three, a change of one. The equivalent weight of permanganate is therefore one-fifth the molecular weight, and the equivalent weight of ferrous salt in this case is its molecular weight. A tenth normal solution of permanganate contains one-fiftieth of the molecular weight in a liter of solution, i.e., 3.161 grams per liter.

Titration

In the determination of total nitrogen, organic matter is oxidized with sulfuric acid. The ammonium sulfate formed is decomposed by the addition of sodium hydroxide, and the liberated NH_3 is distilled into a flask containing 25 ml. N/14 H_2SO_4. Part of the acid is converted into $(NH_4)_2SO_4$, and the excess of the acid is titrated with N/14 NaOH, using methyl red as indicator. Suppose it took 15 ml. of N/14 NaOH to bring about the red color of the indicator. Therefore, the amount of acid neutralized by the NH_3 is equal to 25 - 15 = 10 ml. Since 1 ml. of N/14 ammonium sulfate contains 0.001 gm. of nitrogen, the total nitrogen content is equal to 0.001 x 10 = 0.01 gm. per soil sample. Providing 5 gms. of soil were used in analysis, the content of nitrogen in the soil is (0.01÷5)x 100 or 0.2 per cent. Since the surface layer of soil weighs about 2,000,000 pounds per acre, the nitrogen content is equal to 0.2 per cent of 2,000,000 or 4,000 pounds per acre.

In determinations of carbonates, humus and biological activity of soil the CO_2 evolved as the end product of either the chemical or biological reaction is allowed to form a carbonate salt with an alkaline solution. The excess of base is then titrated with the acid, and thus the content of CO_2 determined. For example, 50 ml. of $Ba(OH)_2$ were used for the absorption of CO_2 evolved from calcareous soil after treatment with HCl. The pink color of phenolphthalein indicator disappeared after the addition of 15 ml. of 0.1 N oxalic acid. According to the equation $Ba(OH)_2 + CO_2 = BaCO_3 + H_2O$ the amount of barium hydroxide converted into barium carbonate is equal to 50 - 15 or 35 ml. One ml. of 0.1 N $Ba(OH)_2$ reacts with 2 + (16 x 2) ÷ 2 x 1,000 or 0.0022 CO_2. Therefore, the total amount of CO_2 evolved is equal to 0.0022 x 35 or 0.077 gm. One gm. of CO_2 corresponds to $CaCO_3$ ÷ CO_2 = 100 ÷ 44 or 2.27 gms. of $CaCO_3$. The calcium carbonate content, hence, is equal to 0.077 x 2.27 or 0.165 gm. If a 5 gm. soil sample was used in analysis, the calcium carbonate content is equal to (0.165 ÷ 5) x 100 or 3.3 gms. per 100 grams of soil, or 3.3 per cent.

The calculation of volumetric analyses are conveniently accomplished by use of <u>titre</u>. The term titre expresses the grams of solute contained in a cubic centimeter (ml) of solution or the weight of any substance which will react with or be equivalent to 1 ml. of the solution. A solution of hydrochloric acid which contains 3.0 g. of pure HCl per liter has an HCl-titre of 0.003. The NaOH-titre of this solution is found from the relation:

HCl:NaOH = 0.003:x or 36.5:40.0 = 0.003:x wherefrom

x = 0.0033 g.

In volumetric analysis the percentage of constituent sought is calculated as follows:

Desired constituent, per cent =

$$\frac{100 \times \text{vol. of titrating sol.} \times \text{titre of desired constituent}}{\text{weight of sample}}$$

Table 29

Value of Solutions of Acids and Bases and Oxidizing and Reducing Agents Used in Soil Analysis

Substance	Formula	Molecular Weight	Grams in a Normal Solution (per liter)
Acetic Acid	$H.C_2H_3O_2$	60.032	60.03
Ammonium Hydroxide	NH_4OH	35.048	35.05
Calcium Chloride	$CaCl_2$	110.98	55.50
Hydrochloric Acid	HCl	36.465	36.47
Magnesium Carbonate	$MgCO_3$	84.320	42.16
Magnesium Oxide	MgO	40.32	20.16
Nitric Acid	HNO_3	63.016	63.02
Oxalic Acid	$H_2C_2O_4$	90.016	45.01
Phosphoric Acid	H_3PO_4	98.051	98.05
Potassium Hydroxide	KOH	56.104	56.10
Potassium Oxide	K_2O	94.192	47.10
Sodium Carbonate	Na_2CO_3	105.994	53.00
Sodium Hydroxide	$NaOH.12H_2O$	40.005	40.00
Sulphuric Acid	H_2SO_4	98.080	49.04
Sodium Oxalate	$Na_2C_2O_4$	133.99	66.99
Calcium Oxalate	CaC_2O_4	128.07	64.04
Copper Sulfate, crystals	$CuSO_4.5H_2O$	249.71	124.85
Hydrogen Peroxide	H_2O_2	34.02	17.01
Mercuric Chloride	H_9Cl_2	271.52	271.52
Nitric Acid	HNO_3	63.02	21.01
Potassium Permanganate	$KMnO_4$	158.03	31.61
Selenium di-oxide	SeO_2	111.20	27.80
Sodium Hydroxide	NaOH	40.01	40.01
Sodium Oxalate	$Na_2C_2O_4$	133.99	67.00
Stannous Chloride	$SnCl_2$	189.61	94.81
Stannous Chloride Cryst.	$SnCl_2.2H_2O$	225.64	112.82

Preparation of Indicators

Brom cresol green: Make a stock solution of 0.01 N sodium hydroxide by dissolving 0.58 g. $NaOH.H_2O$ in 1 liter of distilled water. Dilute 14.3 ml. of stock solution to 250 ml. with distilled water. Weigh out 0.1 g. of brom cresol green, place it in an agate mortar and wet with a few drops of the sodium hydroxide solution. Grind vigorously until the powder is in solution. Add this to the balance of the sodium hydroxide solution. This constitutes a 0.04% solution.

Brom thymol blue: This indicator is made up the same as is brom cresol green except that 16.0 ml. of the stock solution is diluted to 250 ml.

Methyl Orange: Wet 0.02 g. of methyl orange powder with water and grind to a paste in an agate mortar. Dilute to 200 ml. with distilled water for a 0.01% solution.

Phenolphthalein: Dilute 125 ml. of 95% ethyl alcohol to 250 ml. with distilled water. Dissolve 0.125 g. of phenolphthalein in this solution.

Methylene blue - methyl red: Dissolve 0.248 g. of methylene blue and 0.375 g. of methyl red in 300 ml. of 95% ethyl alcohol.

Standard Solutions

For calculating the weight of a salt necessary to make one liter of a standard solution of an element, divide the molecular weight of the salt by the atomic weight of the element times the number of atoms of the element present in the salt. Multiply this result by 1000 times the part per million desired and divide by one million. For example, a standard solution containing 20 parts per million (p.p.m.) of potassium made from dipotassium phosphate (K_2HPO_4), is prepared by dissolving the following amount of salt in one liter of water:

$$\frac{(39 \times 2) + 1 + 31 + (16 \times 4) \times 1000 \times 20}{(39 \times 2) \times 1,000,000} = 0.0447 \text{ gm.}$$

Milliequivalents

For calculating the equivalent weight, the atomic weight of the element must be divided by its valence. For obtaining the milliequivalent weight (m.e.), the equivalent weight must be divided by 1000. In order to get m.e. in the soil sample, the content of the element present in grams is divided by its milliequivalent weight. Usually, the m.e. are calculated per 100 gms. of soil by dividing the number of m.e. found by analysis by the weight of the soil sample in grams, and multiplying the result by 100.

<u>Example</u>. Using a 5 gm. soil sample, replaceable Ca has been determined by titration of the oxalate with N/10 $KMnO_4$. Twelve ml. of potassium permanganate were used in the titration until the pink color persisted. One ml. of N/10 $KMnO_4$ corresponds to .002 gms. of calcium. Twelve ml., hence, correspond to 12 x .002 = .024 gms. of calcium. Since 1 m.e. Ca is equal to 40 ÷ (2 x 100) = .02 gms., then .024 ÷ .020 = 1.2 m.e. per 5 gms. of soil, or 1.2 x 100 ÷ 5 = 24 m.e. per 100 gms.

Milliequivalents express the actual atomic or molecular concentration of the elements of compounds present in the soil, whereas parts per million or percentage give the content of elements or compounds per unit weight. For instance, there may be determined in soil 1 per cent of calcium and 1 per cent of magnesium. Since, however, the atomic weight of Ca is 40, and the atomic weight of Mg is 24, the number of Mg ions is 40 ÷ 24 times that of Ca ions. Therefore, it is more desirable to use m.e. as a standard for comparison of replaceable bases, as well as for obtaining a true picture of the base exchange properties of soil.

In order to convert milliequivalents into per cent, or into pounds per acre, a similar procedure is followed. Suppose the content of calcium in soil is 3.0 m.e. per 100 g. and the amount of calcium in pounds per acre is desired. Since 1 m.e. of Ca is 0.02 g., the total content of calcium is 0.02 x 3.0 or 0.06 g. per 100 grams which is 0.06 per cent. Because the weight of a 7 inch layer of silt loam is 2,000,000 pounds per acre, the total amount of calcium in this layer is 2,000,000 x 0.06 ÷ 100 or 1,200 pounds per acre.

Milliequivalent weight is often used in calculating the results of titration. The percentage of the constituent sought follows from the equation:

Constituent sought =

$$\frac{100 \times \text{vol. used in titr.} \times \text{nom.} \times \text{milliequiv. wt. of const. sought}}{\text{weight of soil sample}}$$

Suppose in the determination of total nitrogen by the Kjeldahl method, 12 ml. of 1/14 <u>N</u> H_2SO_4 were used. Then, the content of nitrogen is as follows:

$$\frac{100 \times 12 \times 1/14 \times 0.014}{10} \text{ or .12 per cent}$$

Table 30

Solubility of the More Important Inorganic Compounds

Used in Soil Analysis

Name	Formula	Solubility in 100 Gm. of Cold Water: Grams	Cold Water: °C	Hot Water: Grams	Hot Water: °C
Ammonia	NH_3	89.9	0	7.4	100
Ammonium Acetate	$NH_4C_2H_3O_2$	148.0	4	---	---
Ammonium Chloride	NH_4Cl	29.4	0	77.3	100
Calcium Chloride	$CaCl_2.H_2O$	59.5	0	102.0	30
Calcium Hydroxide	$Ca(OH)_2$	0.185	0	0.077	100
Calcium Oxalate	CaC_2O_4	0.00067	13	0.0014	95
Calcium Oxide	CaO	0.140	0	0.071	80
Copper Sulfate	$CuSO_4.5H_2O$	31.6	0	203.3	100
Hydrochloric Acid	HCl	82.3	0	56.1	60
Magnesium Carbonate	$MgCO_3$	0.0106	20	---	---
Magnesium Oxide	MgO	0.00062	20	---	---
Potassium Chloride	KCl	27.6	0	56.7	100
Sodium Ammonium Phosphate	$NaNH_4HPO_4.4H_2O$	16.7	20	100.0	
Sodium Hydroxide	$NaOH$	42.0	0	347.0	100
Sodium Oxalate	$Na_2O_2O_4$	3.7	20	6.33	100
Stannous Chloride	$SnCl_2$	83.9	0	269.8	15

Buffer Action

Buffer action refers to the resistance which some solutions offer to a change in pH when an acid or alkali is added. For weakly ionized electrolytes the ratio of the product of the gram-ion concentrations to the molar concentration of the non-ionized electrolyte is a constant. The ionic equilibrium for acetic acid is as follows:

$$\frac{H^+ \times C_2H_3O_2^-}{H.C_2H_3O_2} = K$$

Because of this, H ions and $C_2H_3O_2^-$ ions in any solution form undissociated $H.C_2H_3O_2$, until the ionization constant is satisfied. Consequently, the addition of salts of a weakly ionized acid or base tends to keep the concentration of the hydrogen or hydroxyl ions within specific limits. Salts which behave in this way are called buffers, and their effect is referred to as the common-ion effect. Salts of weak acids and weak bases, amphoteric substances, and relatively insoluble acids, bases, or salts will also act as buffers. The common buffers used in the determination of hydrogen ions are acetate, phosphate, borate, and citrate salts.

Dilution

Because the dilution of concentrated solutions is followed by contraction or expansion, in exact analyses the calculations must be made on a weight, not on volume basis. The following example gives a correct procedure.

How much water must be added to 100 ml. of concentrated sulfuric acid having a specific gravity 1.8 and containing 88.92 per cent of H_2SO_4 in order to make a solution of specific gravity 1.08 containing 11.6 per cent by weight of H_2SO_4?

$$100 \times 1.8 \times (88.92 \div 100) = (100 \times 1.8 + x) \times (11.6 \div 100)$$

$$160.06 = 20.88 \quad 0.116\ x$$

$$x = (160.06 - 20.80) \div 0.116 = 1200.5 \text{ grams or ml. of water}$$

All of the problems related to quantitative chemical analysis are discussed in detail in the literature cited.

Engelder, Carl J. 1929. Elementary Quantitative Analysis. John Wiley & Sons, New York.

Olsen, J. C. 1920. Quantitative Chemical Analysis. D. Van Nostrand Co., New York.

Town, G. G., Hall, N. F. and Meloche, V. W. 1936. Quantitative Chemical Analysis. Edwards Brothers, Inc., Ann Arbor, Michigan.

Rapid or Field Methods of Analysis

These methods are used chiefly in reconnaissance studies of forest soils, selection of planting sites, examinations in regard to improvement cuttings, investigations of unproductive or diseased forest stands and seed beds, selection of suitable natural fertilizing materials, and other problems which must be solved in the field or in a simple laboratory located at the nursery office or ranger station. Although the procedure of the rapid or field methods has been greatly simplfied, reliable results are likely to be obtained only by a person experienced in this type of work. It should be remembered that these methods were not intended for the solution of scientific problems, but to provide general practical information.

Recently a number of commercial outfits for the determination of pH and available nutrients have been placed on the market. These outfits are devised on somewhat different principles and use varying strengths of extracting solutions. Consequently, the results obtained by these methods are not always comparable, and each requires special interpretation in regard to tree growth. Since the exact composition of the reagents used in these commercial outfits is not given, only methods whose procedures and reagents have been fully described in literature are included in the following outline.

Soil Texture

(Wilde Method)

The soil is separated from gravel and other coarse material by passing the soil through a 20-mesh sieve onto a piece of ordinary paper. A sample of approximately 40 grams of sieved soil is taken with a measuring spoon. Special attention should be given to filling the measuring spoon completely by packing the soil and then striking off just level full with a spatula. The sample is placed in a 125 cc. flask with a wide neck and approximately 1 gram of dispersing agent (sodium oxalate) is added, using a small measuring spoon that is filled level full. The flask is filled with water up to the 100 cc. mark. A rubber stopper is inserted and the flask is shaken vigorously 60 times by hand and then placed on a level surface. After exactly one minute, a tube 5.5 inches high and 1 inch in diameter is filled with some of the suspension to the 60 cc. mark. A small, specially calibrated hydrometer is immediately floated in the suspension in the tube, and the reading is taken as soon as possible.

The maximum amount of the fine soil material which can be read on the scale is 35 per cent. If a content higher than 35 per cent is to be determined, only

30 cc. of the suspension are transferred to the test tube and diluted to the 60 cc. mark with water. The test tube is vigorously shaken, placed on a level surface, and the hydrometer is floated. The reading is multiplied by two to give the approximate percentage of fine soil material. For more exact determinations in soils containing more than 35 per cent of fine material the measured samples should be dispersed in a mortar with a rubber pestle after the addition of 30 cc. of water and the dispersing agent. The suspension is rubbed thoroughly for two minutes and transferred carefully to the shaking flask, from whence the procedure is the same as previously outlined. In the majority of cases the percentage of fine material higher than 35 per cent has no significance in practical field work.

Since the temperature and quality of water used in analysis affect to a certain extent the hydrometer reading, the hydrometer, before analysis, should be placed in the test tube with pure water to check whether or not the water level and zero mark of the hydrometer correspond. In case the zero mark is higher or lower than the water level, the difference must be subtracted from or added to the final reading. The difference due to temperature and quality of water does not exceed two divisions of the hydrometer scale.

The details of this analysis and the interpretation of data may be found in the literature cited.

Anonymous, 1934, Fitting Trees to the Soil. Central Scientific Company Bulletin No. 7. Wilde, S. A., 1935, The Significance of Soil Texture in Forestry, and its Determination by a Rapid Field Method. Journal of Forestry, Vol. 33, No. 5, p. 503. Cady, J. G., 1936, Comparison of the Standard Hydrometer Method with Rapid Field Test for Determination of Fine Soil Particles. Technical Notes No. 14, Soils Dept., U. W. in cooperation with Wisconsin Conservation Department, Madison, Wisconsin.

Soil Reaction

(Truog Method)

Fill the hole in the test block one-quarter full of air-dry, pulverized soil. Add 3 or 4 drops of Truog triplex indicator and stir vigorously. The amount of indicator should be just sufficient to form a semi-fluid paste with the soil. Scrape the soil into the bottom of the hole and level off a smooth surface. Immediately after leveling sprinkle the barite powder evenly over the surface. This is done by tapping the bottom of the container with the rubber cap, held on the index finger. Use just enough powder to completely mask the color of the soil.

Exactly three minutes after application of the powder read the reaction by comparing the color with the standard scale. Most accurate readings are obtained by sliding the edge of the chart over the center of the hole while facing a window, but not in direct sunlight.

The indicator should be neutral, and its color should correspond to the color marked 7 on the chart. If the indicator is acid or alkaline, it must be adjusted by addition of N/20 HCl or N/20 NaOH. All possible contaminations from acid or alkali in the air, on the hands, or any other sources must be carefully avoided.

The test is accurate within 0.2 of a pH as determined by comparison with the glass electrode.

Truog, E., 1933, Instructions for Making the Soil Reaction Test. Hellige, Inc., New York. Wilde, S. A., 1934, Soil Reaction in Relation to Forestry and its Determination by Simple Tests. Journal of Forestry, Vol. 32, No. 4; 411-418.

Org. Matter and Total Nitrogen by Ignition

Five grams of 20-mesh soil are placed in a weighed porcelain crucible provided with a fitted cover and dried to constant weight at 105° C. in an oven. The soil is ignited with the crucible partly open, at first with a low flame which is gradually increased until it imparts a dull redness to the crucible. A complete ignition requires about 30 minutes, after which the crucible is cooled in a desiccator, covered, and weighed. If the soil contains carbonates, it should be moistened with 5 drops of a saturated solution of ammonium carbonate, to restore the CO_2 driven off from the carbonates. After this treatment, the soil is dried in an oven at 150° C. to constant weight. The loss in weight divided by 5 and multiplied by 100 gives the percentage of organic matter. The percentage of organic matter divided by 45 gives the approximate percentage of total nitrogen. This method is suitable for soils having less than 9 per cent of organic matter.

Available Nutrients

(Morgan Methods)

Nitrate Nitrogen

Extracting liquid: Distilled water.

Testing solution: Dissolve 0.05 gm. of diphenylamine in 25 ml. of concentrated H_2SO_4. The reagent should not give a blue color when tested with distilled water.

Standard solutions: These are prepared by dissolving potassium nitrate in distilled water. Since molecular weight of KNO_3 is 39 + 14 + (16 x 3) or 101, a solution containing 100 p.p.m. of nitrogen is obtained by dissolving 101 x 1000 x 100 ÷ 14 x 1,000,000 or 0.72 gm. of KNO_3 in 1000 ml. of water. Ten, 5, 3, 2, and 1 ml. of this solution diluted to 100 ml. with water will give standard solutions containing 10, 5, 3, 2, and 1 p.p.m. of nitrate nitrogen, respectively.

Standard chart: For use in the field prepare a hand-colored chart using wash crayon E. Faber "Aquarello" No. 1145.

Procedure: Weigh or take with a measuring spoon 2.5 gms. of 20-mesh soil. Place soil in a vial with 10 ml. of distilled water. Shake vigorously 60 times. Filter the suspension through Munktell's Swedish filter paper No. 3. Transfer 1 drop of leachate by means of a calibrated medicine dropper to a spot plate, add 4 drops of diphenylamine reagent, stir the mixture with a glass rod, and after exactly 2 minutes compare the color produced with a standard color chart or standard solutions tested in a similar way. Since 2.5 gms. of soil were extracted with 10 ml. of water, divide the results by 2.5 and multiply by 10 to obtain the nitrate content of soil in parts per million. In converting to pounds per acre also multiply by a conversion factor, which is 2 in case of silt loam soils and 2.5 in case of sandy soils. For example, a sandy soil leachate contained 5 p.p.m. when compared with the standard solution. Therefore, the soil contains 5 x 10 ÷ 2.5 = 20 p.p.m. or 50 pounds per acre. When large amounts of nitrates are present, dilute 1 drop of leachate with 4 drops of distilled water, take 1 drop of this dilute solution for testing, and multiply the results by five.

Ammonia Nitrogen

Extracting solution: Acidified 1 N solution of sodium acetate. Dissolve 82 gms. of sodium acetate in 500 ml. of distilled water, add 30 ml. of glacial acetic acid, and dilute to 1000 ml.

Testing solution: Nessler's reagent. Dissolve 5 gms. of potassium iodide in 15 ml. of distilled water. Add a saturated solution of mercuric chloride until a slight precipitate occurs. Add 40 ml. of a 50 per cent solution of potassium hydroxide. Dilute to 100 ml. Allow to settle for a week, decant, and keep in a brown bottle in a dark place. The reagent should not produce a yellow color when tested with extracting solution.

Standard solutions: A solution containing 100 p.p.m. of ammonia nitrogen is prepared by dissolving 0.47 gm. of $(NH_4)_2SO_4$ in 1000 ml. of water, according to the following calculation:

$$\frac{36 + 32 + 64 \times 1000 \times 100}{2 \times 14 \times 1,000,000} = 0.47$$

Twenty-five, 10, 5, 3, 2, and 1 ml. of this solution diluted to 100 ml. with distilled water will give standard solutions containing 25, 10, 5, 3, 2, and 1 p.p.m. of ammonia nitrogen, respectively.

Standard chart: A hand-colored chart for use in the field is prepared with wash crayons, E. Faber "Aquarello" Nos. 1127 and 1112.

Procedure: Weigh or take with a measuring spoon 2.5 gms. of 20-mesh soil. Place soil in a vial with 10 ml. of extracting solution, shake vigorously 60 times and filter. Transfer 4 drops of leachate to a spot plate by means of a medicine dropper, add 1 drop of Nessler's reagent, and stir with a glass rod. After 1 minute compare the resulting color with standard chart, or colors produced by testing the standard solutions. Since 2.5 gms. of soil were extracted with 10 ml. of water, divide the results by 2.5 and multiply by 10. In converting to pounds per acre also multiply by a conversion factor.

Available Phosphorus

Extracting solution: Add 5 ml. of concentrated HNO_3 and 2 ml. of concentrated HCl to 100 ml. of distilled water, mix and dilute to 200 ml.

Testing solution: Dissolve 5 gms. of ammonium molybdate in 50 ml. of distilled water, filter through phosphorus-free Munktell's Swedish No. 3 filter paper. Add filtrate slowly, with constant stirring, to a mixture of 100 ml. of distilled water, 50 ml. of concentrated HCl, and 25 ml. of HNO_3. Dilute the solution to 400 ml., and keep in a brown bottle.

Testing rod: A rod of pure tin, about 4 inches long and 1/8 inch in diameter is pointed with a pencil sharpener or with a knife.

Standard solutions: Are prepared by dissolving monopotassium phosphate in distilled water. Because the molecular weight of KH_2PO_4 is 39 + (1 x 2) + 31 + (16 x 4) or 136, a standard solution containing 100 p.p.m. is prepared by dissolving 136 x 1000 x 100 ÷ 31 x 1,000,000 or 0.45 gm. of monopotassium phosphate in 1000 ml. of water. Solutions containing 25, 20, 15, 10, 5, and 2.5 p.p.m. are prepared by appropriate dilutions of the concentrated solution.

Standard chart: For use in field work, a hand-colored chart is prepared with the E. Faber wash crayon "Aquarello" No. 1075.

Procedure: Place 2.5 gms. of 20-mesh soil in a vial with 10 ml. of extracting solution. Shake vigorously 60 times, and filter through phosphorus-free filter paper. Transfer 2 drops of leachate to a spot plate, add 1 drop of testing solution, and stir with tin rod for 30 seconds. Compare the color with the standard solutions or the chart. Multiply the results by 4 to obtain p.p.m. in the soil or multiply by eight or ten to obtain pounds per acre.

Available Potassium

Extracting solution: Acidified 1 N solution of sodium acetate.

Testing solution: Dissolve 5 gms. of $Co(NO_3)_2$ and 30 gms. of $NaNO_3$ in 50 ml. of distilled water acidified with 2.5 ml. of glacial acetic acid. Dilute to 100 ml. Let stand 24 hours and filter.

Standard solutions: A standard solution containing 100 p.p.m. of potassium is prepared by dissolving 0.259 gm. of potassium nitrate in 1000 ml. of distilled water. Five, 15, 25, and 50 ml. of this solution diluted to 100 ml. will produce the solutions containing 5, 15, 25 and 50 p.p.m.

Standard chart: A turbidity chart is prepared by drawing sets of lines with India ink, varying in heaviness of ruling to match the standard turbidities.

Procedure: Transfer 5 drops of sodium acetate soil extract into a 50 x 10 mm. flat-bottomed test tube. Add 5 drops of sodium acetate extracting solution, 1 drop of testing reagent, and 8 drops of 95 per cent ethyl alcohol. Shake and let stand 2 minutes. Examine turbidity by holding test tube 1/4 inch above standard chart. Multiply the reading by 4 to obtain the results in p.p.m. or by 8 or 10 to obtain results in pounds per acre.

Replaceable Calcium

Extracting solution: Acidified 1 N solution of sodium acetate.

Testing solution: Saturated solution of sodium oxalate.

Standard solutions: These are prepared by dissolving calcium acetate in distilled water. Since the molecular weight of $Ca(C_2H_3O_2)_2$ is equal to 176, a solution containing 1000 p.p.m. of calcium is prepared by dissolving 4.4 gms. of salt in 1000 ml. of water. The dilution of this solution will give the standard solutions containing 25, 50, 100, 250, and 500 p.p.m.

Standard chart: A turbidity chart is prepared by matching the turbidities of standard solutions with spots, painted with black India ink of different dilution.

Procedure: Transfer by means of a medicine dropper 10 drops of sodium acetate soil extract into a 50 x 10 mm. flat-bottomed test tube. Add 1 drop of testing solution. Shake gently back and forth and compare turbidity with the standard chart. Multiply the reading by 4 and 8 to convert the results into p.p.m. and pounds per acre, respectively.

Morgan, M. F. Microchemical Soil Tests; Conn. Agr. Exp. Sta. Bul. 333.

While this outline was being mimeographed, a new publication "The Universal Soil Testing System" by M. F. Morgan, Bul. 392, Conn. Agr. Exp. Sta., 1937, was released. This bulletin contains several improvements in the technique of analysis and valuable information as to the interpretation of analytical results.

Biological Methods for Determination of Available Nutrients

(After Mehlich, Truog, and Fred)

In biological determinations, the growth of lower organisms is correlated with the amount of available plant nutrients. In these analyses the soil is supplied with all nutrients except the one to be determined, and the growth of fungi or bacteria is measured after a definite period.

A. Nitrogen

Organism: Cunninghamella blakesleana.

Stock solution: 10 gms. $MgSO_4.7H_2O$; 0.2 gm. $FeSO_4.7H_2O$; 0.2 gm. $ZnSO_4$; 100 ml. distilled water. This solution can be kept indefinitely.

Nutrient solution: 5 ml. of stock solution; 25 grams glucose; 2 gms. $Ca(HPO_4)_2$; 2 gms. $Mg(HPO_4)_2$; 2 gms. KCl; 1000 ml. distilled water. This solution must be made for each determination.

Procedure: Place an 8 ml. scoopful of dry soil in a suitable dish. Add 2 ml. of nutrient solution. Bring the moisture to about 25 per cent saturation, so that soil particles just stick together. Mix the soil and solution thoroughly with a spatula, and transfer into two special clay culture dishes. Smooth the surface and press soil slightly below the upper rim. Add 2 ml. of water to a test tube containing a culture of Cunninghamella and stir with a glass rod. Take a loopful of this culture suspension and touch the center of the soil. Place the inoculated dishes in a large pan containing some water and cover with window glass. Incubate at 28° C. At the end of 48 hours measure the diameter of the hyphae, using a caliper. A diameter of 30 mm. corresponds to about 50 pounds of available nitrogen per acre. A diameter smaller than 20 mm. indicates an amount of available nitrogen less than 20 pounds per acre. Very slight developments of hyphae indicate a pronounced nitrogen deficiency.

B. Phosphorus

The procedure for the determination of available phosphorus is the same as that described for nitrogen, with the exception that in preparing the nutrient solution 2.5 gms. of NH_4NO_3 must be substituted for the phosphate salts. A diameter of hyphae of 30 mm. corresponds to 70 pounds of available phosphorus per acre. A diameter less than 15 mm. corresponds to an amount smaller than 30 pounds per acre.

C. Potash

Organism: Aspergillus niger.

Nutrient solution: 5 ml. of stock solution used in previous tests; 100 gms. glucose; 10 gms. citric acid; 6 gms. $(NH_4)_2SO_4$; 1 gm. peptone; 1.5 gms. $NH_4H_2PO_4$; 1000 ml. distilled water.

Procedure: Place a 2.5 ml. scoopful of soil into a 125 ml. Erlenmeyer flask. Add 30 ml. of nutrient solution. Add 10 ml. of distilled water to a test tube containing a culture of Aspergillus, and stir with a glass rod. Add 5 drops of this spore suspension to the flask and shake vigorously. Stopper with a cotton plug. Incubate at 28° C., and after 4 days remove the pads, wash, dry, and weigh. A 0.5 gram pad corresponds to about 300 pounds of available potash (K_2O) per acre. A 0.3 gram pad corresponds to about 120 pounds of potash. A weight of pad less than 0.2 gm. corresponds to an amount of available potash lower than 40 pounds per acre, and indicates a pronounced potash deficiency.

Mehlich, A., Truog, E., Fred, E. B., Soil Sci., 35: 259-273, 1933; Soil Sci. 3 8: 448-458, 1934; and Jour. Am. Soc. of Agron. 27: 826-832, 1935.

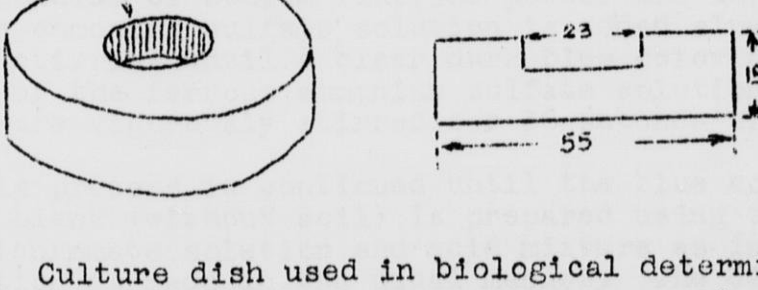

Figure 55. Culture dish used in biological determinations of available nutrients (From Mehlich et al).

Organic Matter by Reduction of Chromic Acid

(Modified Schollenberger's Method)

Reagents

Potassium bichromate solution. Dissolve 9.807 grams of oven-dry $K_2Cr_2O_7$ in 75 cc of water and make up to 100 cc in a volumetric flask. Keep this solution tightly stoppered to prevent evaporation.

Sulfuric-phosphoric acid mixture. Add by volume 2 parts of concentrated sulfuric acid, C.P. grade, to 1 part of 85% phosphoric acid U.S.P. grade.

0.2 N ferrous ammonium sulfate solution. Dissolve 78.44 grams of $FeSO_4(NH_4)_2SO_4.6H_2O$ in 500 cc of water containing 20 cc of concentrated H_2SO_4 and make up to 1 liter. Keep this solution in a tightly stoppered brown bottle.

Diphenylamine indicator. Dissolve 0.5 gram in 100 cc of concentrated H_2SO_4 and transfer into a 200 cc beaker containing 20 cc of water. Store in a tightly stoppered brown bottle.

Procedure

The air-dry soil sample is passed through a 20-mesh screen. With gravelly soils, the percentage of corase material is determined on a gross balance in the usual manner. A representative portion is ground with mortar and pestle or with a steel rocker on an extra hard steel plate until all of the particles pass through a 100-mesh screen. A measuring spoon, calibrated to deliver a one-half gram sample, is filled heaping full of the soil. After packing the soil with a spatula, the spoon is struck off level full. The sample is transferred to a dry 1 x 6 inch Pyrex test tube. One cc of potassium bichromate solution is measured with a pipette and transferred to the tube. Fifteen cc of the sulfuric-phosphoric acid mixture are added, thoroughly washing down the soil particles.

The tube is placed for 10 to 15 minutes in a bath of 85% phosphoric acid heated to 160° C. The contents of the tube are agitated occasionally. Ordinarily, a battery of twelve tubes is digested in the same bath. After digestion is complete, the tube is removed, allowed to cool for several minutes, and then placed in flowing cold water. The cooled contents of the tube are poured into a beaker. Four rinsings of the tube with water are necessary for complete transfer. The solution in the beaker is diluted to 200 cc. Five drops of diphenylamine indicator, and a quarter teaspoonful of sodium fluoride powder are added. Then 0.2 N ferrous ammonium sulfate solution is added slowly from a burette with stirring until a clear dark blue color develops. Another drop of the ferrous ammonium sulfate solution is added and the contents are vigorously stirred for 30 seconds or more.

This process is continued until the blue color changes to green. A blank (without soil) is prepared using the same amounts of bichromate solution and acid mixture as in the regular test. Titration is made in the usual manner. The difference between the titration figures of the blank and unknown solution multiplied by 0.125 and divided by the weight of the sample in grams gives the percentage of organic matter.

If the soil sample contains more than 2.5% of organic matter, 2 cc of bichromate solution and 30 cc of acid mixture should be used in the digestion. The digested solution should then be diluted to 400 cc. Soils having contents of organic matter higher than 5% will require still greater amount of reagents, and hence greater dilution. Experience will teach the desirable amount of acid needed under various conditions.

If titration is inconvenient, it may be replaced by a colorimetric procedure. The cooled, digested solution is diluted to 75 cc and allowed to settle. The reduction of chromic ions (orange) to the chromous state (green) produces a variation of color ranging from bright orange to bluish-green. Comparison of the unknown solution with a set of standards, or with a suitable color chart gives the content of organic matter within an accuracy of about 0.25%. With certain adjustments, the comparison of colors may be facilitated by the use of a photoelectric cell.

References

1. Allison, L. E. Organic soil carbon by reduction of chromic acid. Soil Sci., 40: 311-320. 1935.
2. Schollenberger, C. J. Determination of soil organic matter. Soil Sci., 31: 483-486. 1931.
3. Wilde, S. A. and Patzer, W. E. The role of soil organic matter in reforestation. Jr. Amer. Soc. Agron. 32: No. 8, pp. 551-562. 1940.

STANDARD METHODS OF ANALYSIS

The standard methods of chemical analysis require considerable time and expense. They are used by foresters primarily in determinations of nursery soil fertility or in investigations of various research problems. The following outline includes the description of analytical procedures for determination of the most important available nutrients and associated soil factors.

Total Nitrogen

(Standard Kjeldahl Method)

Reagents

12/N Commercial sodium hydroxide: Dissolve about 500 g. of sodium hydroxide in 1 liter of distilled water.

Concentrated sulfuric acid:

15% Copper sulfate: Dissolve 150 g. of copper sulfate in 1 liter of distilled water.

N/14 potassium biphthalate: Dissolve exactly 14.5814 g. of oven-dry potassium biphthalate R.G. in 1 liter of distilled water.

N/14 Sodium hydroxide: Dissolve 41.428 g. of carbonate-free sodium hydroxide C.P. ($NaOH.H_2O$) in 10 liters of distilled water and standardize with N/14 potassium biphthalate.

N/14 Sulfuric acid: Dilute 20 ml. of concentrated sulfuric acid to 10 liters with distilled water and standardize with N/14 sodium hydroxide.

Standardization of N/14 sodium hydroxide: Pipette 25 ml. of exactly N/14 potassium biphtalate into a 250 ml. beaker. Dilute to 150 ml. with distilled water and add 6 drops of phenolphthalein indicator. Fill a 50 ml. burette with the sodium hydroxide to be standardized until the bottom of the meniscus is at the zero mark. Place the beaker of potassium biphthalate solution under the burette and carefully regulate the flow with the stop cock until 1 drop turns the solution pink. If the bottom of the meniscus is at the 25 ml. mark the sodium hydroxide is exactly N/14. If only 24 ml. of the sodium hydroxide are needed to neutralize the 25 ml. of potassium biphthalate, the hydroxide is too strong and must be diluted. When calculating the water to be added, it must be remembered that a 50 ml. aliquot was taken from the 10 liters of hydroxide, leaving 9,950 ml. Thus the amount of water to be added is as follows:

$$(25 \div 24 \times 9,950) - 9,950 = 398 \text{ ml.}$$

If 26 ml. of hydroxide were necessary to neutralize the potassium biphthalate, the hydroxide is too weak and more must be added. When calculating the hydroxide to be added it must be remembered that 41.428 g. of sodium hydroxide were used per 10 l. Thus the amount of the crystalline hydroxide to be added is as follows:

$$(26 \div 25 \times 41.428) - (41.428 \times 0.9950) = 1.865 \text{ g.}$$

Check the normality of the solution by titration and make further adjustments, if necessary.

Procedure

Weigh out 10 g. of 100-mesh soil or 1 g. of 20-mesh peat or humus. Transfer the sample to an 800 ml. Kjeldahl flask. Add 10 g. of sodium sulfate, 5 ml. of 15% copper sulfate, and 30 ml. of concentrated sulfuric acid. Rotate the flask gently until the contents are mixed. Digest on the digestion rack. Start with a low flame and gradually increase it. Do not allow the flame to touch the flask above the liquid or a loss of ammonia will result from decomposition of the ammonium sulfate. Shake the flask at 15 minute intervals. The organic matter is destroyed and the digestion is complete when the mixture attains a light gray or a pale straw color. This usually takes about 2 hours for mineral soils and about 1 hour or less for peat and humus. Cool and add 400 ml. of ammonia-free water and shake thoroughly. Add 2 horn spoonfuls of powdered pumice (about 10 g.). Place 30 ml. of N/14 sulfuric acid into a 300 ml. Erlenmeyer flask. Wash down the sides of the flask with 15 ml. of water. Add 3 drops of methylene blue-methyl red indicator. Place the receiving tube beneath the surface of the liquid in the Erlenmeyer flask. Measure into the Kjeldahl flask 125 ml. of 12/N sodium hydroxide. Light the burner and regulate to a low flame.

Attach the Kjeldahl flask to the still and shake thoroughly. Increase the flame until the contents boil very gently. Collect about 200 ml. of distillate. Disconnect the receiving tube and turn off the burner. Wash the receiving tube with water from a wash bottle catching the washings in the Erlenmeyer flask. Titrate the excess acid with N/14 sodium hydroxide. Each ml. of N/14 sulfuric acid used up represents 1 mg. of nitrogen. Consequently the percentage of total nitrogen is calculated as follows:

$$\frac{(\text{ml. acid} - \text{ml. titration}) \times 1 \times 100}{\text{soil sample in milligrams}} = \text{percent of total nitrogen}$$

Run at least one blank for each set of determinations

Nitrates

Colorimetric Phenoldisulphonic Acid Method (Harper's Modification)

It is imperative to determine the nitrates on the fresh field sample because the nitrate content changes upon drying. Make a moisture determination on a part of the soil sample so that nitrates may be calculated on an oven dry basis. In case of highly colored soil extract that cannot be decolorized by the copper sulfate copper hydroxide treatment, add 1 teaspoonful Norite (activated bone charcoal) to 100 ml. of supernatant liquid secured as recommended for colored extracts and shake 15 or 20 minutes before adding the calcium hydroxide and magnesium carbonate to the solution.

Reagents

Phenoldisulphonic acid: Dissolve 25 g. of pure phenol (carbolic acid) in 150 ml. of concentrated sulfuric acid. Add 75 ml. of fuming sulfuric acid, mix and heat in a flask by placing the flask in boiling water for 2 hours. Store in a brown bottle.

Dilute ammonium hydroxide: Dilute 1 volume of the strong reagent with 2 volumes of water.

N/1 copper sulfate: Dissolve 249.71 g. of copper sulfate crystals in 2 liters of distilled water.

Calcium hydroxide C.P.

Magnesium carbonate C.P.

Standard nitrate solution: Dissolve 0.7215 g. of pure potassium nitrate in water and dilute to 1000 ml. Of this stronger solution dilute 100 ml. to 1000 ml. This latter solution contains 0.01 mg. nitrogen per ml. and constitutes the standard used to make the colorimetric solution.

Standard colorimetric solution: Evaporate 10 ml. of standard nitrate solution to dryness in a porcelain dish on the steam hot plate. Treat as in analytical procedure with 3 ml. of phenoldisulphonic acid, 10 to 15 ml. of cold water and dilute ammonium hydroxide until yellow color is permanent and solution is slightly alkaline. Dilute to 100 ml. in a graduated cylinder. The solution now contains 1 p.p.m. of nitrate nitrogen.

Procedure

Place 50 g. of 20 mesh soil or 10 g. of peat or humus in a 600 ml. wide neck bottle. Add 245 ml. of distilled water and 5 ml. of N/1 copper sulfate and shake on a mechanical shaker for 10 minutes. For soils that are not very acid and do not give a colored extract add 0.5 g. calcium hydroxide and 1 g. magnesium carbonate to the soil suspension and shake for 5 minutes to precipitate the copper and flocculate the soil. Filter through a dry filter paper discarding the first 20 ml. If the soil is very acid or gives a colored extract, allow the soil suspension to settle after the initial 10 minute shaking and decant about 150 ml. of the supernatant liquid into an empty flask. Add 0.2 g. calcium hydroxide and 0.5 g. magnesium carbonate and shake for 5 minutes. Filter as above after after allowing the flocculated suspension to settle. In either case pipette 10 ml. to an evaporating dish and evaporate on the steam hot plate. Use a 25 ml. aliquot if the nitrate content is low. Cool the dish and add rapidly 3 ml. of phenoldisulphonic acid with a pipette with a large opening. Rotate the dish at 2 minute intervals for 10 minutes. Dilute with 10 ml. of cold distilled water and stir with a glass rod. Add dilute ammonium hydroxide until red litmus turns blue or until the solution remains permanently yellow. Transfer the solution to a Nessler tube and dilute to 50 ml. Hold the tube containing the unknown solution and an empty Nessler tube above a white piece of paper which has been folded in the center to resemble the slanting sides of a roof. Pour the contents of the graduate containing the standard solution into the empty Nessler tube until the unknown has been matched when looking down through the vertical columns of liquid. Accurate color comparisons cannot be made if the amount of standard needed is less than 25 ml. or more than 50 ml. In the first case a larger aliquot must be evaporated. In the second the unknown must be diluted until 25 to 50 ml. of the standard matches 50 ml. of the unknown. Sometimes all of the copper is not precipitated which is indicated by a blue colored residue after evaporation. In this case add an additional 0.5 g. of calcium hydroxide and 1 g. of magnesium carbonate to the suspension or to the supernatant liquid, whichever the case may warrant. Shake 5 minutes and proceed as before.

Suppose 50 g. of soil have been extracted with 250 ml. of solution. Then a 10 ml. aliquot represents 10/250 x 50 or 2 g. of soil. The following formula will give the nitrate content of the soil.

$$\frac{\text{ml. of standard used} \times \text{concentration of standard}}{\text{gm. of soil sample}} = \text{p.p.m. of}$$

nitrate nitrogen.

Ammonia

(Harper's Modification)

Reagents

10% Potassium chloride: Dissolve 100 g. of potassium chloride in 1 liter of distilled water.

Magnesium oxide C.P.

N/14 Sulfuric acid: See total nitrogen determination.

N/14 Sodium hydroxide: See total nitrogen determination.

Procedure

Make certain that the laboratory is free of ammonia fumes. Run at least one blank on each set of determinations. Weigh out 50 g. of 20 mesh soil or 12.5 g. of peat or humus and place the sample in a 600 ml. wide neck bottle. Add 500 ml. of a 10% potassium chloride solution. In case of neutral or alkaline soils use a 20% potassium chloride solution. Shake for 30 minutes in a mechanical shaker. Allow to settle for 10 minutes and filter. Transfer 400 ml. of the filtrate to a Kjeldahl flask. Add 1 g. of magnesium oxide. Place 10 ml. of N/14 sulfuric acid in a 300 ml. Erlenmeyer flask and add 3 drops of methyl red-methyl blue indicator. Attach the receiving tube and place it beneath the surface of the liquid. Attach the Kjeldahl flask and light the burner. Gradually increase the flame until the mixture is boiling very gently. Catch 200 ml. of the distillate, detach the receiving tube and turn off the flame. Wash the receiving tube with water from the wash bottle and catch the washings in the Erlenmeyer flask. Titrate the contents of the Erlenmeyer with N/14 sodium hydroxide. Each ml. of acid used represents 1 mg. of ammonia nitrogen. The following formula will give the ammonia nitrogen in the soil sample:

$$\frac{(\text{ml. acid} - \text{ml. titration}) \times 1 \times 100}{\text{soil sample in milligrams}} = \text{per cent ammonia nitrogen}$$

Determination of Ammonia by Nesslerization

If minute amounts of ammonia are to be determined, Nesslerization is recommended.

Reagents

Nessler's reagent: Dissolve 62.5 g. of potassium iodide in 260 ml. of distilled water. Make a saturated solution of mercuric chloride by dissolving 35 g. of mercuric chloride in 500 ml. of hot water. Allow the mercuric chloride solution to cool. Add slowly with stirring the cold mercury solution to 250 ml. of the potassium iodide solution until a slight permanent precipitate is formed. This will require about 400 ml. of the mercury solution. Dissolve the red precipitate by adding the remaining 100 ml. of potassium iodide solution. Again add mercuric chloride solution drop by drop until a slight permanent precipitate remains. Dissolve 150 g. of potassium hydroxide in 250 ml. of water. Add this to the first solution and dilute to 1 liter with distilled water. Mix thoroughly and allow the solution to stand for several days until the precipitate has settled, leaving a pale straw-colored solution. This is siphoned or decanted off into another bottle for use. The 2 ml. portions used for each test must be measured quite carefully, as the depth of color produced with a given amount of ammonia depends to a certain extent upon the amount of Nessler's solution used.

Standard ammonia solution: Dissolve 1.9094 g. of pure dry ammonium chloride in ammonia-free water and dilute to 500 ml. One ml. of this solution will contain 1 mg. of nitrogen as ammonia. Dilute 10 ml. of this stock solution to 1 liter with ammonia-free water.

One ml. of this solution will contain 0.01 mg. nitrogen and is the standard solution. One, 5 and 10 ml. of the standard solution diluted to 100 ml. will produce solutions containing 0.1, 0.5, and 1.0 p.p.m. of ammonia nitrogen respectively.

Procedure

Dilute the distillate in the Erlenmeyer flask to a convenient volume such as 200 ml. Place 2 ml. of Nessler's reagent and 50 ml. of the distillate in a Nessler tube. Allow to stand 5 minutes and compare with a standard containing 0.1 p.p.m. or as much stronger as the amount of ammonia present warrants. Follow the technique outlined in the nitrate determination. Before the p.p.m. of ammonia nitrogen can be calculated, the actual number of mg. of ammonia nitrogen in the total distillate must be determined as follows:

$$\frac{(\text{ml. of st. to match unknown} \times \text{mg.N. in st.}) \times \text{total ml. of distillate}}{\text{total ml. of st. (100)} \times \text{aliquot of distillate (50 ml.)}} =$$

mg. of ammonia nitrogen in the total distillate. The p.p.m. of nitrogen in the soil can now be determined by the following formula:

$$\frac{\text{mg. nitrogen in the distillate} \times 1{,}000{,}000}{\text{soil sample in milligrams}} = \text{p.p.m. of}$$

ammonia nitrogen.

Determination of Available Phosphorus

(Truog Method)

Reagents

Ammonium molybdate-sulfuric acid solution: Dissolve 25 g. of ammonium molybdate in 200 ml. of distilled water heated to 60° C. and filter. Dilute 275 ml. of arsenic and phosphorus-free concentrated sulfuric acid (approximately 35/N.) to 800 ml. After both solutions have cooled, add the ammonium molybdate solution slowly, with shaking, to the sulfuric acid solution. After the combined solution has cooled to room temperature, dilute with water to exactly 1000 ml. This is approximately a 9.6/N. sulfuric acid solution containing 2.5 gm. of ammonium molybdate per 100 ml.

Stannous chloride solution: Dissolve 25 gm. of stannous chloride in 100 ml. of concentrated hydrochloric acid, warming if necessary to dissolve. Dilute to 1000 ml. and filter if cloudy. Store in a bottle with a siphon or side opening near the bottom, arranged with a glass stop cock for delivering the solution in drops. The solution should be protected from the air by floating a layer of white mineral oil about 10 mm. thick over the surface. Thus protected, the solution will give satisfactory results for about 6 months.

Sulfuric acid solution for extraction: Prepare a stock solution of exactly N/10 sulfuric acid by titrating against standard alkali. Dilute convenient volumes of this to 0.002 N and buffer by adding 3 gm. of ammonium sulfate or potassium sulfate per liter so as to produce a pH of about 3.0 in the final solution.

Standard phosphate solution: Dissolve 0.2195 g. of recrystallized potassium-dihydrogen-phosphate and dilute to 1000 ml. This solution contains 50 p.p.m. of phosphorus and serves as the base stock solution. Prepare a second stock solution by taking 50 ml. of the base stock solution and dilute to 500 ml. This second stock solution contains 5 p.p.m. and is used for making the standard solution for comparison. To make this standard solution, take 5 ml. of the stock solution, dilute to 96 ml. with distilled water, add 4 ml. of the ammonium molybdate-sulfuric acid solution, and mix thoroughly by shaking in an Erlenmeyer flask. Add 6 drops of stannous chloride and shake, after which a maximum blue color should develop in about 1 minute. It is now ready for use and contains 0.25 p.p.m. of phosphorus. For a more dilute standard, use 2 ml. of the stock solution, but the same amounts of reagents, giving a standard which contains 0.1 p.p.m. of phosphorus. After standing 10 to 12 minutes, the standard starts to fade, and a drop more of stannous chloride should then be added to bring the full color back which will again be permanent for 10 to 12 minutes.

Extraction and Determination of the Readily Available Phosphorus

Extraction and determination: Place 2 grams of 20-mesh soil and 400 cc. of the 0.002 N H_2SO_4 acid in a 750 cc. Erlenmeyer flask or other suitable flask or bottle and shake for exactly one-half hour. If more convenient, use one gram of soil and 200 cc. of 0.002 N H_2SO_4 and a smaller container. Filter immediately through S.S. 589 filter paper, or Munktell's No. 3 paper. Discard filtrate until it comes through perfectly clear. Then place 50 cc. of the clear filtrate in a 125 cc. Erlenmeyer flask, add 2 cc. of the ammonium molybdate-sulfuric acid solution, and shake well. Then add 3 drops of the stannous chloride solution, shake, and compare with the standard within a few minutes. In making the color comparison with ordinary Nessler tubes it is convenient to proceed as follows: Place the 52 cc. of unknown in a Nessler tube and the standard in a 100-cc. cylinder. Hold the tube with the unknown together with an empty Nessler tube over a white background and pour standard solution from the cylinder into the empty tube until the colors match. Then read the cylinder to ascertain the amount of standard required. For accurate comparisons, the intensity of color of the standard should not vary by more than about 50% from that of the unknown. Also, the strength of the unknown should be adjusted to within the limits of 0.5 to 0.05 p.p.m. of P.

Calculation: When the comparisons are made as just indicated, the calculation to pounds per acre is very simple. The 50 cc. of unknown solution represents 0.25 gram of soil. If the standard contains 0.25 p.p.m. of phosphorus, and if it took, say, 40 cc. of standard to match the unknown, the amount of readily available phosphorus in the soil will be equal to

$$\frac{40}{0.25 \text{ (wt. of soil)}} \times \frac{0.25 \text{ (con. of stan.)}}{1}, \text{ or 40 p.p.m. of P.}$$

The content of phosphorus in fertilizers is given as pentoxide or phosphoric acid (P_2O_5). To convert the P to P_2O_5 multiply the content of P by 2.3.

Important Precautions

It should be noted that arsenic produces exactly the same color as phosphorus, and that reagents, filter paper, and glass often contain appreciable quantities of arsenic and phosphorus. All glassware should be thoroughly weathered by treatment with warm sulfuric acid-dichromate solution for at least 24 hours. Filter paper may be tested by tearing up a sheet of it and throwing the shreds into a blank test. To test the chemicals proceed as follows: Add 4 ml. of the ammonium molybdate-sulfuric acid solution to 96 ml. of water and after mixing thoroughly add, with shaking, 6 drops of the stannous chloride solution. Compare in Nessler tubes with pure water. If the chemicals are free of arsenic and phosphorus, not more than the merest trace of blue color is produced. If the standard and unknown solutions are not acid enough, the stannous chloride will reduce the ammonium molybdate and produce a blue color independently of the presence of phosphates. If the acidity is too high, the color due to the presence of phosphates will not be intense enough. If the leachate is colored, it must be decolorized by the use of Norite which has been leached with the extracting solution until it no longer gives a test for P.

Determination of Readily Available Potash

(Volk-Truog Method)

Reagents

N/1 Ammonium acetate: See calcium determination.

10% Hydrogen peroxide: See calcium determination.

Approximately 0.15 N. Acetic acid: Dilute 9 ml. of 99% acetic acid to 1 liter with distilled water.

Sodium cobalti-nitrite solution: Dissolve 16 g. of sodium cobalti-nitrite (Mallinckrodt's Reagent Grade) in 100 ml. of distilled water and filter through an asbestos mat on a Gooch crucible. This solution is good for about one week if kept below 10° C.

Dilute sulfuric acid: Add 1 volume of concentrated sulfuric acid to 4 volumes of water.

N/20 Potassium permanganate: Dissolve 6.322 g. of potassium permanganage in 4 liters of distilled water.

N/20 Sodium oxalate: Dissolve 6.6995 g. of Soerensen's sodium oxalate (primary standard) in 2 liters of distilled water.

Asbestos: Digest the asbestos in 1:10 nitric acid containing sufficient permanganate to give a deep purple color. Add more permanganate if the color disappears. Digest for at least 24 hours, until the permanganate color is permanent. Destroy excess permanganate with oxalic acid, after which the asbestos should be pure white. Wash thoroughly on a Buechner funnel. Make a blank titration with standard permanganate on each purified lot of asbestos, and if the titration figure is appreciable, subtract it in the determinations. Asbestos improves with use and may be used repeatedly after purification.

Procedure

Place 30 g. of 20 mesh air-dry soil or 5 g. of peat or humus and 400 ml. of N. ammonium acetate solution in a 600 ml. wide neck bottle. Shake by hand intermittently 5 times, giving the bottle 10 vigorous shakes each time, requiring 5 to 6 minutes for a set of 12 bottles. Filter immediately through a dry filter pouring back the first 25 to 50 ml. if cloudy. Evaporate to dryness on a steam hot plate at about 60° C. to 65° C. a 300 ml. aliquot of the filtrate in a 600 ml. beaker. For greater speed boil down gently to about 50 ml. and then place on a steam hot plate. Do not allow the solution to go to dryness at a boiling temperature because the non-volatile acetates decompose at that temperature.

When dry, wash down the sides of the beaker and evaporate again. Add 5 ml. of 10% hydrogen peroxide to destroy the organic matter. Evaporate and repeat until the residue is white. Add 2 drops of phenolphthalein indicator and 10 ml. of water. Add enough 10% sodium hydroxide to turn the indicator red. Avoid the use of more than .5 ml. of sodium hydroxide. Evaporate to dryness to drive off the last traces of ammonia. Cool and add exactly 25 ml. of approximately 0.15 normal acetic acid. Rub the bottom and the sides of the beaker thoroughly with a policeman. Place 1 drop of the solution on a spot plate and test it for ammonia by adding a drop of Nessler's reagent. A brown coloration indicates the presence of ammonia. In such a case add a few drops of 10% sodium hydroxide and evaporate to dryness.

Filter the solution through a dry filter into a dry beaker. Place a 20 ml. aliquot representing 18 g. of soil or 3 g. of peat of humus, in a beaker and cool to 10° C. or less. Add 5 ml. of the cooled cobalti-nitrite solution and rotate the beaker. Let stand in the ice box for 3 hours or preferably overnight. Collect the precipitate on a compact asbestos pad in a Gooch crucible. Use a rubber stopper at the end of a glass stirring rod to compact the asbestos. Rinse the beaker 3 times with water cooled to 10° C. or less. Keep the wash bottle in ice while using. Pour the rinsings into the Gooch crucible and wash the precipitate 3 additional times. Remove the pad with a pointed glass rod and place in the original beaker. Cover with water at room temperature. Add 2 or 3 ml. of N/20 potassium permanganate and immediately add 5 ml. of dilute sulfuric acid. Continue to add permanganate until a pink color is permanent. Stir the mixture vigorously to break up the asbestos. Place the beaker with contents on a low flame and heat to the boiling point. If the permanganate color begins to disappear, immediately add more permanganate. An excess must be present to avoid loss of nitrous acid.

While stirring the mixture add from a burette N/20 sodium oxalate until the solution is colorless. Then add about 1 ml. excess of the sodium oxalate. Let the mixture stand for several minutes, stirring frequently. Titrate the excess of sodium oxalate with N/20 potassium permanganate. Each ml. of N/20 permanganate used is the equivalent of 0.6518 mg. of potassium or 0.4280 mg. of potash (K_2O). The following formula will give the

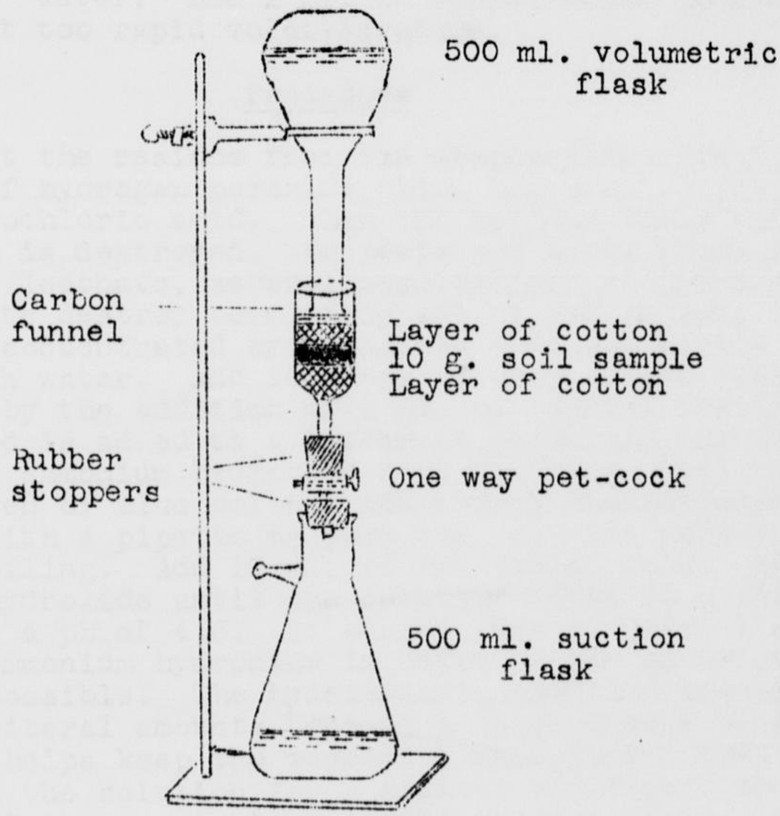

Figure 56. Apparatus for the determination of replaceable bases and base exchange capacity of soils and humus.

N/1 sulfuric acid: Pour 28.5 ml. of concentrated sulfuric acid into 971.5 ml. of water. Do not pour the water into the acid.

N/10 potassium permanganate: Dissolve 12.644 g. of potassium permanganate crystals in 4 liters of warm distilled water. Filter in a Gooch crucible with an asbestos mat made up from asbestos prepared as for the potash determination. Let stand for at least 48 hours and standardize with N/10 sodium oxalate. Keep in a dark bottle.

N/10 sodium oxalate: Dissolve 13.399 g. sodium oxalate in 2 liters of distilled water.

10% hydrogen peroxide: Dilute 33 ml. of 30% reagent to 100 ml. with distilled water. Add 1 ml. of concentrated hydrochloric acid to prevent too rapid volatilization.

Procedure

Treat the residue from the evaporation with 5 ml. of a 10% solution of hydrogen peroxide which has been slightly acidified with hydrochloric acid. When the residue turns white the organic matter is destroyed. On peats and humus which often give a dark colored leachate, several applications of hydrogen peroxide are necessary to destroy completely all of the organic matter. Add 10 ml. of concentrated hydrochloric acid and dilute to a volume of 300 ml. with water. Add 10 drops of brom cresol green indicator, followed by the addition of 1 ml. of glacial acetic acid. The acetic acid is added as a buffer to stabilize the pH of the solution. Add ammonium hydroxide with stirring until the solution turns to a green or blue color. Add enough concentrated hydrochloric acid with a pipette to turn the solution yellow. Heat the solution to boiling. Add 10 ml. of 2/N oxalic acid. Add slowly N/1 ammonium hydroxide until the solution turns to a full green color which is a pH of 4.6. It should take at least 5 minutes to add the last ammonium hydroxide in order to get as large a crystal formation as possible. The hydrochloric acid and ammonium hydroxide are added in liberal amounts because a large amount of ammonium salts (NH_4Cl) helps keep the magnesium from coming down with the calcium. Boil the solution for 2 minutes and digest on the steam hot plate until the supernatant liquid becomes clear. Filter off the calcium oxalate precipitate on a close textured filter paper and wash about 12 times with hot water in order to wash away all surplus oxalates. Pierce the filter paper and wash away the main mass of precipitate into a 400 ml. beaker. Heat 75 ml. of N/1 sulfuric acid to 70° C. and pour this over the filter paper. Dilute to 250 ml. Heat to 70° C. and titrate to a faint pink color. Add the filter paper and stir. Continue the titration if the pink color disappears. The reaction from the titration is as follows:

$$2\ KMnO_4 \text{ plus } 5\ CaC_2O_4 \text{ plus } 8\ H_2SO \text{ equals } K_2SO_4$$

plus

$$2\ MnSO_4 \text{ plus } 5\ CaSO_4 \text{ plus } 10\ CO_2 \text{ plus } 8\ H_2O.$$

Every ml. of N/10 potassium permanganate used in titration represents 2 mg. of calcium. This results from the following figures:

40.07 = molecular weight of calcium.
20.035 = equivalent weight of calcium.
2.0035 = g. of calcium per liter in an N/10 solution.
0.002 = g. calcium per ml. in an N/10 solution.

Therefore each ml. of $KMnO_4$ represents 0.002 g. or 2 mg. calcium. For conversion to milliequivalents per 100 g. use the following formula:

$$\frac{\text{Number of ml. titrated} \times 100 \times \text{normality of solution}}{\text{G. of soil sample}} = \text{m.e./100 g.}$$

Replaceable Magnesium

Reagents

N/56 potassium biphthalate: Dissolve 3.647 g. of oven-dry potassium biphthalate (primary standard grade) in a small quantity of water. Pour the resulting solution into a one-liter volumetric flask and make to volume with distilled water.

N/56 sodium hydroxide: Dissolve 10.357 g. sodium hydroxide ($NaOH.H_2O$; reagent grade) in 10 liters of distilled (carbon dioxide free) water and standardize with N/56 potassium biphthalate solution, using 3 drops of phenolphthalein indicator.

N/56 sulfuric acid: Dilute 5 ml. of concentrated sulfuric acid to 10 liters and standardize with N/56 sodium hydroxide, using 3-4 drops of methyl red-methylene blue indicator.

Concentrated ammonium hydroxide.

Dilute ammonium hydroxide: Dilute 100 ml. of concentrated ammonium hydroxide to 1 liter with distilled water.

10% solution of sodium ammonium phosphate: Dissolve 50 g. of sodium ammonium phosphate in 500 ml. of distilled water.

Procedure

Add 10 ml. of concentrated nitric acid to the filtrate from the replaceable calcium determination and evaporate to dryness on a hot plate. Make up enough dilute HCl (3 ml. of conc. HCl per 100 ml. of water), allowing 100 ml. of dilute HCl for each sample. Add 100 ml. of the latter solution to each beaker and stir until salts are dissolved. Add concentrated NH_4OH to make the solution just alkaline as indicated by litmus paper and heat on hot plate until steaming. Filter through No. 42 Whatman's or S.S. 589 filter paper into a 300 ml. Erlenmeyer flask. Wash beaker and filter paper with N/1 NH_4OH. Add slowly to filtrate with a pipette, 20 ml. of 10% sodium ammonium phosphate; stir contents vigorously while adding. Then add 10 ml. of concentrated NH_4OH and bring slowly to a boil while stirring. Let stand for 12 hours, at which time magnesium will be completely precipitated. Filter through a 9 cm. S.S. 589 Blue Ribbon Filter. Wash the flask 4 times and the filter 10 times with dilute ammonium hydroxide. It is not necessary to remove the precipitate sticking to the flask. Place the filter paper upon a blotting paper or toweling. Dry at a temperature not to exceed 45° C. to eliminate free ammonia. Dry the flask similarly. Return the filter paper and precipitate to the flask. Add 10 ml. of N/56 sulfuric acid for mineral soils and 20 ml. for organic soils. Let stand for half an hour and shake at 5 minute intervals. Add 5 drops of brom cresol green indicator. Break up the filter paper with a glass rod. Add 50 ml. of water and back titrate with N/56 sodium hydroxide until the first distinct blue color appears. If in doubt as to the proper color, dissolve a little pure KH_2PO_4 in water, add 5 drops of indicator to it and take the resulting color as a standard for an end point. Every ml. of N/56 sulfuric acid used represents 0.217 mg. magnesium. This results from the following figures: 24.32 = molecular weight of magnesium, 12.16 = equivalent weight of magnesium, 0.01216 = g. magnesium in 1 ml. normal solution, 0.000217 = g. magnesium in 1 ml. of N/56 solution or 0.217 mg. To convert to milliequivalents use the following formula:

$$\frac{\text{ml. acid} - \text{ml. titration} \times 100 \times \text{normality of solution}}{\text{gm. soil sample}} = \text{m.e./100 g.}$$

Determination of Base Exchange Capacity

Reagents

N/1 calcium chloride: Dissolve 735 g. of calcium chloride ($CaCl_2$ plus $2H_2O$) in 10 liters of water. Add pow dered calcium hydroxide until the pH is up to 7.0.

Silver nitrate solution: Dissolve about 3 g. of silver nitrate in 100 ml. of distilled water. Add 3 or 4 drops of con. nitric acid.

Procedure

Leach 500 ml. of N/1 calcium chloride at the rate of 1 drop every 3 seconds through the same soil from which the replaceable bases have been removed. Discard the leachate. Fill the flask with water and wash the soil with the petcock wide open. Fill the flask again with water and wash at the rate of 15 drops per minute until leachate is free of chlorine and, hence, no precipitate with silver nitrate is formed when a few drops from the filter funnel are tested. Discard washings. Leach again with N/1 ammonium acetate and determine replaceable calcium, as previously outlined. Base exchange capacity is calculated from the following formula:

$$\frac{\text{Number of ml. titrated} \times 100 \times \text{normality of solution}}{\text{g. of soil sample}} = \text{m.e./100 g.}$$

Total Soluble Salts

Place 100 g. of 20-mesh soil with 500 ml. of distilled water in a liter beaker. Stir well and let stand over-night. Filter and wash the residue several times with distilled water. Evaporate filtrate to a small volume on a hot plate. Transfer the contents to a weighed evaporating dish and evaporate to dryness. Ignite the residue and weigh. Subtract weight of the evaporating dish and calculate the content of salts in parts per million or in pounds per acre.

ANALYSIS OF PLANT TISSUE

Preparation of the Sample

The content of essential nutrients, such as nitrogen, phosphorus and potash, is ordinarily determined on the entire seedling. In some instances, however, the leaves, roots, or stems are analyzed separately. The material for analysis is carefully washed in water. The air-dry tissue is ground in a Wiley mill to 60 to 80 mesh. The moisture content is determined on representative samples.

Determination of Total Nitrogen

Weigh 1 g. of the prepared tissue and brush onto a filter paper. Fold the filter paper carefully around the sample. Place the sample in a Kjeldahl flask and proceed as in the standard Kjeldahl analysis.

Determination of Total Phosphorus

Place .2 g. of the sample into a evaporating dish. Add 2 ml. of 40% $Mg(NO_3)_2.6H_2O$ in 95% Ethyl alcohol. Allow to stand for fifteen minutes. Light the alcohol and permit it to burn off. Cautiously ignite with a low Bunsen burner until the brown fumes are no longer emitted. Increase the flame and complete the ignition.

Dissolve the ash in 10 ml. of 2 N H_2SO_4. Stir well and filter through No. 42 Whatman filter paper. Take 5 ml. of the filtrate and dilute to 100 ml. in a volumetric flask. Stopper the flask and shake. Pipette 5 ml. of the solution into a Nessler tube. Add 25 ml. of water and 3 drops of phenolphthalein indicator. Neutralize with N/15 NaOH. Proceed as in the Truog method for the determination of available phosphorus.

Determination of Total Potash

Place .5 to 1 g. of the ground tissue in a crucible. Add 10 ml. of 2 N H_2SO_4. Place on a steam hot plate and evaporate to dryness. Drive off the SO_2 and SO_3 fumes under the hood with a low Bunsen flame. Place in an electric furnace at a temperature of 650° C. for 30 minutes. Take up the ash in 25 ml. of .15 N acetic acid. Filter through a No. 42 Whatman filter paper. Place a 20 ml. aliquot of the filtrate in a 250 ml. beaker. Proceed as in the Volk-Truog method for the determination of available potash.

Determination of Total Calcium and Magnesium

Place 1 g. of the tissue in a crucible. Heat with a low Bunsen flame in the hood until all fumes have been driven off. Increase the flame of the Bunsen burner and ignite for fifteen to twenty minutes. Cool the crucible and add 20 ml. of 6 N HCl. Stir well and filter through No. 42 Whatman filter paper. Wash the residue three times with water. Proceed as in the determination of replaceable calcium and magnesium.

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CHAPTER XX
BIOLOGICAL ANALYSIS OF FOREST SOILS

The use of biological analysis is largely confined to investigations of specific problems. Such studies require an extensive knowledge of microbiological methods. A comprehensive description of laboratory technique may be found in the attached references. This outline is limited to a few more commonly used methods.

Nitrifying Capacity of the Soil

Incubate about 50 g. of air-dry soil or an equivalent volume of pulverized organic remains in covered tumblers at 28° C. after the moisture content of material is brought to two-thirds of saturation. A weekly determination of the nitrates by phenoldisulphonic acid method gives a picture of activity of nitrifying organisms. If the soil is low in organic matter, 0.1 g. of ammonium sulfate may be added to the sample before incubation.

Estimation of Carbon Dioxide Evolved from Soils

One hundred grams of soil or an equivalent volume of weighed humus are placed in a 500 ml. Erlenmeyer flask. The moisture content of the sample is brought to two-thirds of saturation and it is incubated for 48 hours at 28° C. After incubation, the flask is connected with an aspiration unit (Fig. 57) including the soda-lime tower (A), tower containing

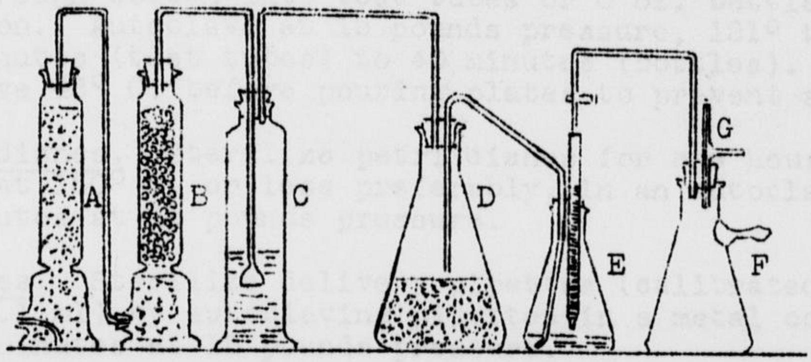

Figure 57. Apparatus for the estimating of carbon dioxide evolved from a soil (After A. F. Heck).

coarse pumice saturated with H_2SO_4 (B), tower with dilute solution of $Ba(OH)_2$ (C), flask with soil sample (D), and carbon dioxide trap with 0.5 N NaOH (E). Rubber fittings are attached and air drawn through the entire system by means of a water vacuum pump. The air current is adjusted by screw clamps to a rate of one bubble per second.

After a definite period of aspiration the carbon dioxide trap is detached. An excess of 2 N $BaCl_2$ is added and the solution titrated with CO_2-free 0.5 N HCl, using phenolphthalein as indicator.

Suppose CO_2 trap contains 25 ml. of 0.5 N NaOH and the red color of indicator ceased after the addition of 22 ml. of 0.5 N HCl. The amount of NaOH converted into Na_2CO_3 by the evolved CO_2, hence, is equal to 25 - 22 = 3 ml. Because 1 ml. of 0.5 N NaOH takes up 0.011 gm. CO_2, the total amount of carbon dioxide evolved is equal to 0.011 x 3 = 0.033 gm. per sample.

In a careful investigation the aspiration is continued for a number of days until CO_2 evolution is nearly constant.

In most cases, the biological activity of unknown material is compared with a standard sample of a productive nursery soil or an active type of humus.

Determination of the Number of Microorganisms

The number of microorganisms in the soil or in composted fertilizers is determined by making a series of dilutions of a soil or humus suspension. A definite amount of suspension from each dilution is transferred to petri dishes and nutrient agar is added. After incubation, colonies of bacteria and fungi are counted and the number of microorganisms per gram is calculated.

Reagents and equipment. Melt 17 g. of agar in 1,000 ml. of water by heating on a water bath or in an autoclave at 100° C. to 122° C. Add 3 g. of beef extract and 10 g. of peptone and restore to volume, if necessary. Heat until everything is in solution. Filter through cotton into test tubes or 6 oz. bottles. Plug with cotton. Autoclave at 15 pounds pressure, 121° to 122° C. for 20 minutes (test tubes) to 40 minutes (bottles). Keep agar at or above 45° C. before pouring plates to prevent solidification.

Petri dishes. Sterilize petri dishes for one hour in a hot-air oven at 160° C. or less preferably, in an autoclave for 20 to 30 minutes at 15 pounds pressure.

Pipettes. Sterilize delivery pipettes (calibrated to deliver 1.0 and 1.1 ml) by autoclaving pipettes in a metal container for 20 to 30 minutes at 15 pounds pressure.

Six-ounce bottles. Sterilize several 6-oz. bottles in the autoclave for 20 to 30 minutes at 15 pounds pressure.

Sterile distilled water. Autoclave distilled water in exactly 100 ml. quantities in cotton-stoppered Erlenmeyer flasks for 30 to 40 minutes at 15 pounds pressure. From 250 to 500 ml will be needed for the analysis of one soil or compost sample.

Procedure. Add 9 ml. of sterile water to sterile bottle No. 1. To each of bottles 2 and 3 add 99 ml of sterile water by pouring in 100 ml and removing 1 ml with a pipette. Add 1 g. of air dry soil to the bottle containing 9 ml of water to give a dilution of 1:10. Shake well without splashing the contents to the top of the bottle, and transfer 1 ml of the suspension to bottle 2, giving a 1:1000 dilution. Shake, and transfer, with a sterile pipette, 1 ml. of suspension from bottle 2 to bottle 3 to give a 1:100,000 dilution; shake the suspension.

Label duplicate petri dishes with the dilutions to be used (1:1000, 1:10,000, 1:100,000, 1:1,000,000, etc.). One petri dish is not inoculated and serves as a check on contamination. Transfer with sterile pipettes, 1.0 ml of the 1:1000 dilution suspension to duplicate dishes labelled "1:1000". Transfer 0.1 ml of the same suspension to the "1:10,000" dishes. Transfer 1.0 ml of the 1:100,000 dilution to dishes labelled "1:100,000" and 0.1 ml of the same suspension to the "1:1,000,000" dishes. Further dilutions can be made if desired.

Allow the agar to cool to 45° C. Carefully and quickly pour 15 to 20 ml of agar into each dish. Replace cover and rotate the dish to mix the agar and water, taking care not to spill agar over the inner edge of the dish. Allow the agar to solidify, then invert the plates and incubate one week at 30° C. Count the colonies developed on duplicate plates, preferably containing between 30 and 300 colonies per plate.

Results of determinations are expressed as number of microorganisms per gram of soil or compost by multiplying the average number of colonies from two plates by the dilution factor.

Suppose duplicate plates have 58 and 64 colonies respectively on the 1:100,000 dilution plates. The average number is 61, multiplied by the dilution factor, 100,000, gives a value of 6,100,000 microorganisms per gram.

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PART VI

FOREST SOILS IN RELATION TO SILVICULTURE AND FOREST MANAGEMENT

"The forest is a peculiar organism of unlimited kindness and benevolence. It makes no demands for its sustenance. It extends generously the products of its life activity. It provides protection to all beings, offering shade even to the axeman who destroys it."

Gautama

Introduction

Forests provide a source of income for millions of people. In the United States alone, 6 million people get their daily bread from industries dependent on forest resources (Silcox). Forests retard the run-off of water and moderate wind velocity, thus helping to control floods and erosion. The forest cover conserves moisture which becomes the life blood of cultivated crops. The forests exert a profound influence upon the physical and mental development of nations. The U. S. National Forests in themselves, provide each year recreation for more than 30 million people. Being a source of labor, the forest serves as a buffering agent moderating disturbances of economic equilibrium in time of depression, and its significance as a social factor is immeasurable. The forest is truly "man's most wonderful gift of nature" (Morozov).

The previous experience and research data leave no doubt that utilization of forest resources on sustained yield basis, or their "use without abuse" (Goodman), cannot be realized without due respect of soil and other environmental conditions involved in timber production. Specifically, the knowledge of forest soils is essential in solution of the following problems of silvicultural practice:

Survey and subdivision of land tracts for the purpose of forest management;

Selection of tree species suitable for reforestation, selection of planting sites and suitable planting methods;

Thinnings and loggings on different soils;

Diagnosis of detrimental conditions in unproductive or degenerating forest stands, plantations and nursery beds; amelioration of forest land through drainage, cultivation, application of fertilizers, and changes in the system of forest management;

Classification of forest land according to its productivity for the purpose of constructing yield tables, calculating the rate of annual cut, determining financial returns on reforestation investment; appraisal of forest land for purchase, land exchange, taxation, and settlement of damage suits.

Selection of nursery sites and maintenance of fertility in nursery soils;

Control of soil-inhabiting parasitic organisms.

CHAPTER XXI
FOREST SOIL SURVEY

"Ohne floristische Arbeit-keine pedologischen Untersuchugen; und vice versa: ohne pedologische-keine floristische. Suum cuique."
Arthur Feiherr von Kruedener

Purpose and Technique of Forest Soil Survey

In growing agricultural crops much can be done to secure satisfactory conditions of the soil for the crop selected. Drainage can be effected, the tilth of the soil modified by cultivation and additional plant food supplied by fertilizers. In the growth of forests, however, such modifications are, as a rule, impracticable. Thus, the only way to secure a maximum income from the reforestation enterprise, is to plant, or to encourage by means of partial cuttings, the species which are best adapted to a given set of physiographic factors. The information on the physiographic conditions, namely, climate, topography, ground water and soil, is obtained by means of a special study and mapping called "Forest Soil Survey." Because this survey usually deals with a whole complex of ecological or site factors, as well as the soil, it may be also referred to as "Forest Site Survey" or "Forest Land Survey."

The survey of forest land constitutes the first and most important step in organization of a forest tract for planned management, as it determines the areas suitable for different forms of silviculture and other uses. In many instances, the survey provides a physical basis for subdivision of a forest with regard not only to silvicultural practice, but also with regard to transportation, logging operations, and fire control.

In surveying land for forestry purposes, the area is traversed back and forth at fixed intervals, which vary from one-half to one-eighth of a mile, depending upon the nature of land and intensity of management. The distance is measured by careful pacing while the direction is kept by means of a hand compass. The variations in soil and other conditions are recorded on the original field map and in the notebook together with the remarks about specific characteristics of land, vegetation and silvicultural treatments. In order to locate exact site boundaries, offsets are taken from the traverse line. Offsets are particularly important in the hilly areas or tracts with dense forest growth.

The details of the mapping technique are discussed in the attached references (Beaman, W; Kellogg, C.E.)

Use of Soil Survey Reports and Maps Issued by the State and Federal Agencies

During the past forty years the State and Federal agencies have accomplished numerous soil surveys throughout this country. The results of these surveys, published as bulletins and maps, are of great assistance in forest soil surveys as well as in the solution of forest management problems.

As it would be expected, in the course of time, the technique of soil surveying has been considerably modified. The intensity and accuracy of mapping have been increased and interpretation of soil features placed on a broader scientific basis. Because of this, the recent soil maps and survey reports are much more valuable to foresters than those issued in the earlier period of soil surveying. Yet, even the older maps contain much valuable information and with some additional field work they may be converted into maps of planting sites or maps showing potential possibilities of forest growth. This conversion may require either consolidation or further subdivision of the types originally surveyed.

The classifications of the older soil surveys were based entirely upon the possibilities of agricultural land utilization. This viewpoint, however, is not always in agreement with the interests of forest management. In many cases, the conditions of forest growth are essentially the same on a number of soil types of different agricultural importance, viz., stony or stoneless soils, loam or silt loam soils, soils of glacial or residual origin, and so forth. On the other hand, soil types of the agricultural classifications may not be sufficiently uniform from an ecological standpoint to satisfy the needs of forestry practice. This is particularly true of soils having minor agricultural value, such as wind blown sands, light sandy outwash soils, soils of rough morainic deposits, poorly drained mineral soils and peat soils. Types of this nature, though unproductive agriculturally, may show considerable variation in forest growth. These variations may be affected by topography, leaching, drainage, nature of organic remains, and soil texture. The ecological and silvicultural significance of all these factors is discussed in the following outlines.

(a) Topography. In surveying land for agricultural use the topography is usually classified into different types, such as level, undulating, rolling or rough. In forest land surveys, however, it is necessary to consider not the types or forms of topography, but its elements such as hilltop, ridge, plateau, valley basin, and s lopes of different gradient and exposure. This difference in the classification of topographical features is likely to cause most of the difficulties when an attempt is made to adapt the data of a general soil survey to forestry purposes. Since the composition of the soil profile varies depending upon its location on top of the hill, on the slope, or in the depression, surveys which consider only the general lay of the land, may neglect essential differences in the type of organic matter, degree of leaching, content of nutrients, and other important soil properties.

As a concrete example, stony unassorted morainic loams, appear on older soil maps under the name "Kennan loam." As reforestation experience has shown, this type may include two silviculturally important phases, namely, strongly leached, often cemented podzol loams with raw humus, and a reaction as low as pH 4.0 and unleache d, friable loams with mull humus, and a reaction approaching pH 7.0. These two phases require different methods of selective logging, as well as different species for planting and must be carefully differentiated by means of an additional survey.

Figure 58 illustrates a more complex condition found in northern Wisconsin on rough glacial deposits of sandy texture (Vilas sandy loam). This example emphasizes the enormous importance of topographic features in the distribution of forest vegetation and, hence, in the selection of planting sites for various tree species.

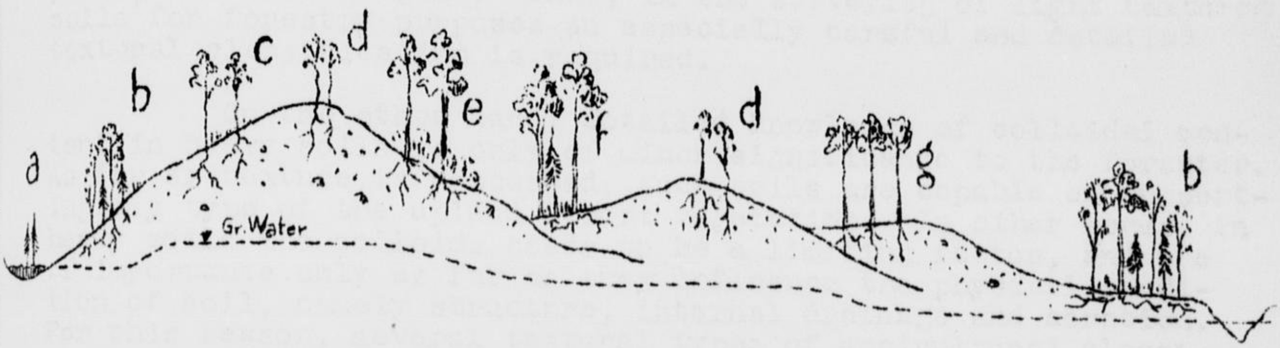


Figure 58

Forest sites encountered on partly assorted glacial sandy deposits of recent drift derived from granitic rocks (Vilas sandy loam, Langlade County, Wisconsin).

(a) Stagnant pothole; Black spruce-tamarack (Ledum-Chamaedaphne) site; (b) Swamp-border podzol; Pine-aspen-birch-balsam fir (Cornus-Rubus) site; (c) Slightly podzolized denuded sand, steep southern exposure; Jack pine-red pine (Myrica-Gaultheria) site; (d) Barren gravelly sandy ridge (Cladonia-Arctostaphylos) site; (e) Podzolized sandy loam, northern exposure: Red pine-white pine (Vaccinium-Gaultheria site; (f) Sandy loam podzol with ortstein: White pine-balsam fir (Vaccinium Cornus) site; (g) Weakly podzolized humic sand, considerably assorted: Red pine (Arctostaphylos-Ceanothus) site.

When the land attains a mountainous character, the variation in climatic conditions of different aspects may greatly over-rule the effect of soil properties. In such localities, the survey for forestry purposes requires a specific approach as outlined later under a special heading.

(b) Soil Texture. The soil containing less than 12 per cent of silt and clay are of minor value for farming. Therefore, such soils appear in agricultural classifications as a single type, for instance Plainfield sand or Vilas sand. From the standpoint of reforestation, however, very small differences in the content of fine separates in such sandy soils are of great importance. For instance, in northern regions, the soils containing less than 5 per cent of silt and clay are not suitable for commercial reforestation; soils having 5 to 10 per cent of fine material are suitable only for planting high light demanding pines, such as jack pine; slightly heavier soils are adapted to semi-tolerant pines, such as red pine. Thus, in the surveying of light textured soils for forestry purposes an especially careful and detailed textural classification is required.

On the other hand, detailed knowledge of colloidal content in heavy soils is only of minor significance to the forester. As far as texture is concerned, such soils are capable of supporting any type of the upland forest vegetation. In other words, in heavy soils the colloids cease to be a limiting factor, and are of importance only as far as they influence the physical condition of soil, namely structure, internal drainage and aeration. For this reason, several textural types of agricultural classifications, such as loam, silt loam, and ~~aley~~ clay loam in some instances may be regarded as one forest soil type.

(c) Stoniness. Some of the agricultural surveys distinguish the soil types according to the amount of stones per acre, as stoniness is a highly important factor in the possibilities of agricultural land utilization. In such a classification some types may be divided into as many as four sub-types, based upon the degree of stoniness. From the standpoint of silviculture, the presence of large stones is of significance because it eliminates the possibility of plowing and, hence, should be considered in forest soil mapping. At the same time the detailed classification of stoniness is of little importance to the forester because stones do not interfere with the spot planting method, and may even be beneficial by providing shade to trees planted on cut-over or burned-over land.

Degree of Accuracy and Cost of Survey

The survey of land for forestry purposes is confined to specific areas selected for intensive forest management. It seldom covers an area larger than one township, or 36 square miles, and is ordinarily carried on by traversing land at intervals of one-eighth of a mile. The area mapped as a separate type may be as small as two acres. This great intensity is justifiable because the character of a plantation or of selectivity logged stand can not be changed for many years. Therefore, the surveyor of forest land is responsible for the results of a long time investment.

The survey of forest sites is relatively expensive, its cost often running as high as 10 cents per acre. This expense, however, is allowable as the planting of trees includes not only the cost of seedlings and planting operation, but also the expenses on taxes, fire protection, silvicultural care, and compound interest on all this money for a period of 30 or more years. Under such circumstances an insufficiently detailed survey, and subsequent improper planting may result in great losses. The minimum cost of planting is 7 to 10 dollars per acre. The minimum cost of the total investment is 30 to 40 dollars per acre. Thus, the cost of planting one township is nearly a quarter of a million dollars, and the total investment may exceed a million dollars. The cost of a detailed soil survey of one township is about 2,000 dollars which constitutes but 0.2 per cent of the total investment. These figures show clearly that it is advisable to spend the necessary amount of money on a careful selection of planting sites in order to be sure that the most decisive step in reforestation is taken in the right direction.

Equipment

Below are listed the most important items of equipment required in forest soil surveys.

Spades and soil augers, forester's compasses, tally counters, field-sheet holders with rubber bands or tatum-holders and supply of field sheets, graduated rulers, triangles, paper, pencils, pens, erasers, ink, and thumbtacks.

Hyposometer, diameter tape, increment borer, folding rule for soil profile measurements, soil testing outfits, bags for soil samples, blotters and herbarium frame for the collection of plants.

An accurate tire pressure gauge, in case a car with speedometer is used in surveying the area.

Plane table with accessories when there is no base map and an accurate survey of roads is required.

The chief of the surveying crew must make sure that all the equipment needed is in sufficient quantity and good order so as to prevent unnecessary delay of work.

Correlation of Soils and Forest Growth as a Basis for Establishing Soil Types

The greatest fault of the early soil survey classifications was the establishment of soil types on the basis of theoretical, speculative assumptions instead of observations of soils and grow th of plants in nature. As a result of this, in many instances "The soil surveyor knew the difference in soil properties when the vegetation did not." To overcome these discrepancies, the abstract classifications were gradually subjected to critical ecological analysis, using as an indicator the distribution of natural plant associations, and their rate of growth. As a result of these studies, there was recently advanced a theory of "ecological equivalents", based upon the fact that the floristic composition of a stand and its rate of growth on a given site are a complete expression of all the productive forces of that environment. In other words, the condition of vegetation was accepted as the only faultless classificational basis and the soil and other environmental factors were correlated with the distribution and growth of plants. Simultaneously, the mere "soil" classifications were replaced by broader and more elaborate ecological "site" classifications.

Since the condition of the forest association is the only object of importance to the forester, the ecological relationships form the foundation of the present day surveys for forestry purposes. On the basis of these principles the general procedure of the establishment of types to be surveyed is outlined below.

The soil surveyor selects in nature a sufficient number of sample areas, supporting forest stands of similar composition of trees, shrubs and ground vegetation. These areas are usually selected within the surveyed tract, but in case of cut-over or burned-over land may be located in the surrounding territory. The outstanding floristic and mensurational characteristics of the sample areas are recorded. The determination of the average rate of growth, and the identification of the typical plant indicators are of particular importance in this phase of the study. A careful investigation of the soil profile is made at the same time that the mensuration and botanical records were taken. The statistical treatment and comparison of all the data obtained, outlines the principal ecological units. These may be further subdivided in accordance with the needs of reforestation practice. For instance, the same silt loam mull soil, supporting a hardwood stand with a ground cover of Maidenhair fern, may be divided into two types, namely: level outwash silt loam, allowing for furrow planting, and rough stony morainic silt loam, requiring spot planting.

Invariably, in forest soil surveys, the areas separated must have differences of practical significance either in their adaptation to tree species, rate of stand growth, possibilities of natural reproduction, technique of planting, or methods of thinning and logging.

The actual surveying of land is usually influenced by the rule of "practical balance" requiring separation of <u>small areas</u> characterized by <u>great differences</u>, and <u>large areas</u> characterized by <u>small differences</u>. According to this rule, frost pockets or potholes 3 acres or less in size may be mapped separately in a sand region, while areas of a light sandy loam can be overlooked unless they attain a size of 8 or more acres. The mapping of small but conspicuous areas, such as leather leaf bogs or rock outcrops, is often desirable not because of importance of the areas themselves, but because of their value as landmarks.

Nomenclature

Soil types or sites surveyed are designated on the basis of location of the representative area of the type, morphological properties, suitability for certain tree species, or characteristic ground cover.

Naming soil types after a certain town or locality, such as <u>Plainfield sand</u> or <u>Kennan loam</u>, is the easiest way to classify a great variety of soil types. It eliminates the necessity of using long descriptive names such as "slightly podzolized sandy loam over clay", and prevents possible confusion of soil types in different regions. However, a map provided with a legend of this kind cannot be interpreted without an accompanying report, and is inconvenient in the field.

On the basis of morphological features the soils are designated as, for example, barren sand, leached sand, outwash mull loam, morainic loam podzol, wet loam, mottled loam, structured clay, etc. This is the most direct and descriptive method, and should be used at least on the basic soil map, provided the survey is confined to a limited area. If the area surveyed has a great variety of soil types, nomenclature often involves a combination of textural, genetical, geological and hydrological characteristics.

Designation of sites according to characteristic tree species such as "Jack pine site", "Spruce site", "Lowland hardwood site", is most useful on the map showing planting possibilities. Such a map is usually constructed from the basic soil map by combining soil types suitable for planting to the same species, or the same mixture of species. This system meets with the enthusiastic approval of practical foresters, because of its simplicity and directness. However, the presentation of the entire survey in terms of planting sites often may not be desirable as there may be great differences in productivity and response to management of soils suitable for the planting of the same species, or supporting stands of the same composition.

The use of the characteristic ground cover as a basis for classification such as Vaccinium site, Fern site or Wood-sorrel site, is very convenient in surveys of extensive forest tracts supporting virgin or mature forests. Also, the map of floristic sites may be very helpful in carrying on the planting, thinning and selective logging program in regions with diversified topography. In surveying tracts with large areas of cut-over land or young second growth stands a purely floristic legend may lead to serious misinterpretations and general confusion.

In the majority of instances it will be found desirable to present the results of the survey on a map showing soil types classified on the basis of their morphology. This map may be further supplemented by the map of ecological sites, based upon adaptation of land to certain tree species, or upon characteristic ground cover vegetation. In some instances boundaries of sites may be superimposed upon the soil map by using lettering, water colors, dotting, cross-hatching, or some other method.

Soil Survey Report

The map of forest soil types, or forest sites, must be accompanied by a report written in clear, carefully worded language. This report must contain the following information:

(1) General Characteristics of the Area Surveyed. Geographic location, variation in altitude and topography, water basins, rivers and creeks, ownership, transportation facilities, local wood-using industry, importance of area in recreation, wild life management, forest fire hazard, and other data of practical significance.

(2) Climate including data on mean annual, minimum, maximum, and growing season temperatures, occurrence of early spring and late fall frost; annual and growing season precipitation, frequency and duration of drought periods; number of cloudy days per growing season, air humidity, precipitation-temperature or precipitation-saturation deficit ratios, direction of prevailing winds and possibly other data of importance.

(3) Geology. Nature of surface formations and underlying rocks; mineralogical origin of parent soil material; processes of erosion.

(4) Vegetation. Record of forest trees, important shrubs and characteristic ground cover associations.

(5) Technique of mapping employed including the statements in regard to reliability of controls, intervals at which the land was traversed, size of area recognized as individual type or site, general accuracy of survey.

(6) Soil and site classification giving a brief review of soil types or sites recognized, method of soil study, number of soil profiles investigated, frequency of borings, designation of horizons, use of forest cover and ground vegetation as a guide in soil classification.

(7) Detailed description of types surveyed. Composition of soil profile, statement about nature of organic remains, content of colloids, depth of ground water, moisture of the surface soil layers, aeration, reaction, and available nutrients. Composition of main forest stand, understory, shrub layer, and ground vegetation. Approximate rate of growth. Possibilities of natural seed reproduction, ability of certain species to sprout, competition of weed species. Suitable systems of silvicultural management; types of thinnings, release cuttings or selective logging. Species important in soil conservation, game and fish protection, reduction of fire hazard, or as seed trees and nurse trees. Possibilities of artificial reforestation; species suitable for planting and advisable methods of planting.

It is advisable to attach to the report a schematic drawing of representative soil profiles. Such a drawing should indicate the minimum and the maximum depth of separate genetical horizons, emphasizing especially the impervious layers of hardpan, strata with a high content of carbonates, and water-logged layers of gley.

Figures 59 and 60 present examples of a forest soil map and a schematic outline of well-drained soil profiles from the podzol region.

Some examples of Soil Survey reports may be found in the literature cited.

The Use of Soil Survey Data in Forest Management

The soil types delineated by the survey usually serve as the units of forest management, called "compartments" or "lots". Depending on circumstances, however, the forester in charge may

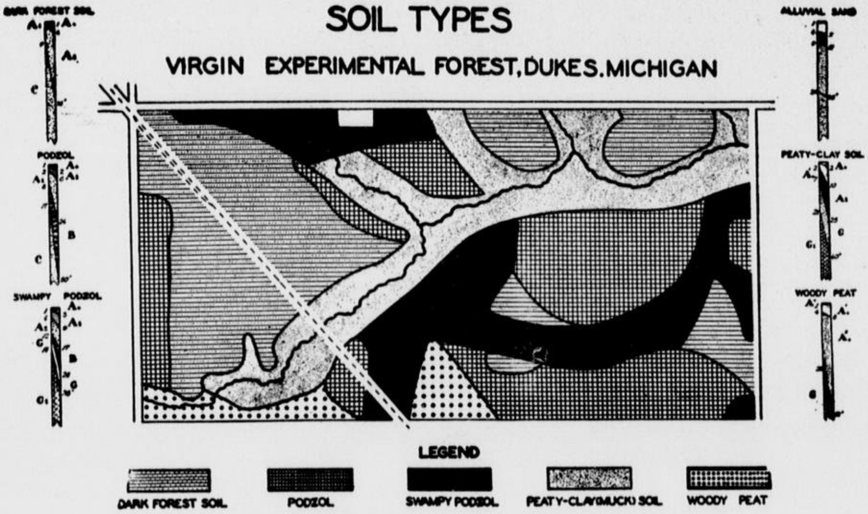


Figure 59. An example of a forest soil map.

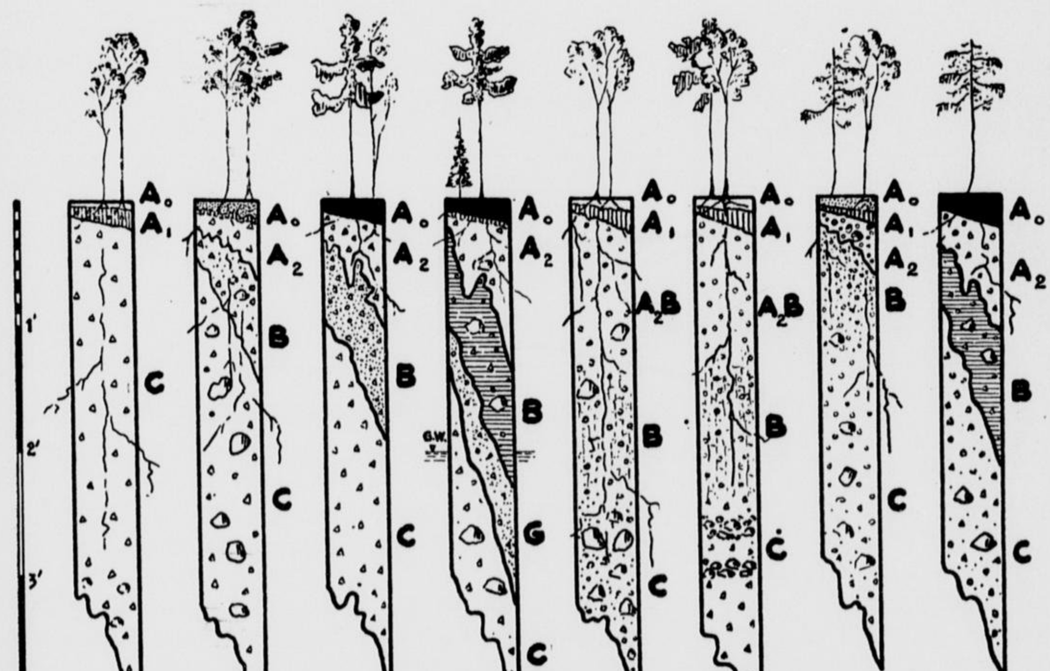


Figure 60. Schematic drawings of profiles of upland forest soils: (1) Outwash sand; (2) Leached morainic sand; (3) Sandy podzol; (4) Swamp podzol with hardpan and gley layers; (5) Humus-incorporated morainic loam; (6) Humus-incorporated outwash loam; (7) Leached morainic loam; (8) Loam podzol with a hardpan layer.

either combine several soil types, occupying small areas, into one compartment, or may subdivide extensive areas of the same type into a number of compartments. When a compartment includes a complex of soil types, these are treated as "subcompartments". The subdivision into subcompartments may also be necessary because of differences in the origin, age, or composition of forest cover.

The compartments are customarily designated by Arabic numbers and subcompartments by small letters. Such designation helps greatly to keep a permanent orderly record of all the data pertinent to the growth and silvicultural treatment of individual forest stands. Table 31 gives an example of stand inventory comprising a part of the management plan.

Table 31. Stand Inventory

Unit	Composition of soil	Composition of stand	Area acres	Age yrs.	Site index	Remarks
7a	Podzolic sandy loam; level outwash	0.8 Wh.pine[4], Red pine[1], Aspen[5]	17.3	22	70	Release cutting due
b	-"-	Recently burned area	5.5	--	--	To be planted to red pine in 1941
c	Swamp-border sandy podzol	0.7 Wh.pine[3], Wh. spruce[1], ba. fir[2], aspen[4]	3.4	22	50	No treatment until 1950

In the event that the forest tract is composed of several large areas having different conditions of physiography and forest cover, such areas are treated as independent broad management units referred to as "working circles". Usually working circles are managed on different rotations and under different silvicultural systems. Heavy morainic deposits with hardwood stands attaining suitable lumber dimensions at the age of 80 years, and sandy outwash with jack pine available for pulp at 40 years may be given as examples of two working circles.

Survey and Subdivision of Forest Tracts in the Mountains

In a country with sharply pronounced relief, especially in high mountains, the conditions of exposure and gradient play just as important a part in the forest growth as do the properties of soil. Because all physical factors of forest growth, including climate, ground water, and soil, are affected by topography, the intimate knowledge of its influences is essential for proper subdivision of forest tracts.

Hill tops, ridges, and similar elevated portions of topography receive much light and heat; they are exposed to the wind and their available moisture is at a minimum. The valleys and basins, on the contrary, receive a smaller amount of light and heat, but an abundance of moisture. As a result of this, the xerophytic forms of forest cover tend to occupy the elevated localities, whereas the mesophytic and hygrophytic vegetation is largely confined to depressions. The valleys and trough-like or kettle-like depressions tend to accumulate cold, stagnant air, which is detrimental to vegetation. As a result of this, such depressions, or "frost pockets", support only frost resistant trees. Very often frost pockets are treeless or covered with dwarf specimens.

The conditions of light, heat, and moisture are also influenced by the exposure of slopes. In general, the exposures to be considered from an ecological standpoint are: northeastern, northwestern, southwestern, and southeastern. The northeastern exposure is the darkest and coolest. The southwestern exposure is the warmest and receives the most light. The other two exposures occupy intermediate positions. In the majority of cases, the northeastern and northwestern slopes retain a greater amount of available moisture because of the lower temperature, moderate evaporation, and retarded melting of snow in the spring. But the moisture content of different exposures, of course, varies greatly with the direction of rain-bearing or dry winds. The variation of climatic conditions on slopes of different exposures becomes more pronounced with increase in gradient.

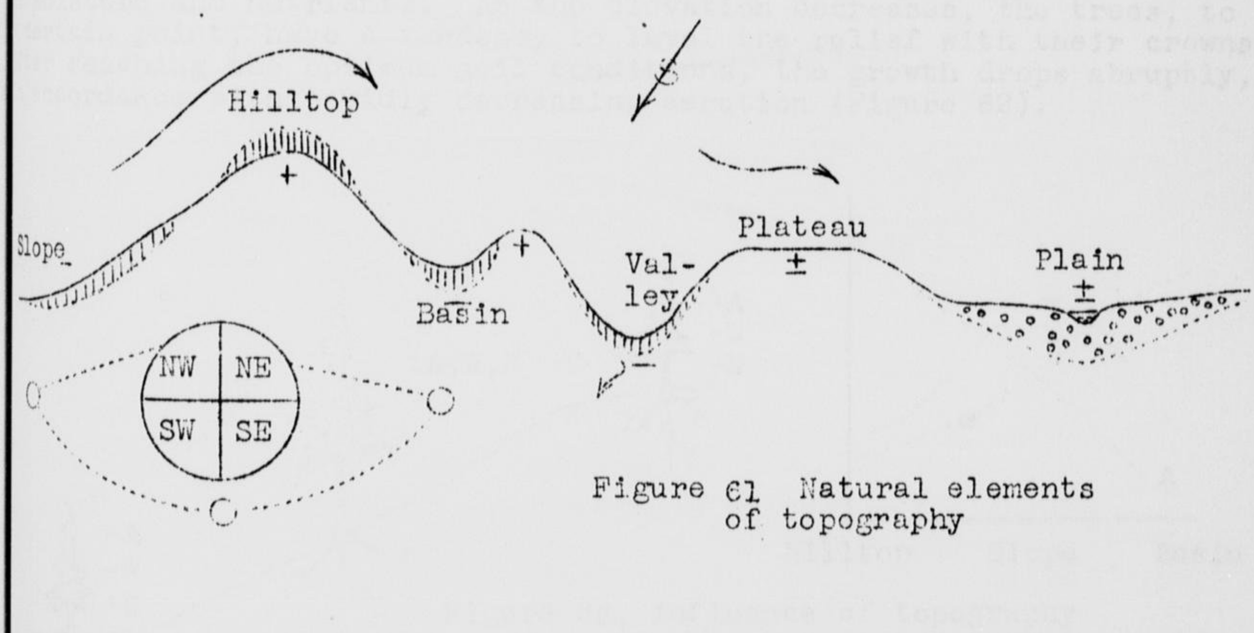


Figure 61 Natural elements of topography

The influence of exposure is often manifested in the distribution of tree species. Almost all over the northern hemisphere the pine forests at high elevations tend to occupy the southern slopes, while spruce and fir stands are found on the northern slopes. Paper birch of satisfactory growth in southern Wisconsin is prevalent on northern exposures, whereas oaks in northern Wisconsin make the best growth on southern exposures. In general, the forest species near the boundary of the region in which they occur tend to occupy the slopes facing that region.

The growth of forest trees in the spring on northeastern and also on northwestern exposures starts late; consequently, there is little danger of injury by the late frosts, and the plantings are more successful. For obtaining natural reproduction on these exposures a rather heavy thinning of the mother stand is required in order to secure sufficient light for young seedlings. On southwestern, and to some extent southeastern exposures, seedlings suffer from late frosts. Therefore, the spring planting and seeding should be done on such exposures as late as possible. The intense evaporation on these sites is often responsible for the lack of moisture and failure of plantings. The fire hazard is especially great in these localities. In cuttings for natural reproduction, a rather dense canopy of the mother stand must be maintained to prevent too rapid decomposition of humus.

Topography affects the properties and productivity of soil. Water running down a slope carries eroded fine soil material, humus, and dissolved salts which are deposited on the lower slopes and in depressions. Because of this, three basic land types may be distinguished: (1) eroded tops of hills and ridges, often dry, low in available nutrients and with a relatively poor tree growth; (2) enriched lower slopes, usually fairly moist, well aerated, and fertile; characterized by productive forest stands; (3) basins and valleys with a high content of humus and mineral salts, but also often with excessive moisture, insufficient aeration, and, hence, little availability of nutrients and poor tree growth.

It has been found by mensuration studies that the rate of growth on a complete topographical complex is expressed by a curve which can be correlated with the three main factors of forest growth: moisture, aeration, and available nutrients. The poor growth of forest occurring on the highest areas is correlated with a low amount of moisture and nutrients. As the elevation decreases, the trees, to a certain point, have a tendency to level the relief with their crowns. After reaching the optimum soil conditions, the growth drops abruptly, in accordance with rapidly decreasing aeration (Figure 62).

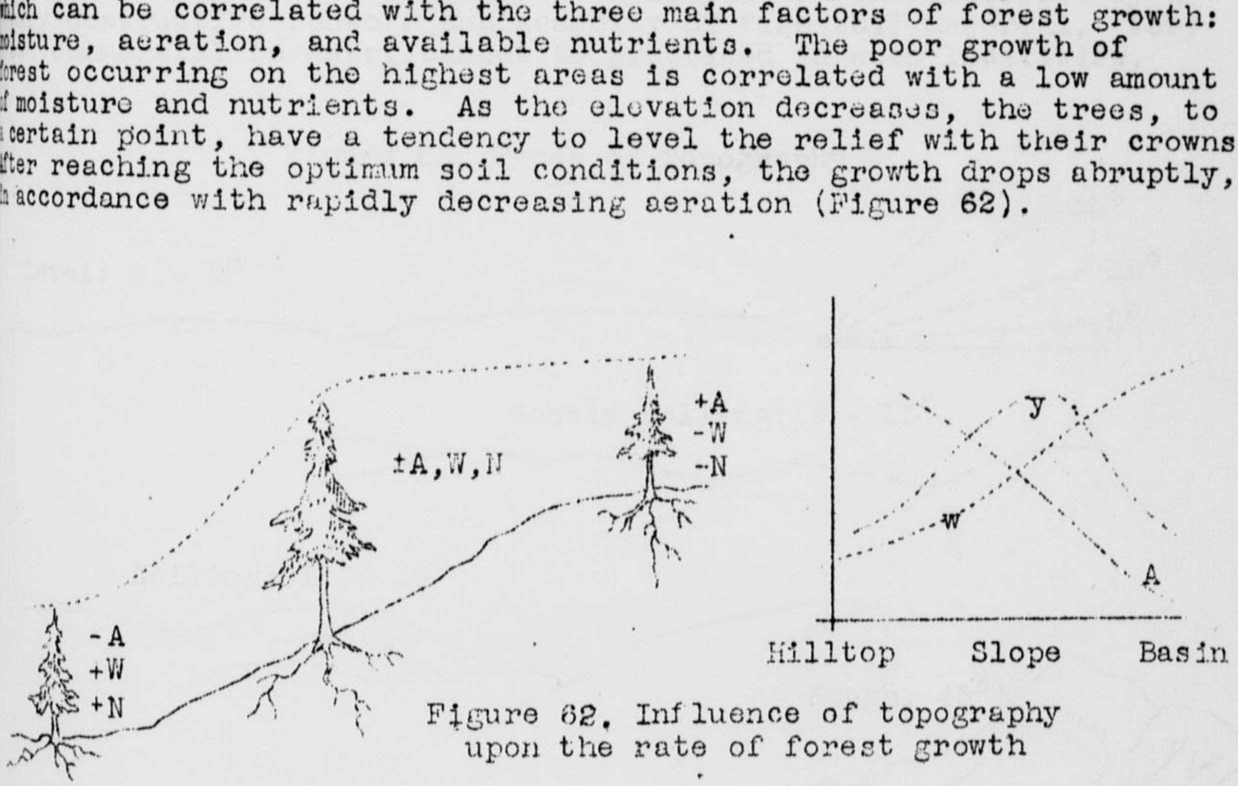


Figure 62. Influence of topography upon the rate of forest growth

With reference to the erosion and deposition of eroded materials, topography may be classified, according to Passarge, into three principal types.

<u>Positive topography</u>, including the portions of relief subject to erosion, such as peaks, ridges, hill tops, hog backs, and higher slopes;

Neutral topography, including nearly horizontal formations, such as plains, terraces, and plateaus;

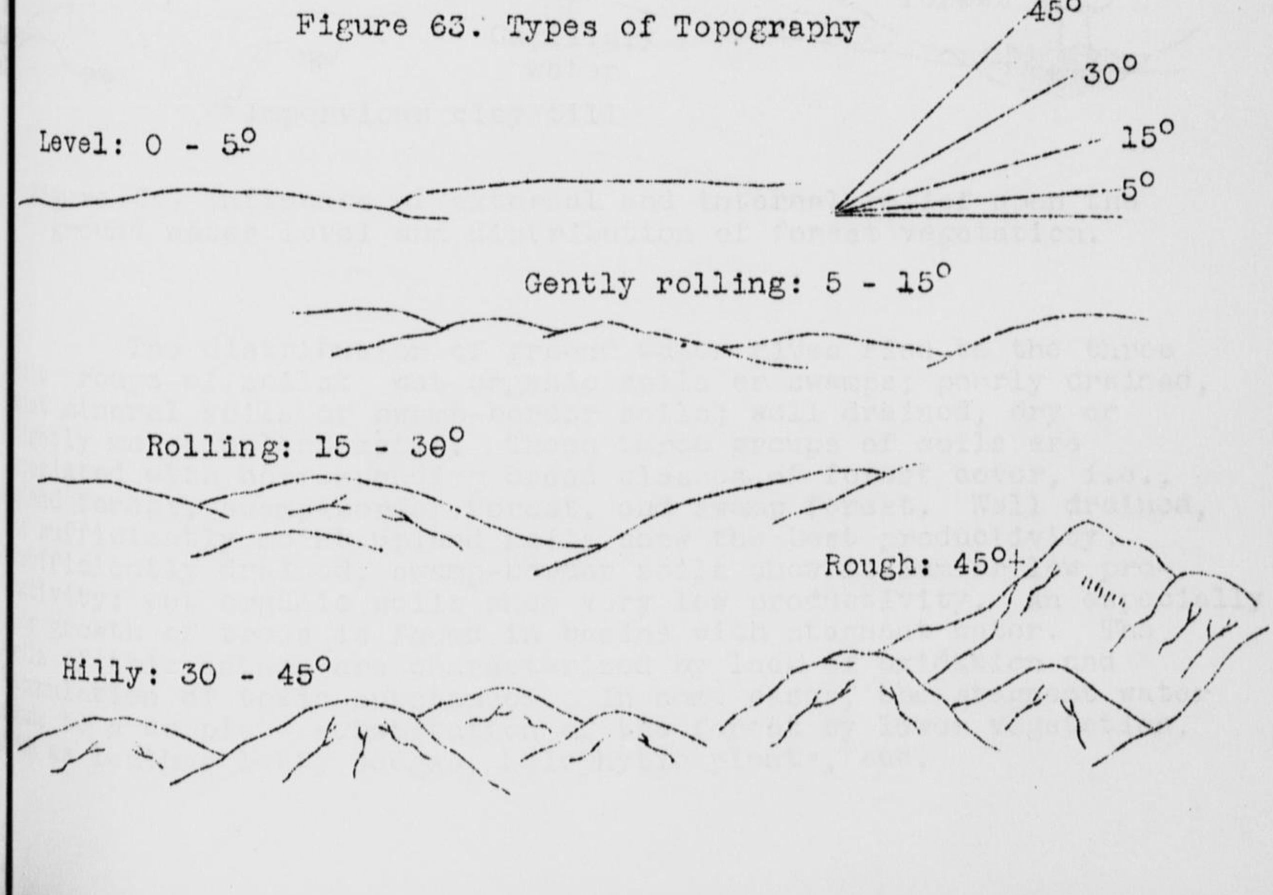
Negative topography, including the portions of relief subject to deposition of eroded materials, such as lower slopes, valleys, canyons, and basins. Valleys and canyons have a definite surface run-off, and show certain re-translocation of deposited matter. The basins have no surface run-off, and are the areas of a final deposition.

The intensity of erosion, the productivity of forest soils and their adaptation to silvicultural practice depend upon the steepness of slope. Accordingly, the topographic features are expressed by the following classification:

Degree of Gradient	Type of Topography	Type of Slope
0-5	level or undulating	-----
5-15	gently rolling	gentle
15-30	rolling	moderate
30-45	hilly	steep
45 or more	rough	precipitous

The best conditions for silvicultural practice are found on level land and gentle slopes. Moderate slopes are also satisfactory for tree growth, but plowing the land for planting is more expensive. Steep slopes are absolute forest lands, and subject to intensive erosion; selective logging is preferred since artificial reforestation encounters difficulties. Precipitous slopes are characterized by a highly destructive run-off and scarcity of fine soil material. Very often commercial forestry cannot be practiced in such localities.

Figure 63. Types of Topography



In the majority of cases, the topography is responsible for the distribution of ground water. The depressions have a high water level which permanently influences the soil and forest vegetation. The lower slopes are influenced by the ground water rather periodically either directly or by means of capillarity (Figure 64. The elevated areas are not influenced by the ground water at all. This relationship, however, does not always hold true in nature. It is possible to find the ground water level higher on the elevated plain, than on the lower slopes. This may be caused by the occurrence of rock substratum, weathered glacial till, or layers of colloidal shale. Also, the ground water table may be formed in upland relief by the impervious claypan layers resulting from translocation of colloidal substances.

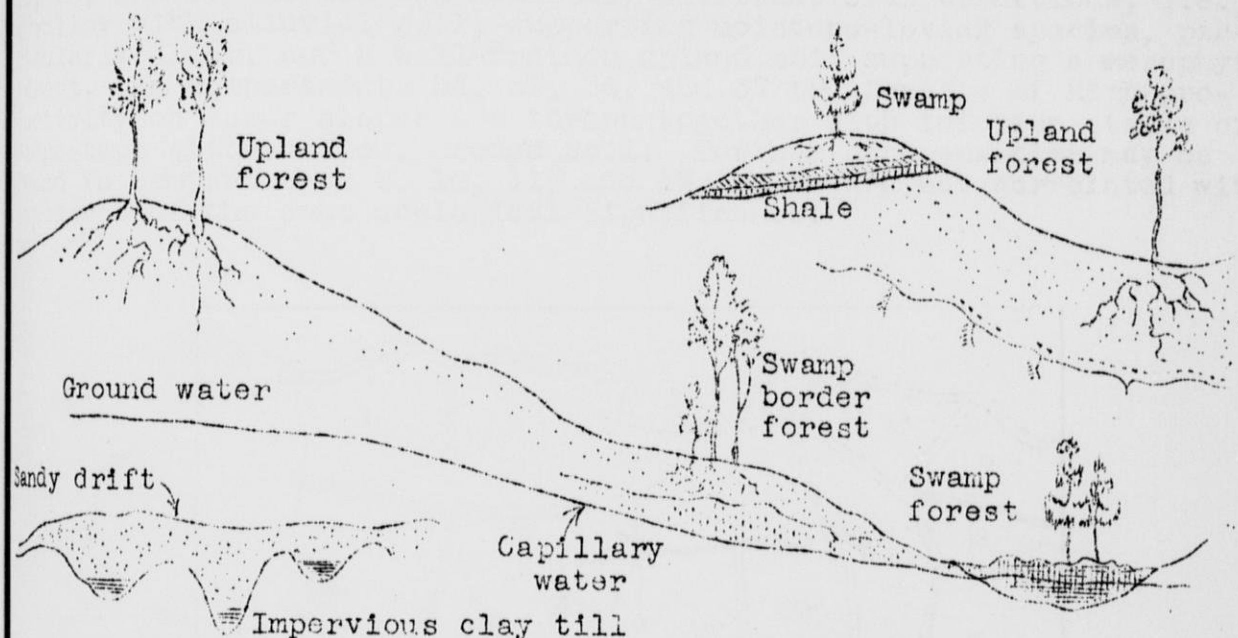


Figure 64. Influence of external and internal relief upon the ground water level and distribution of forest vegetation.

The distribution of ground water gives rise to the three basic groups of soils: wet organic soils or swamps; poorly drained, moist mineral soils or swamp-border soils; well drained, dry or slightly moist upland soils. These three groups of soils are associated with corresponding broad classes of forest cover, i.e., upland forest, swamp-border forest, and swamp forest. Well drained, but sufficiently moist upland soils show the best productivity; insufficiently drained, swamp-border soils show medium or low productivity; wet organic soils show very low productivity. An especially poor growth of trees is found in basins with stagnant water. The soils of this nature are characterized by lack of oxidation and accumulation of toxic substances. In some cases, the stagnant water leads to a complete substitution of the forest by lower vegetation, such as leather leaf, sedges, halophytic plants, etc.

From the earliest days of organized silviculture in European countries, topography usually served as a basis for subdividing forest tracts into compartments, which are the permanent units of forest management. According to old practice, the boundaries of compartments usually coincided with ridges, cliffs, streams, lake shores, and roads. A subdivision of this kind, however, disregarded the uniformity of soil and forest vegetation within the compartment and led to unnecessary complications in forest management. Under the influence of findings of soil scientists and ecologists, the recent tendency has been to subdivide the forest areas into compartments containing ecologically uniform topographical features, and consequently, uniform conditions of forest growth.

Figure 65 gives an example of an erroneous, purely mechanical subdivision of a forest tract taken from the standard European text on forest management by Guttenberg. It is obvious that compartments 17, 18, 28, and 33 embrace two radically different site conditions, i.e., a valley with alluvial soil, supporting moisture-loving species, particularly alder, and a well-drained upland soil supporting a mesophytic forest. In compartments 34, 35, 36, and 37 the forests of high productivity on lower slopes are thrown together with inferior stands of ridge-tops with shallow, eroded soil. Further discrepancies may be found in compartments 9, 10, 11, and 12, which are not correlated with exposures of the same ecological significance.

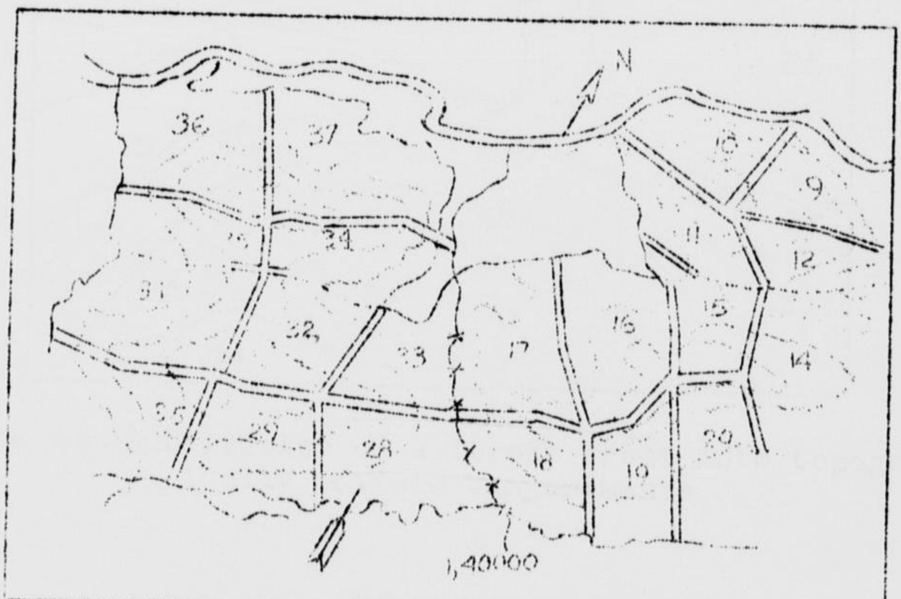


Figure 65. Subdivision of the Purkersdorf Forest near Vienna. (Adopted from A.v. Guttenberg's Forstbetriebseinrichtung).

Subdivision of forests on an ecological basis often meets with objections from practical foresters, who point out the inconveniences which may be created in logging operations and road construction. Their arguments are based chiefly on the assumption that the compartment boundaries must coincide with roads and other permanent objects. However, for all practical purposes the ecological boundaries of compartments can be marked in nature by blazing trees or setting a limited number of posts. In many instances, the boundaries of compartments will be sufficiently indicated by differences in topography as well as by composition of the forest, and will need no marking. Also, quite often it will be found that construction of roads along the ecological boundaries is just as cheap and convenient as otherwise. When the forest stands mature and are cut in different ways, according to conditions of habitat, the differences in the regenerated stands will serve as boundaries.

Figure 66 represents a contour map of a forest tract in rolling topography, illustrating a method of subdivision which sufficiently preserves the ecological uniformity of compartments. The roads are indicated by heavy solid lines and the blazed boundaries or trails by the broken lines.

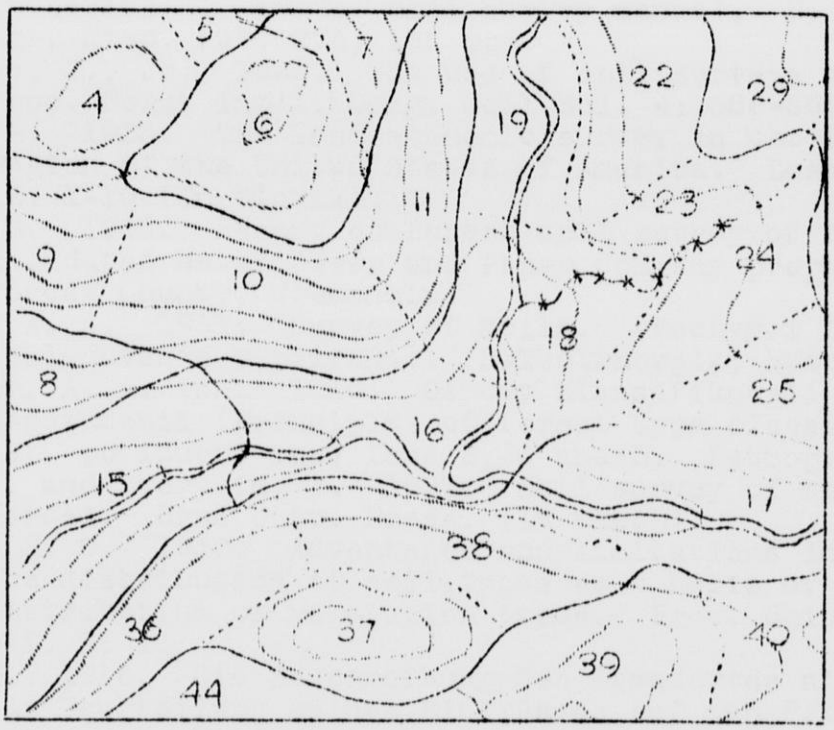


Figure 66. Subdivision of a forest tract into topographically uniform compartments

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CHAPTER XXII

SOILS AND TREE PLANTING

"Probieren geht ueber Studieren;
aber erst studieren, dann
probieren."

Heinrich Mayr

Reforestation Program

The reforestation program in a given region includes the following major steps: the selection of the species suitable for planting, production of the planting stock, selection of planting sites for each species, and planting proper.

Selection of Tree Species

The species for planting are usually selected by the chief administrative officer responsible for the reforestation of a large territory, such as a state or a national forest. The conditions of climate and soils, resistance to insects and diseases, and the commercial importance of the species are the principal points considered in the selection.

In order to facilitate the location of nurseries and the proper distribution of stock, extensive regions are sometimes roughly divided into several areas adapted to certain combination of tree species or specific type of reforestation. Figure 67 gives an example of such broad division on the basis of climate and soils.

The seed of the chosen species is acquired from reliable sources and used either for direct seeding or for raising planting stock in nurseries. In the great majority of cases the selection of trees to be planted is confined to native species the seed or cuttings of which are collected in the same region, and from areas ecologically similar to the planting sites.

The planting of species introduced from aborad or from other sections of the same country is hazardous and must be carried on with rigid observance of the rules of acclimatization. The wholesale recent destruction of Norway spruce stands of central Europe by Nun moth, spruce beetle, and red-rot has given most convincing evidence of the danger involved in the violation of the site requirements of a species.

Whereas the danger of the introduction of "foreign" or "exotic" species is usually emphasized, little consideration is given to the shifting of "native" species within the boundaries of a political unit, even though such a translocation sometimes involves much greater changes in the environmental conditions. A translocation of white spruce, for example, 200 miles from northern to southern Wisconsin may present a much more difficult problem of acclimatization than the translocation of Scotch pine from the Danube Valley, 5,000 miles, to central Wisconsin. Thus, a "foreign species," in a political sense, may be a "native species" in an ecological sense, and vice versa.

Tree Planting Areas

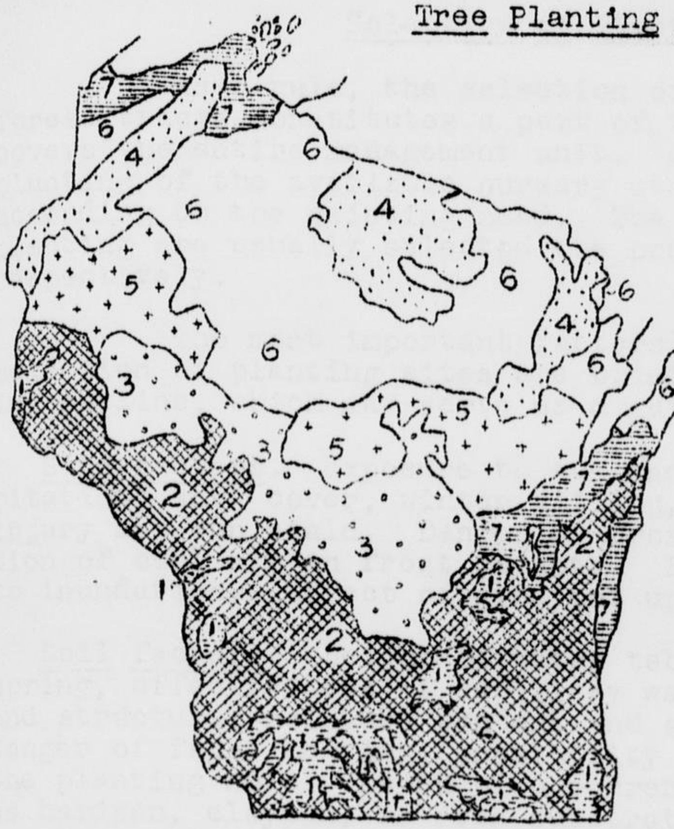

Figure 67. Silvicultural Regions of Wisconsin

1. Prairie soils: Tree planting is limited to shelterbelts, game-cover, and erosion control.

2. Silt loams derived from limestone or calcareous drift: White or green ash, American elm, black walnut, hickory, and oak species; red and white cedar. Planting of other conifers is questionable.

3. Sands and sandy loams derived from siliceous rocks: Jack pine, red pine and white pine; black locust and cottonwood. Planting of other deciduous species should be confined to a few areas having a heavy clay subsoil. The planting of spruce is inadvisable.

4. Sands and sandy loams derived from granitic rocks: Jack pine, red pine, white pine; planting of spruce should be confined to the more favorable areas with boulder clay subsoil and accessible ground water.

5. Slightly leached loam soils with mild humus: Northern hardwoods: hard maple, basswood, American and rock elm, red oak; white pine. Planting of spruce is questionable.

6. Strongly leached loam soils with raw humus: White spruce, yellow birch, elm. Other northern hardwoods should be confined to sporadic areas of slightly acid soils. The planting of interspersed sandy soils should be limited to pines.

7. Lacustrine clay: Planting is handicapped by the unfavorable physical properties of the soil, heaving, and high content of lime in the subsoil, and should be carefully investigated in each individual case.

Selection of Planting Sites

As a rule, the selection of planting sites on organized forest tracts constitutes a part of the forest soil survey which covers the entire management unit. Otherwise, areas suitable for planting of the available nursery stock are selected periodically according to the existing need. The sites for spring and fall planting are usually selected the preceding fall and summer, respectively.

The most important factors to be considered in the selection of planting sites are briefly summarized in the following outline, which may serve as a guide in field work.

Site factors. Exposure to sun and wind; distribution of precipitation, snow cover, winter killing, frost heaving, drought injury and sun scald. Danger of frost injury from the accumulation of cool air in frost pockets. Position of the area in regard to inundation. Effect of gradient upon soil erosion.

Soil factors. Height of water table; saturation of soil in spring, effectiveness of capillary water in summer. Soil texture and structure; moisture content and aeration in critical periods, danger of frost heaving, possibility of leaving air pockets in the planting hole. Depth of occurrence of impervious layers, such as hardpan, claypan, or rock substratum, and their effect on root development; danger of drought and windfall. Amount and kind of humus; its effect upon the growth of plantation and possibilities of natural reproduction. Reaction of soil. Content of essential nutrients, viz. nitrogen, phosphorus, potassium, calcium and magnesium. Toxic substances, especially calcium and magnesium carbonates and highly concentrated soluble salts.

Biotic factors. Competition of herbaceous and woody vegetation. Danger of injury by rodents, game and grazing livestock. Possibilities of natural reforestation. Sociological relations of planted species to native vegetation including trees, shrubs, ground cover and lower plant forms. Danger of insect attacks and infection by diseases.

It is obvious, that in addition to ecological conditions a number of purely economic factors, such as recreational value of area, transportation facilities, danger of fire, etc., must be considered in the selection of planting sites.

Because the significance of soil factors varies considerably under different climatic conditions and with different ecological varieties of the same species, only general suggestions can be given in regard to the suitability of soils for planting various trees. Table 32 presents the approximate data on the depth to ground water level, soil texture, content of organic matter, and reaction of soil related to the planting of several silviculturally important coniferous and hardwood species. It should be stressed that a success of planting cannot be assured with the species having only medium or low ability to survive on exposed cut-over areas unless such species are planted under protection of a nurse stand.

Table 32. Planting Site Requirements of Representative Coniferous and Deciduous Species

Species to be planted	Ability to survive on exposed cutover areas	Minimum depth to ground water table	Minimum content of silt & clay particles	Minimum content of organic matter in 7-inch layer	Range of suitable reaction
		feet	percent	percent	pH
JUNIPERUS VIRGINIANA* Red cedar	High	4.5	none	none	5.5-8.0
LARIX LARICINA* Tamarack	High	1.5	15	2.5	3.7-6.8
PICEA GLAUCA White spruce	Low	3.0	30	4.0	4.7-6.8
PICEA EXCELSA Norway spruce	Low	3.0	30	4.0	4.7-6.8
PINUS LARICIO* Austrian pine	High	4.5	15	2.5	6.8-8.0
PINUS BANKSIANA Jack pine	High	4.5	5	1.0	5.5-6.8
PINUS ECHINATA Shortleaf pine	High	4.5	10	1.0	4.7-6.8
PINUS PALUSTRIS Longleaf pine	High	3.0	none	none	4.0-6.8
PINUS PONDEROSA We. yellow pine	High	4.5	10	1.0	5.5-8.0
PINUS RESINOSA Red pine	Medium	4.5	10	1.8	5.5-6.8
PINUS SILVESTRIS* Scotch pine	High	4.5	10	1.8	4.0-5.5
PINUS STROBUS White pine	Medium	3.0	15	2.5	4.7-7.3
THUJA OCCIDENTALIS* White cedar	Medium	1.5	30	4.0	4.0-8.0
ACER SACCHARUM Sugar maple	Low	4.5	30	4.0	5.5-7.3
ALNUS GLUTINOSA* Eur. Black alder	High	1.5	none	4.0	5.5-7.3
BETULA LUTEA Yellow birch	Medium	3.0	30	4.0	4.7-6.0
CARYA OVATA Shagbark hickory	Medium	3.0	30	4.0	5.5-8.0
FRAXINUS AMERICANA White ash	Medium	4.5	30	4.0	5.5-8.0
JUGLANS NIGRA Black Walnut	Medium	3.0	30	4.0	5.5-8.0
LIRIODENDRON TULIPIFERA - Tulip poplar	Medium	3.0	30	4.0	5.5-7.3
POPULUS DELTOIDES* Cottonwood	High	1.5	none	2.5	5.5-8.0
ROBINIA PSEUDOACACIA* Black locust	High	4.5	none	none	5.5-8.0
TILIA GLABRA American basswood	Low	4.5	30	4.0	5.5-7.3
ULMUS AMERICANA American elm	Medium	3.0	30	4.0	5.5-8.0

* Emergency planting for control of erosion, watershed protection, and similar purposes.

The minimum contents of silt and clay particles refer to well-drained upland soils; they may be somewhat high for planting on soils with a high ground water table, or in regions influenced by large bodies of water. However, even under such conditions it is not advisable to lower the standards without an urgent need, as the content of colloids is related not only to the water-holding capacity of soil but also to the content of available nutrients. Of prime importance in the selection of planting sites is to keep in mind that the species planted should not only survive on the selected site, but also produce high yield of timber justifying the planting cost.

Ordinarily, the content of available nutrients is correlated with the content of soil colloids, organic matter, and the pH value of soil, and hence detailed chemical analysis of soil in the majority of cases can be omitted in the selection of planting sites. Nevertheless, the chemical composition of soil cannot be completely ignored, as stagnant growth of numerous plantations in Germany and elsewhere was traced to the deficiency of certain nutrient elements.

In a broad way, chemical composition and the potential fertility of soils, not greatly altered by the processes of podzolization or laterization, may be estimated on the basis of the origin of the parent soil material, as outlined in Table 33.

Table 33. Relation of Geological Origin of Soils to Their Potential Productivity and Planting Possibilities

Nature of parent soil material	Probable chemical composition of soil or substratum	Reforestation possibilities
SILICEOUS ROCKS Sandstone Quartzite Siliceous shales	Low content of nutrients, especially phosphate and potash	Pines and less exacting deciduous pioneer species.
ACIDIC ROCKS Granite Syenite Gneiss	Adequate content of nutrients with possible exception of lime	Conifers and hardwoods with the exception of pronounced lime-demanding species.
FERRO-MAGNESIAN ROCKS Diorite Diabase Basalt	High content of nutrients, especially calcium and magnesium.	Hardwoods; Conifers, particularly spruce, tend to produce high yields, but are often subject to fungus diseases.
CALCAREOUS ROCKS Limestone Dolomite Calcareous shales	High or excessive content of lime; possible deficiency of phosphate and potash.	Lime-tolerant hardwoods and conifers, viz. oaks, hickory, walnut, ash; beech, red and white cedar, Austrian pine. Planting of the majority of conifers is questionable.

In order to ascertain the presence of an adequate supply of essential nutrients in soils proposed for reforestation, representative soil samples should be analyzed in the laboratory. Such analyses are particularly desirable in regions showing poor growth of native stands or plantations. As a rule, the analysis can be limited to the upper 7-inch layer of soils as its composition usually reflects the properties of the substratum and is of decisive importance in the initial growth of planted trees. In some instances, however, it may be necessary to analyze the lower soil layers provided they occur at a depth which can be reached by the roots of seedlings within a few years. The roots of cottonwood or some other deciduous species may reach the nutrient-bearing substratum as deep as 6 or 7 feet during the second growing season after planting.

The available data on the minimum fertility levels necessary for a satisfactory growth of different groups of trees are given in Table 34.

Table 34. Minimum Contents of Essential Nutrients Necessary for a Satisfactory Growth of Representative Tree Species in Plantations

Tree species planted at a spacing 4 by 4 feet or greater	Content of nutrients in the upper 7-inch layer of soil: Total N (%)	Avail. P_2O_5 (lbs./acre)	Avail. K_2O (lbs./acre)	Repl. Ca (m.e./100 gms.)	Repl. Mg (m.e./100 gms.)
Pioneer pines, such as Longleaf pine, jack pine and Scotch pine	.02	Tr.	30	.4	.1
Intolerant coniferous and deciduous spp., viz. larch, red pine, wh.pine, birch and alder	.05	20	50	1.5	.3
Tolerant conifers and northern hardwoods--e.g. spruce, fir; hard maple, basswood	.10	50	125	2.5	.7
Lime-demanding hardwoods; e.g. white ash, black walnut and hickory	.10	50	150	4.5	1.2

It should be noted that the contents of nutrients required by trees in forest plantations are very low in comparison with agricultural or forest nursery standards. This is because trees in plantations derive their nutrients from a much greater volume of soil than do field crops or nursery stock. For this reason, the deficiency of nutrients in reforestation practice occurs as an exception, confined chiefly to the soils derived from purely siliceous rocks and high-grade limestones, or soils depleted by repeated burning and cultivation.

Ground Cover Vegetation as an Indicator of Reforestation Possibilities

The composition of the ground cover vegetation, if correctly interpreted, furnishes very valuable information in regard to the selection of suitable species in planting or silvicultural cuttings. Table 35 presents an example of a floristic classification related to the reforestation possibilities in the area of recent glacial drift of northern Wisconsin. As a general rule, floristic classifications have only local significance and should be modified on the basis of a careful study of conditions as they occur within a given region.

Table 35. Ground Cover Vegetation as an Indicator of Reforestation Possibilities in Northern Wisconsin

Type of ground cover and soil	Outstanding members of ground cover association	Species to be planted or encouraged in selective and release cuttings
CLADONIA-NUDUM (Barren sand)	Reindeer moss, related lichens, xerophytic mosses and grasses.	Reforestation is limited to control of wind erosion.
ARCTOSTAPHYLOS-CEANOTHUS (Humus-incorporated sand)	Bearberry, New Jersey tea, low blueberry, dwarf hazel and willow	Jack pine; red pine on more favorable areas. The site is well suited to artificial reforestation.
GAULTHERIA-MAIANTHEMUM (Leached sand or light sandy loam)	Wintergreen, dwarf Solomon's seal, blueberries, shin leaf, trailing arbutus, sweet fern, hazel, raspberry and blackberry.	Red pine; white pine on more favorable protected areas. Natural reproduction is easily obtainable.
VACCINIUM-CORNUS (Sandy podzol)	Large blueberry, bunchberry, wintergreen, bracken fern, partridgeberry, twin flower, dew berry, fly honeysuckle.	Natural reproduction is likely to be more successful than planting; the latter is often handicapped by the occurrence of Ortstein or Gley layers. White pine on more favorable areas.
ADIANTUM-OSMORHIZA-THALICTRUM (Humus-incorporated loam)	Maidenhair fern, sweet Cicely, meadow rue, waterleaf, green briar, leatherwood; numerous shrubs.	Reforestation is confined to rough and stony areas because of the high agricultural value of land. Natural reproduction is very vigorous. Hard maple basswood, other hardwoods; spruce.
SMILACINA-POLYGONATUM	False, true, and dwarf Solomon's seal, twisted stalk, bellwort, trillium, sarsaparilla.	Spruce; yellow birch and elm. This site is well suited to artificial reforestation.
CLINTONIA-LYCOPODIUM (Loam podzol)	Clintonia, club mosses, partridge berry, gold thread, bunchberry, twin flower, mosses and ferns; no shrubs.	Planting is often handicapped by the occurrence of Ortstein or Gley layers and natural reproduction of hemlock, balsam fir and hardwoods should be given preference whenever possible.

As a rule, modern reforestation practice devotes much attention to the selection of species to be planted on various sites, but often neglects to ascertain the ecological suitability of the planting methods used. Actually, the selection of the proper method of planting is just as important as the selection of the species to be planted. The following outline gives a review of the common planting methods and their adaptation to different conditions of soil and site.

1. Slit planting. A slit about 10 inches deep is made by means of a spud or planting bar (Figure 68,1).The roots of the seedling are placed in the slit, and the slit is closed by another thrust of the spud and the planter's heel.

This type of planting is the cheapest but not entirely reliable. During the first season, the roots are forced to feed and absorb water entirely in one vertical plane. Long roots must be trimmed to a length corresponding to the depth of the planting hole. Air pockets are often left in closed slit allowing the roots of seedlings to dry out.

Satisfactory results are obtained only on sandy stone-free soils. On soils of heavy texture the method is impracticable, particularly because of the difficulty of eliminating the air pockets.

2. Spade planting. A wedge shaped portion of soil is removed with the spade (Figure 2). The roots of the seedling are placed against the vertical side of the hole. The wedge of soil is then replaced and thoroughly tamped with the foot. This method is essentially the same as slit planting. However, it involves less danger of leaving an air pocket at the bottom of the hole and, therefore, is somewhat better adapted to soils of heavier texture than the slit method.

3. Hole planting. The mattock, grub hoe, shovel or spade are used to dig a hole slightly larger than the extension of the seedling roots (Figure 3). The seedling is held in position with the roots well distributed in the hole. The humic soil is placed about the roots and thoroughly firmed with the foot.

Hole planting allows better distribution of roots than the slit method, and enables the seedlings to utilize larger quantities of moisture and nutrients in the earlier stages of growth. This planting is one of the most reliable methods, being suitable to a wide range of soil and site conditions with the exception of very shallow and poorly drained soils. It is the only method for planting stony or gravelly soils. It allows the mixing of additional fertile soil and the use of fertilizing materials.

4. Mound planting. The sod layer is destroyed by spade or mattock. On this exposed spot the humic soil from nearby is made into a mound on top of which the seedling is planted by hand, with the root system spread as much as possible (Figure 4). Sometimes the mounds are prepared a year or more in advance of planting, and a dibble or a spade is used to make the hole for the seedlings. A special planting iron devised by Henning is also used to impress a hole in the mound. This iron makes three slit-like holes extending

radially and being highest in the middle so that the roots may be spread laterally downward in their natural position and covered with fertile soil (Figure 5).

This type of planting is of greatest importance in reforesting poorly drained soils where the mounds insure a fair degree of aeration to the seedlings and reduce frost heaving. Mounds are sometimes used on heavier, upland soils in order to place the seedlings in an elevated position and thus give them a better opportunity to compete with weed vegetation. This method may be necessar in planting shallow residual soils, particularly those derived from calcareous rocks. It is advantageously practiced on podzol soils underlain by a hardpan layer. On soils of a light sandy texture wind erosion is apt to destroy the mounds and expose the root systems.

5. Planting in furrows. Furrows for tree planting are made with a special plow and tractor. The depth of furrows is varied according to site requirements from 3 to 12 inches. The planting itself is accomplished by means of mattock, spade or spud (Figure 6).

The chief advantages of furrowing are: (a) the plow and tractor destroy the grass, brush, and other competing vegetation; (b) when furrows follow contour lines they may retain run-off water and thus provide a greater amount of moisture for the seedlings; (c) the plowing may help the seedlings to reach the capillary water in a shorter time; (d) on exposed sites, deep furrows protect the seedlings from wind and sun. The north-south direction of furrows offer maximum protection seedlings from the sun. In regions where desiccating winds occur predominantly from north or south, the direction of the furrows should be somewhat inclined to the east or west as to avoid the direct passage of wind along the furrows.

The most serious disadvantages of furrowing are: (a) The plow removed the surface humus layer of the soil thereby decreasing the water holding capacity and content of nutrients; (b) on heavier soils, and in regions subject to early or late frosts, the water accumulated in the furrows may cause frost heaving; (c) plowing may expose toxic or impervious layers, such as hardpan, claypan, calcareous layers or unweathered rock substratum.

Experience has shown that deep furrowing is particularly beneficial in increasing the survival of seedlings on extensive cut-over areas, exposed to the desiccating effect of wind and sun. On sandy soils this increased survival is usually obtained at the cost of a somewhat lower rate of growth of the plantation during its earlier stage of development. Shallow plowing is beneficial chiefly on heavy mull and brown forest soils where it destroys the abundant competing vegetation. Planting in furrows is usually impracticable on podzols and shallow residual soils, particularly those derived from limestone. Also this method is not feasible on stony soils and areas supporting heavy sprouts. On some of these sites, as well as on protected areas, furrowing may be advantageously replaced by scalping which preserves the fertile humic layer. In some instances, the same results may be obtained by shallow plowing which destroys brushy vegetation and scalps off the sod, but leaves a certain portion of the humic layer undisturbed.

6. Double furrow planting. A narrow V-shaped furrow for planting the seedlings is made with a special four inch scooter plow. Two broad furrows are turned inward at a distance of about two feet on each side of the scooter furrow (Figure 7). The scooter furrow thus forms a catch basin for rain-water and checks the growth of competing grass.

This method is used principally on soils supporting a heavy cover of strong, fast growing grasses.

7. Planting on turned sod. The seedlings are set on the furrow slice or on the turned back sod of scalped spots (Figure 8). The purpose of the method is to secure the nutrients and moisture of a double humic layer, to place seedlings in a higher position so as to reduce the competition of herbaceous vegetation, and to provide better aeration on wet sites. Plowing or scalping is done in the fall preceding the spring planting or even earlier in order that the furrow slice or sod layer may settle and produce a uniform solid medium for planting. Seedlings are planted with the planting bar or spud.

This method is practicable chiefly in underplanting or in reforestation of small protected cut-over areas. On exposed sites the trees are often destroyed by drought and sun scald. Planting on turned sod is sometimes used in reforestation of podzol areas underlain by an ortstein horizon. In such plantings, the ridge is often made by turning two furrows inward. Similar technique may be employed in planting wet soils and drained peats.

8. Inverted "V" method of planting. The hole is dug with two separate downward strokes of a Baldwin planting hoe or a mattock in such a manner that an inverted V-shaped ridge or saddle of soil is left across the hole. The roots of the seedling are spread over this ridge. The tree is held with one hand, and some soil is pulled into the hole over the roots and packed tightly with the fist. The remaining soil is then placed in the hole and firmed with the feet (Figure 9).

The method provides a greater surface area for contact of the roots with the soil. It is largely suitable to sandy or light loam soils which are relatively free from stones and gravel. This method is not applicable to seedlings with a single tap-root.

9. Cone planting. The planting hole is made with a spade or grub hoe. A small conical mound is formed in the bottom of this hole using some of the best soils and the roots of the seedling are spread over its surface with the hand (Figure 10). More of the best soil is then placed over the roots and packed with the hands. Finally all the remaining soil is added and thoroughly firmed.

This method of planting accomplishes essentially the same purpose as the inverted V method, but the feeding roots are placed in a medium of the richer soil.

The method is primarily adapted for planting shallow rooted species, such as spruce, and is suitable for use on any deep well drained soil.

10. Sod cover planting. A block of sod, of about one square foot in area, is cut loose on three sides with the spade. This layer is turned back and the seedling is planted in the exposed soil (Figure 11). The sod layer is then cut through the middle and folded back into its original position. The depth of planting is regulated by the thickness of the sod layer so that the seedling is not buried too deep. This method is used on heavy soils subject to frost heaving, especially in planting large sized stock of deciduous species such as alder, birch and ash.

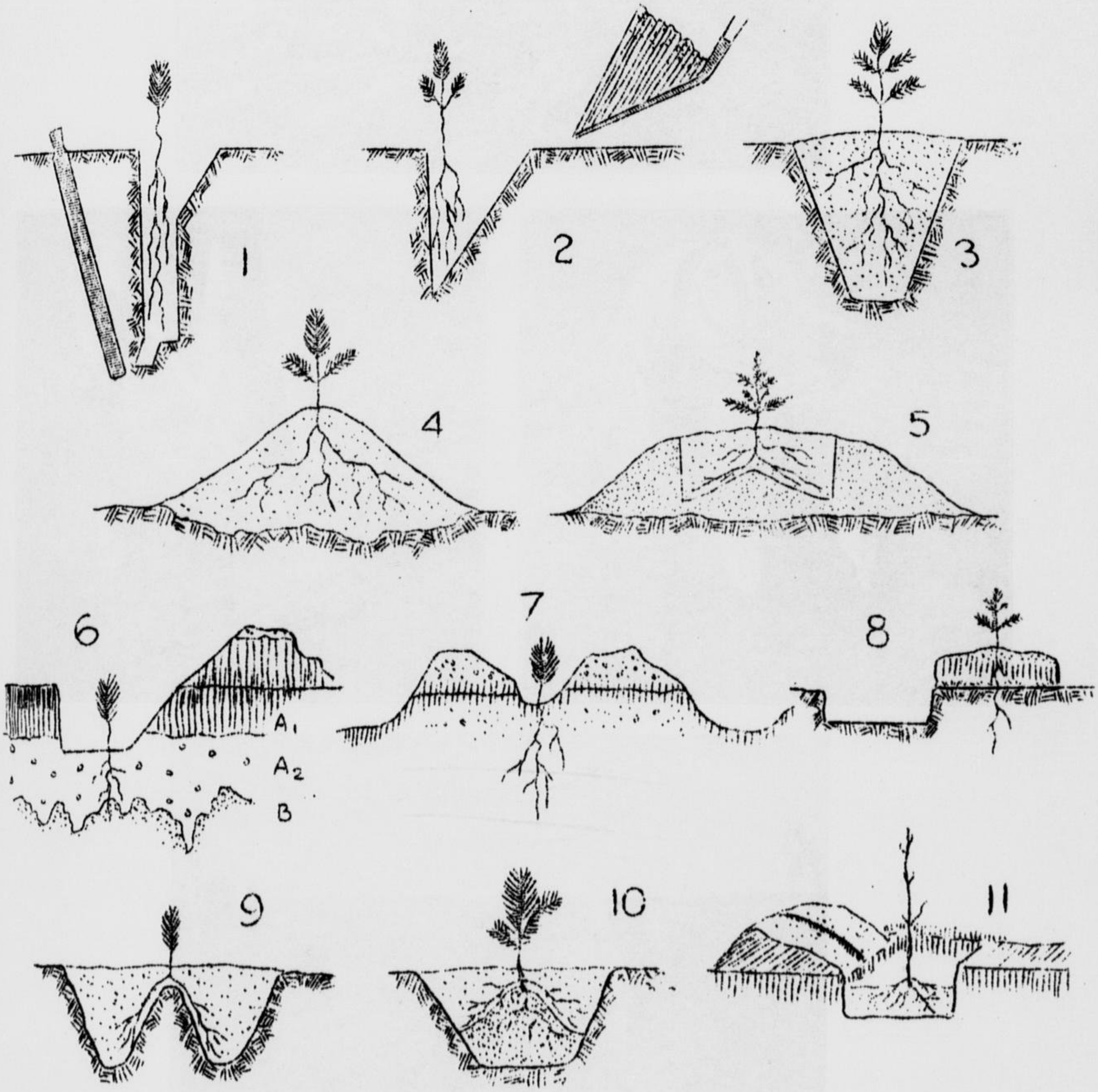

Figure 68

1. Slit planting; 2. Spade planting; 3. Hole planting; 4. Mound planting; 5. Mound planting using Henning's tool; 6. Furrow planting; 7. Double furrow planting; 8. Planting on turned sod; 9. Inverted V planting; 10. Cone planting; 11. Sod cover planting.

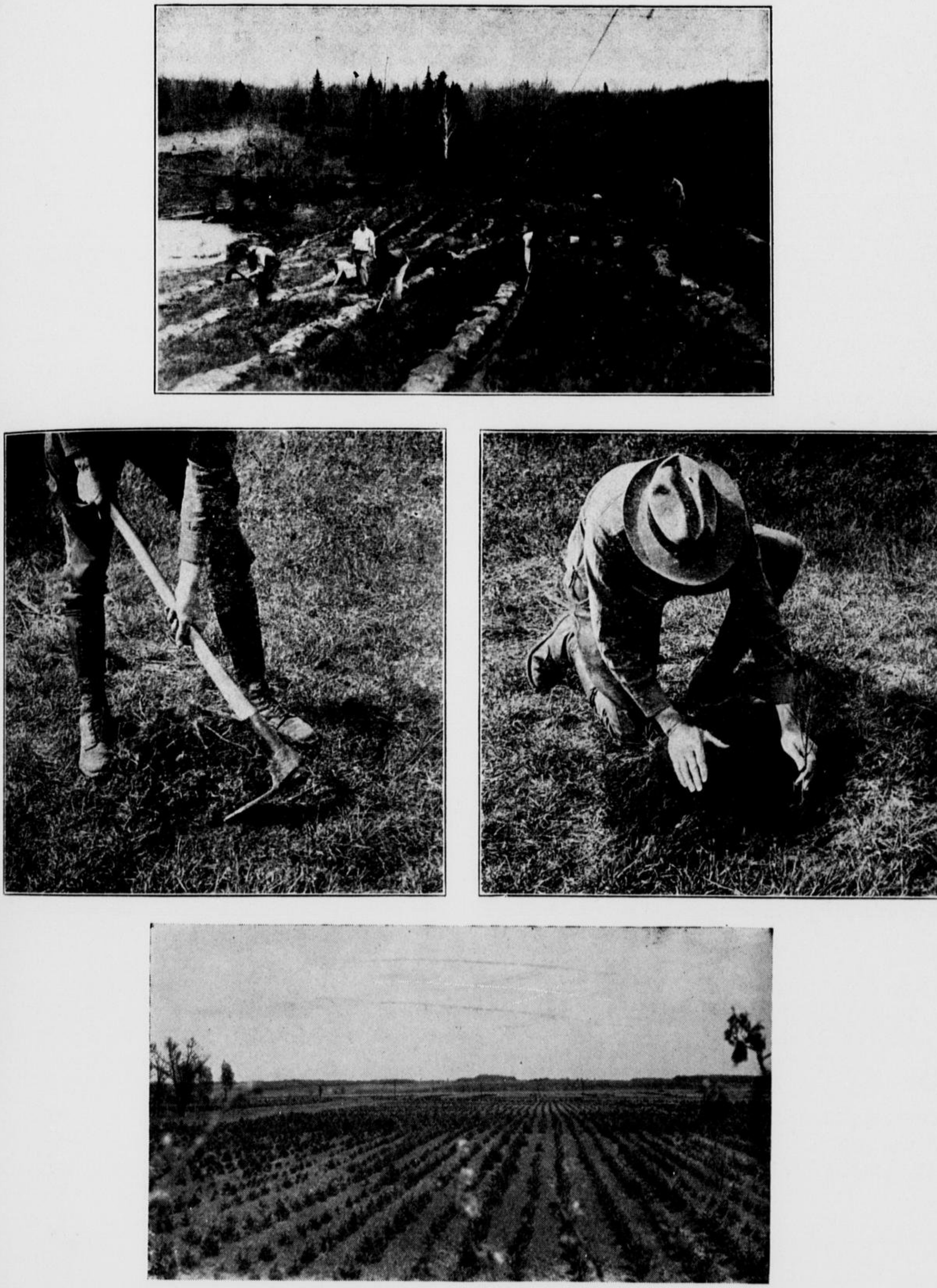

Photo by Wisconsin Conservation Department

Figure 69. Tree planting. Top: Planting in furrows; Center: Scalping and planting in hole; Bottom: Recently established plantation of jack pine and red pine.

Diagnosis of the Causes Responsible for the Failure or Stagnation of Plantations

Unsatisfactory growth of planted trees may be caused by a number of factors, including environmental conditions, origin of stock, method of planting, and destructive biotic agents. The following outline of the adverse conditions may be of assistance in making the diagnosis.

Atmospheric factors: Strong evaporating winds; winter killing; early fall and late spring frosts; sunscald.

Physical properties of soil: Dryness of soil; excessive wetness of soil and subsequent insufficient aeration; unsatisfactory structure of soil due to high content of clay, packing by livestock, cementation by colloids; cracking of soil following drouth; frost heaving.

Chemical properties of soil: Deficiency of humus or available nutrients; presence of toxic substances; unsuitable reaction.

Miscellaneous influences: Inundation; water and wind erosion; forest fire; toxic industrial fumes.

Origin of planting stock: Seed from an unreliable source; stock grown in nursery under radically different conditions of climate and soil from those of the planting site.

Quality of planting stock: Succulent stock grown with excess of water; under-developed stock grown in nursery soils deficient in nutrients; unbalanced stock grown on nursery soils with improper ratio of nutrients; short rooted or flat-rooted stock produced by application of fertilizers as top dressings; unhardened stock kept too long under shade frames; stock injured in nursery by toxic chemicals; stock infested with parasitic organisms, or injured by parasitic insects; stock lacking inoculation with mycorrhizal fungi.

Handling of stock: Mechanical injuries to roots during lifting of stock; allowing roots to dry out during transportation, heeling in or planting; spontaneous heating of baled stock.

Planting technique: Inadequate preparation of ground; too deep plowing exposing toxic layers or layers having unfavorable physical properties; insufficient scalping; too shallow or too deep planting; air spaces in the planting hole; unnatural position of roots.

Destructive biotic factors: Competing vegetation; rodents; insect pests; parasitic fungi; grazing.

If no primary deteriorating factor is revealed in the field examination, information must be obtained on the climatic conditions during the past few years, as well as the origin of stock and planting technique. The advice of plant pathologist or entomologist should be secured, if necessary. The soil should be subjected to analysis in the laboratory only when the careful preliminary study has eliminated the possibility of non-edaphic causes of injury or deterioration. No conclusions should be reported unless they are underlain by sound evidence.

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CHAPTER XXIII

Utilization of Run-off Water

In many instances the rate of forest growth may be materially increased by interception and careful distribution of the run-off water. This is accomplished by a network of shallow ditches or furrows, constructed by means of spades or plows. The furrows are laid out perpendicularly to the main drainage channels with a gradient not exceeding 1 per cent. If the soil is easily eroded, the allowable gradient is even smaller. The water from the drainage channels, as well as from higher portions of the slope, is diverted from its course by furrows and is gradually absorbed by the soil. Simple dams of cull logs or poles are constructed in the main drainage channels to facilitate the diversion of water into the furrows.

The system of intercepting ditches may conserve as much as 30 per cent of the total precipitation which is ordinarily lost in the form of surface run-off. The work of this kind presents a very useful outlet for employment of permanent forest labor in slack seasons.

Drainage

The drainage of wet soils with a thin impervious layer may be improved by breaking up this layer. This is done either by dynamiting or digging holes which facilitate the "sinking" of the excessive water. A special auger with extensions is advantageously employed for this purpose. In some cases it may be necessary to install a vertical tile which comes within 3 feet of the surface of the ground.

Stream improvement work, involving the acceleration of current, or removal of beaver dams, may materially improve the drainage of backwater swamps and marshes.

Frequently a short outlet ditch may be sufficient to penetrate a barrier which is responsible for retention of run-off water. The drainage of ravines choked with fallen logs may be easily improved by merely clearing the rubbish from the surface. Inexpensive intercepting ditches may be installed to keep the surface and seepage water from entering potholes.

By these methods the drainage of large areas may be materially improved with very little expense. As a rule, minor drainage improvements are confined to areas supporting stands or plantations of valuable species and are carried on by permanent forest labor during slack work periods.

The drainage of large areas, particularly swamps, requires a thorough investigation of a number of conditions previous to the initiation of the drainage project proper. Among these conditions, the following are of prime importance: (a) potential productivity of soil or peat; (b) practicability and efficiency of proposed drainage system; (c) expected financial return on the investment; (d) effect of drainage and subsequent lowering of ground water table upon the productivity of surrounding upland stands; (e) effect of drainage upon the entire water regime of the region, and especially its effect upon agriculture. In climates where drought presents a serious problem, the two latter conditions usually make extensive drainage projects inadvisable.

The drainage project involves a thorough study of the subsoil condition and outlet possibilities. The depth and permeability of the subsoil is examined by means of auger or post-hole digger. The outlet is investigated with a surveyor's instrument. It is advisable to use a level even in localities where a liberal fall is apparent in order to plan the outlets most economically. The leveling should be continued some distance below the proposed outlet to make certain there is no danger of backwater. Specific literature on the subject and a technician experienced in drainage work should be consulted whenever an extensive project is contemplated.

The drainage of wet forested land, as a rule, is accomplished by open ditches and rarely by drain tile. The main objection to the installation of tile is the tendency of tree roots to plug the pipes. If the area has no outlet its excessive wetness may be decreased by means of a so-called "Swedish drain." This consists of a continuous storage ditch which surrounds the basin area and intercepts the water from the higher portions of topography.

Planting of Drained Peat Soils

After the drained peat has settled to about two-thirds of its original depth, and an invasion of grasses and sedges is evident, the soil from the drainage ditches is spread on the surface of the peat, and the area is burned. The fire is set on the windward side of the area so that it will move rapidly and not penetrate deeply. The burned-over area is then kept in buckwheat for about 5 years. In the fall of the sixth year the peat is disked, burned once more, and in the spring is planted to trees. Depending on the condition of ground water level, the seedlings are planted in slits, or on top of the ridge formed by two furrows turned inward. In some instances, the surface layer of peat is removed by steam shovel before reforestation, and used as fuel or fertilizer material.

The high cost of soil preparation limits the possibility of planting to areas of special scenic value or to regions where a good market is available.

Stabilization of Blow Sands

"To a person unfamiliar with moving sand dunes, it is hard to realize their magnitude or the grim wave-like action with which they advance, burying everything in their path. Examples of their destructive action are numerous.

"Old geographies of Michigan show that a once thriving sawmill town was located at the mouth of the Kalamazoo River near the present town of Saugatuck. Singapore was completely buried by a sand wave and became known as the Pompeii of America...." "In other sections of the state, highways are being covered, harbors are filling up and resort cottages are threatened with burial

* R. F. Kroodsma. Jour. of Forestry. 1937. Vol. 35: 4.

In only a very few instances, can the movement of sand dunes be arrested by direct planting of forest trees. As a rule, the blow sands must be at least partly stabilized prior to planting. This may be accomplished by means of wooden stakes cut to an approximate length of 20 inches, and driven into the ground to a depth of 8 inches forming a series of fences. The fences are arranged in parallel rows or in the form of squares or rhomboids. The distance between the rows varies with the intensity of erosion and is determined on the basis of experience. The determination of the proper distance between the rows is of extreme importance as it regulates the efficiency and cost of control.

Spreading of slash, cornstalks, hay, reeds or any other suitable materials on the windward side may replace the expensive construction of fences. The planting of xerophytic grasses in clumps or sowing of rye is another method of sand stabilization. Elymus arenarius, Psamma arenaria or Ammophila arenaria, are the grass species commonly used.

After the sand movement is arrested, the dunes are planted to jack pine, scrub pine, pitch pine, Scotch pine, western yellow pine, mugho pine, Russian willow, cottonwood, black locust or similar drought resistant species. In exceptionally humid regions, along the shores of the sea or large lakes, more exacting species, such as birch, aspen, white poplar and European grey alder may also be planted in the depressions between the dunes.

As experience showed, the control of sand movement is best achieved by a combination of several control measures, such as spreading of brush, tree planting and seeding of grass.

Reclamation of Ortstein Barrens

The extensive areas of so-called "Ortstein barrens" or "Heide" supporting exclusively the low shrubs of the heather family, are ameliorated by deep cultivation using a steam plow. The cultivation is often preceded by burning of the vegetative cover. The land is plowed to an approximate depth of 18 inches or deeper and the plowing is repeated in crosswise manner until the hardpan material, leached soil and raw humus are thoroughly mixed. Sometimes the hardpan layer is destroyed by dynamiting instead of plowing. As a rule, lime or marl is added in a considerable quantity to decrease the acidity of soil, speed up nitrification, and convert the nutrients concentrated in the ortstein layer into available form. After cultivation, the land is fallowed for one or two years, or is seeded to green manure crops, particularly to lupine.

Pine and spruce are the chief species used for reforestation, the choice being dependent upon the texture of soil and other conditions. White birch, aspen, oak, blue beech, mugho pine and larch are planted along with spruce and pine for the purpose of soil improvement. American red maple, which grows naturally on podzol soils, may be of great value as an associate species in this type of reforestation. The seedlings are usually planted on the top of the ridge formed by two inward turned furrow slices.

While the amelioration above described may be absolutely necessary on areas with a continuous ortstein layer, as they occur in Holland, Jutland, Northern Germany or Northern Michigan, efforts should be made to avoid such a radical and expensive method. Before the reforestation of an ortstein podzol is attempted, the composition of the soil profile should be carefully investigated over the entire area. Since the depth of the ortstein layer varies considerably from place to place there may be many areas which have a sufficiently deep leached layer to allow hole planting. Plowing is likely to be most advantageous on areas with a shallow and thin ortstein layer which may be completely destroyed by the plow. As experience of the U. S. Forest Service in the Lake States region has shown, the furrowing of hardpan soils under suitable conditions, resulted in the increased growth of planted seedlings due to the benefit of the additional nutrients from the partly disintegrated ortstein material.

When neither plowing nor direct planting are practicable, the area should be left to natural reproduction. The amelioration of the soil is then carried on over a long period of time by means of partial cuttings discouraging the accumulation of raw humus, and by under-seeding or under-planting of soil-improving hardwood species.

Reforestation of Limestone Outcrops

High erodability, the usually shallow layer of weathered material, high content of carbonates and severe drought make the reforestation of residual calcareous soils a difficult and costly task.

If the depth of soil allows, the holes for planting are dug with the mattock. On localities with a shallow soil layer, additional soil is collected in depressions and placed around the planted seedlings in quantity sufficient to cover the roots. Only strong seedlings or transplants are used in reforestation of these sites. The cost of planting may be as high as $60 per acre.

In the initial reforestation of barren calcareous soils the choice of species is limited mainly to Austrian pine, red cedar, black locust and European grey alder. In some regions, certain ecological varieties of Douglas fir, thermophilic pines (Crimean, western yellow and southern European pines), white cedar, ash and oaks may be also used.

At the age of 25 years, or later, the initial plantations are gradually converted into mixed stands including predominantly lime-loving hardwood species such as beech, ash, oak, hickory, walnuts and maple. These species, as a general rule, give the highest financial return and greatest assurance of sound development on calcareous soils. The conversion is accomplished either by underplanting or by underseeding of the initial stands. The management of the established hardwood stands is carried on by very careful selective logging which removes exclusively the inferior specimens.

Gully Planting

The choice of species used in planting of gullies and surrounding territory is governed by their ability to control erosion. Each gully includes three sets of ecological conditions: bottom, which periodically receives a considerable quantity of run-off water; eroded banks with "raw", humusless soil; bordering slopes with a normal soil profile, undisturbed by erosion.

The banks and the drier bottoms are planted to black locust or other drought resistant trees with moderate nutrient requirements and a fibrous, soil-binding root system. In the planting of wet gully bottoms heavy rooted, moisture loving trees, such as cottonwood and willows are used. The bordering strips are planted to a variety of trees and shrubs, such as Russian olive, buffaloberry, Siberian pea tree, Staghorn sumac, Russian mulberry, Osage orange, privet, thornapple, thornless honey locust, highbush cranberry, nannyberry, common lilic and wild plum. The selection of species depends upon the soil reaction, soil moisture condition, and content of nutrients. On suitable soils spruce, pine and cedars are mixed with deciduous species in order to provide game cover in winter.

Because of the low fertility of the eroded portion and heavy sod on the undisturbed slopes bordering the gully, only large and vigorous stock is used. The spacing varies from 2 by 2 to 3 by 3 feet. In some instances, forest planting is supplemented by the seeding of eroded banks to timothy, rye, bluegrass and clover or by laying of sod on more exposed sections. Extensive gullies in an acute state of erosion may require engineering work prior to reforestation.

Planting in the Prairie Region

Climatic conditions of the prairie region are characterized by low annual precipitation, summer drought, great range in temperature extremes and frequent strong winds. The soils of the region include chernozems, chestnut soils, a variety of alkali soils, and areas of dune sands.

The climate, soil and the competition of grass vegetation present a serious obstacle to tree growth and afforestation must be confined to the most favorable sites. The areas which collect snow-drifts, insuring a higher content of soil moisture, are likely to be most suitable for tree planting. On such sites the percolating water lowers the zone of lime enrichment and decreases the total concentration of soluble salts. Those conditions occur mainly on northern slopes and in depressions protected from the dessicating winds.

As a general rule, the survival and growth of trees in the prairie region increases with the sand content and decreases with the clay content of the soil. This is chiefly due to the higher content of available water in sandy soils. The content of available water in heavy soils is low because of slow absorption rate, rapid run-off, retention of light precipitation in the upper soil layer and a high wilting coefficient. Large cracks developing in heavy soils during drought periods may also handicap tree planting.

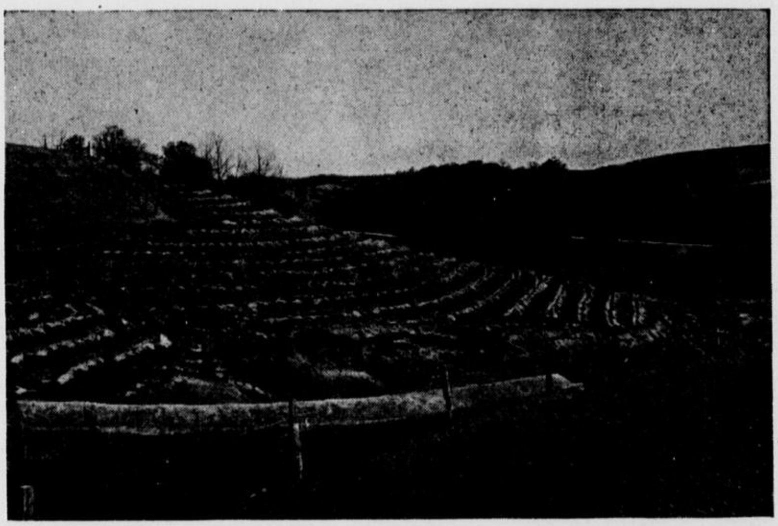

Photo by Wisconsin Conservation Department

Figure 70. Soil erosion. Top: Gully erosion in southwestern Wisconsin. Bottom: Control of erosion by tree planting.

Alkali soils having a high concentration of soluble salts and soils with a zone of lime enrichment or hardpan layer close to the surface should be avoided in tree planting.

The afforestation of prairie is often initiated by the planting, in suitable localities, of shrubs and dwarf trees which help to accumulate snow-drifts and thus tend to promote the process of soil podzolization. After leaching has decreased the pH value of the surface soil, and lowered the zone of lime enrichment, the area may be planted to tree species with a greater chance of success.

The tree species which have proven most successful for prairie planting are: green ash, hackberry, American elm, Chinese elm, bur oak, black locust, honey locust, catalpa, osage orange, willows, cottonwood, western yellow pine, Austrian pine, blue spruce, junipers and eastern red cedar. The shrub species commonly used include Russian olive, buffaloberry, chokecherry, Siberian peatree, serviceberry, hawthorn, Russian mulberry, Tartarian honeysuckle, nannyberry and lilac.

Recent evidence indicates that the presence of mycorrhizae on the roots of planted stock, or an inoculation of seed with mycorrhizae-containing media, is essential in afforestation of prairie soils.

The afforestation of prairies is almost exclusively confined to the establishment of shelterbelts and small woodlots. The areas to be planted are often fallowed to reduce the competition of grasses and increase the content of soil moisture. In some instances, the planted areas are periodically cultivated for the same purpose.

Use of Field Crops in Reforestation

In some instances satisfactory results in reforestation of worn out fields were obtained by raising lupine and other green manure crops previous to tree planting. For this purpose the soil is fertilized broadcast with phosphate and potash. The green manure crop is seeded in the spring and plowed under the next fall. The following spring the soil is disked and harrowed and seeded or planted to tree species. Sometimes, the plowing under of green manure crop is omitted in order to save expenses or to prevent wind erosion.

On soils having a fairly high content of nutrients, cover crops, chiefly rye and oats, are seeded at a sparse density simultaneously with the tree planting. In the fall the cover crop is cut high with a scythe or mowing machine. Such practice reduces competition of weeds and provides some protection to seedlings during the first growing season. The harvested grain may help to defray the cost of planting.

Cultivation of Plantations

The stagnant growth of plantations, caused by the competition of weeds or sod vegetation, can be materially improved by cultivation. This is accomplished by means of a one-horse cultivator, special Neumann forest cultivator, disk, or rototiller. Aside from the control of weeds, the cultivation may increase the growth of plantations by improving the physical properties of soil. Great care must be taken in cultivation to avoid injuring the tree roots.

Burning the Forest Floor

Burning is practiced primarily on soils covered with a layer of raw humus or supporting abundant growth of competing vegetation. While this practice may be desirable in some silvicultural operations, it is decidedly detrimental to soil fertility. Burning destroys organic matter and thus impoverishes soil in nitrogen. The release of bases and phosphates in the form of wood ashes may have a short-lived fertilizing effect which is terminated by the losses of the salts through leaching.

Use of Fertilizers

As experiments in Germany and elsewhere have shown, some soils are not sufficiently fertile for the satisfactory growth of forest plantations or native stands. Remarkable improvements have been obtained by fertilization with not only nitrogen, phosphorus, potassium and calcium, but with magnesium and rare elements as well. At the same time, numerous failures of fertilizer treatments were recorded. These failures may be attributed to the following causes: (1) Insufficient knowledge of soil chemistry, action of fertilizers, and nutrient requirements of various tree species; (2) Competition of grass and other weed vegetation which may develop vigorously on the fertilized soil and thus deprive trees of available moisture; (3) Drought periods which may not only annul the effect of the fertilizer treatment, but even make such treatment harmful; this is especially true in regard to readily soluble salts and peat having a high hygroscopicity.

The success of a fertilizer application depends greatly upon the nutrient requirements of planted trees, state of soil fertility, and the amount of available water throughout the growing season. In many cases, pine species having low requirements for nutrients, fail to respond to fertilizer application, especially on coarse sandy soils, regardless of technique employed. On the other hand, hardwoods and spruce, having high nutrient requirements, often show a rapid and significant response to fertilizers, especially on heavy soils depleted in their nutrient content.

As a rule, the deficiency of nutrients in forest soils is limited to one or two important elements, and only in rare cases is there a need for application of a complete fertilizer. The kind and the amount of fertilizers needed must be carefully determined by means of chemical analysis or pot culture tests. Considerable responsibility is involved in recommendation of fertilizers for plantations or naturally occurring trees, and such recommendations should not be made without a thorough knowledge of soil conditions.

The fertilizer can be applied either broadcast prior to planting in planting holes in borings or slits, as a top dressing, or in solution.

(a) Broadcast application of fertilizer. The area to be fertilized is determined by an approximate survey and is divided into a number of blocks of convenient size for fertilization.

In the application of soluble fertilizers, such as muriate of potash, the area is plowed, if necessary, then disked. The desired amount of salt is distributed with a fertilizer spreader or by hand and is worked into the soil by harrowing.

In the application of less soluble phosphates, the fertilizer is apread over the soil surface and plowed under to an approximate depth of 6 inches. The soil is disked, soluble fertilizers are applied, if necessary, and the area is harrowed. The fertilizers should be applied about two weeks ahead of planting.

On sandy soils of exposed areas the plowing and disking may initiate acute wind erosion and, hence, on such areas the use of some other method of fertilizer application may be necessary. Corn may be planted at suitable spacing as an overhead crop to reduce wind erosion on such areas, or strips of rye may be seeded in drills to accomplish the same purpose. Only moderate success may be expected with application of readily soluble fertilizers to sandy soils because of the losses through leaching.

(b) Application of fertilizers in planting hole. A hole, 14 inches deep and 2 feet in diameter, or somewhat larger, is dug. The measured amount of fertilizer is mixed by hand with about three-fourths of the soil from the hole, somewhat packed, and a wide slit is made with a spade. Into this the roots of the seedlings are lowered, the slit is filled with unfertilized soil which is then firmly packed with the hands and feet. This latter unfertilized portion of soil should consist predominantly of the humic top soil.

This method is limited largely to the application of organic fertilizers such as leaf-mold, peat, and composts as practiced in road-side, shelterbelt and landscape plantings. An application of mineral salts at the time of planting is inconvenient and requires an extremely careful handling of the entire operation. If carried on by an inexperienced, poorly supervised crew, soluble fertilizers may cause serious root injury.

(c) Application of fertilizers as a top dressing. Top dressings are usually applied to older trees showing symptoms of nutrient deficiency, or to plantations one or two years after the seedlings are set in the field.

The amount of fertilizer in pounds per acre needed to re-establish soil fertility is divided by 100. This gives the approximate amount of fertilizer in grams to be applied per each square foot. The area to be fertilized is determined by the extent of the root systems which ordinarily is indicated by the spread of the crowns. The fertilizing material is measured by means of a calibrated scoop and is applied around the tree excluding a zone in the immediate proximity of the trunk. To prevent the removal of the fertilizer by wind or run-off water, the soil may be worked slightly with a garden hoe. Readily soluble synthetic fertilizers, such as ammonium sulfate, Ammophos, Nitrophoska, and potassium nitrate, are well adapted to this method of application.

In some instances, good results have been obtained with applications of one or two-inch top dressings of leaf-mold and other organic remains. However, the top dressings of organic matter absorb a considerable portion of rainfall which may thus be lost through evaporation. Therefore, a thorough working of organic remains into the soil by spading or raking is very desirable. In doing this, care must be taken not to injure the roots of the trees.

(d) Application of fertilizers in slits or borings. This method is used chiefly in the application of commercial organic fertilizers, less soluble phosphates, and briquette or pellet fertilizers. The slits or borings are made around the base of the tree with an auger, a planting bar, or a spade. A measured amount of fertilizer, or a briquette, is placed in the slit and this is closed with a thrust of the heel. The depth and number of slits vary depending upon the age of the tree and its root extension. Usually, the depth does not exceed 10 inches, and one slit is made for each 10 to 20 square feet of the area. It is important to correlate the distribution of the fertilizer as much as possible with the occurrence of the feeding roots.

The application of composted fertilizers, compressed into briquettes, appears to be the safest and the most economical method of tree fertilization. However, it is likely to produce results at a somewhat slower rate than the application of fertilizers in solution or as top dressings of soluble salts.

(e) Application of fertilizers in solution. Treatments with liquid fertilizers have been recently introduced by landscape architects. Their use is confined to localities where there is a readily available supply of water.

The fertilizer solution is prepared in a barrel or a tank mounted on an automobile chassis. The solution is stirred by hand or by means of installed rotating agitators of a propeller type. The liquid is distributed around the trees using either sprinkling cans or a hose. In some cases, the solution of fertilizer is forced into the soil under pressure through a hose with a sharp-pointed nozzle. In application the nozzle is thrust into the ground and the liquid is allowed to flow for a certain length of time. The same technique is used in treatment of large trees with root growth-promoting substances prior to transplanting.

In soils with a high capacity for fixation of phosphates or exchangeable ions, the forcing of solution to the region of root growth may prove to be advantageous. In many soils, however, the pressure method may not have appreciable advantages over the ordinary application of fertilizers in solution or as top dressings of readily soluble salts.

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THINNING AND SELECTIVE LOGGING ON DIFFERENT SOILS AND SITES

"Followest not the system as a blind man followeth a wall."
From Waldmeister's Instruction by Peter the Great of Russia.

The thinning is a partial cutting of a stand of sapling size or larger, usually conducted as one operation. The chief purpose of thinning is to increase the quality and rate of growth of the stand by elimination of superfluous trees. Selective logging is a partial cutting of mature stands, often conducted over a longer period of time. The main object of selective logging is to obtain natural reproduction of the desirable species.

In spite of the extensive cut-over areas in this country, the lumberman's ax, if properly used, is just as important a tool of reforestation as the spade or the mattock. Dead snags, diseased trees, and injured trees, which may serve as breeding centers for parasitic insects or fungi, are removed in all silvicultural cuttings. Furthermore, sprouts, suppressed struggling trees, over developed wolf trees, and trees of undesirable species are eliminated insofar as they interfere with the growth of valuable trees As a general rule, cuttings should give enough space for the sound development of each valuable crop tree; yet an adequately dense canopy should be maintained in order to control the growth of grass and sprouts, to preserve soil moisture, and to retard the loss of nutrients. The classification of tree species into "desirable" and "undesirable" is based usually upon their merchantability and has only a relative significance. In numerous cases the commercially inferior species may be of great silvicultural value; they may improve the soil, protect young seedlings from frost and sunburn, control the growth of weeds, reduce the fire hazard, and act as trainers to the crop trees.

In all cuttings, attempts should be made to protect the exposed boundaries of thinned stands by the establishment of wind shelter belts. For this purpose the boundary of the stand is cleaned of dead material and is carefully thinned so as to give the trees sufficient space to develop a deep crown; the shrubs are left undisturbed, or are cut close to the ground to encourage sprouting. In logging care also must be taken to avoid the formation of frost pockets by cutting passages for air circulation.

Of great importance is the fact that the removal of even a few trees materially affects the conditions of light, temperature, moisture and air movement within the forest stand. Thus, by means of proper cuttings the forester can modify the environment to suit the requirements of different species.

The spacing of tree trunks after cutting or thinning may vary from 6 to as much as 100 feet, depending upon the age of stand and other conditions. A proper distance of single trees, however, is determined by the extent of their crowns, and therefore, no regular spacing of trunks can be maintained in silvicultural cuttings.

Although it is difficult to set up definite standards to govern the intensity of selective logging or thinning, it may be helpful to recognize three degrees of cutting intensity, as follows:

(1) Light cutting, which preserves an unbroken crown canopy;

(2) Moderate cutting, which slightly breaks the canopy so that each remaining tree has enough space for further development;

(3) Heavy cutting, which leaves the distance between the crowns of remaining trees at least as great as the average crow n diameter of the stand.

Light cutting or thinning is practiced: (a) on sites exposed to strong and dry winds where there is a danger of windfall and loss of soil moisture through evaporation; (b) on steep slopes, in order to prevent rapid run-off and erosion; (c) on hot and dry exposures, particularly on southern slopes, in order to preserve the soil moisture and retard the decomposition of humus.

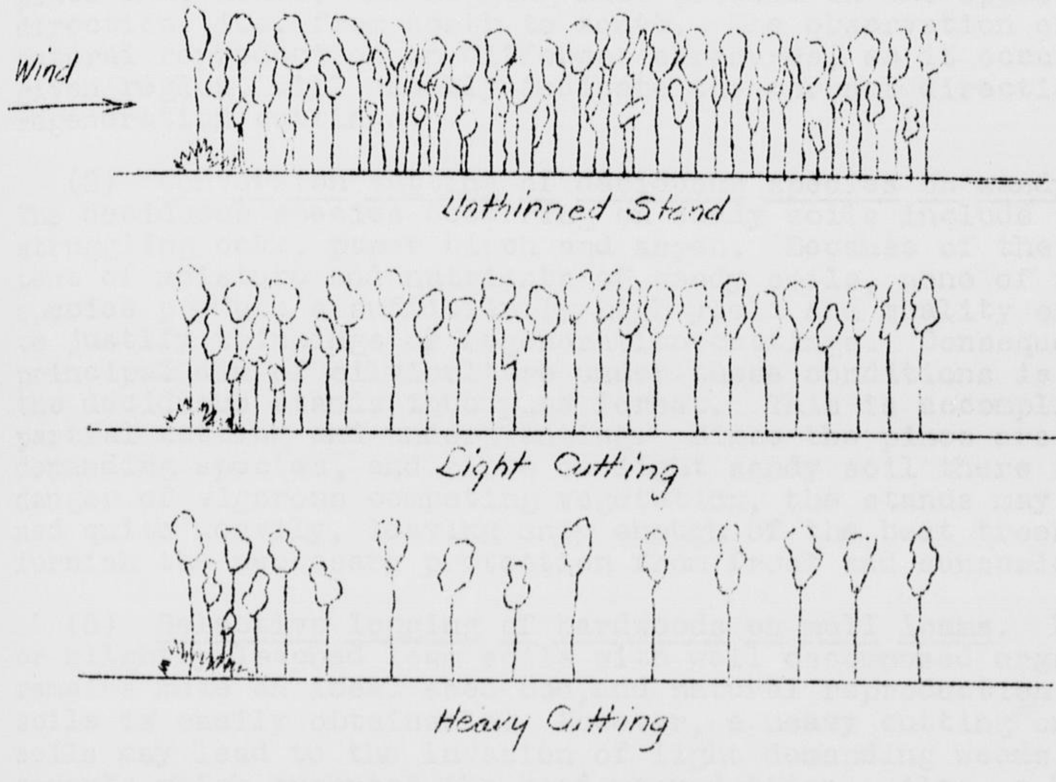
Moderate cutting or thinning is used most commonly. On one hand, this kind of cutting must materially improve the composition of the stand, eliminate the superfluous, competing trees, and secure enough light for the crop trees; on the other hand, it should not promote the development of competing vegetation or decrease the soil fertility.

Heavy cutting or thinning is practiced: (a) on cool and moist exposures, particularly on northern slopes, in order to furnish more light for natural reproduction; (b) on heavy soils with an abundance of undecomposed organic matter, in order to encourage a more rapid decomposition of raw humus; (c) on poorly drained, heavy, or organic soils, when it is necessary to eliminate the inferior or diseased trees.

In carrying on selective logging on different sites and with various species, the rate of cutting is subject to numerous modifications governed by local conditions, particularly by the state of advance reproduction. A few examples drawn from actual conditions will illustrate different procedures employed in silvicultural operations.

(1) Thinning and reproduction cutting of Jack or Scotch pine on sandy soils. These stands are usually thinned at the age of 20 to 25 years. The thinning is carried on with a general tendency to reduce the canopy in the vertical rather than in the horizontal direction. This is done by eliminating the suppressed trees of the understory, while carefully maintaining the continuity of the canopy formed by the dominant trees. Such treatment of the stand allows the maximum precipitation to reach the ground, but protects the soil from direct rays of the sun, thereby retarding the decomposition of organic remains.

On sands of the humid podzol region, light demanding pines reproduce best on southern exposures, where light is



Diagrammatic Illustration of different intensities of cutting

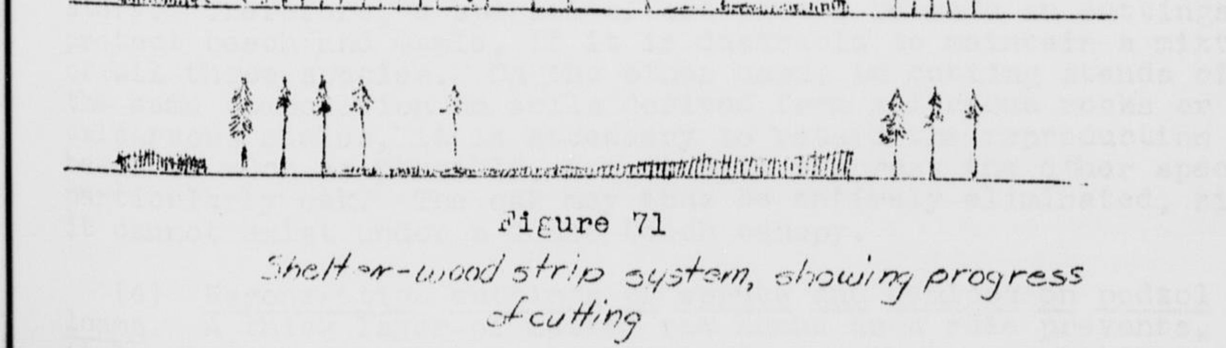


Figure 71

Shelter-wood strip system, showing progress of cutting abundant. Consequently, selective logging must proceed gradually in a northerly direction. This method is particularly suitable on sands with a high ground water level. On sands of the brown-earth or grey forest soils regions, however, the southern exposures may be too hot and dry even for the drought resistant pines and, hence, the logging must proceed in the opposite direction, i.e. from north to south. The observation of the natural reproduction on different exposures, as it occurs in a given region, will usually indicate the correct direction of regeneration cuttings.

(2) <u>Conversion cutting of deciduous species on sandy soils</u>. The deciduous species occurring on sandy soils include inferior struggling oaks, paper birch and aspen. Because of the low content of moisture and nutrients of sandy soils, none of these species produce a sufficiently high yield and quality of timber to justify thinnings or regeneration cuttings. Consequently, the principal aim of silviculture under these conditions is to convert the deciduous stands into pine forest. This is accomplished by partial cutting and underplanting. Since the pines are light demanding species, and since on light sandy soil there is no danger of vigorous competing vegetation, the stands may be thinned quite heavily, leaving only enough of the best trees to furnish the necessary protection from frost and sunscald.

(3) <u>Selective logging of hardwoods on mull loams</u>. Undegraded or slightly leached loam soils with well decomposed organic remains make an ideal seed bed,and natural reproduction on such soils is easily obtainable. However, a heavy cutting on these soils may lead to the invasion of light demanding weeds and sprouts which suppress the seed reproduction. Also, a heavy cutting may greatly hasten the decomposition of humus and cause a loss of nutrients, especially nitrogen. For these reasons, the hardwood stands on mull loams are logged gradually and very carefully. In the majority of cases, the older trees are removed only in places where it is necessary to release the advance reproduction. Thus, the operation may extend over a period of 20 to 40 years. The control of the composition of the future stand is achieved partly by the elimination of the inferior old trees, and partly by not releasing the undesirable reproduction.

The geological origin of soil and its content of nutrients often play a decisive role in determining the ultimate composition of the stand. For instance, in oak-beech-maple stands on a fertile soil derived from trap rocks, oak grows more rapidly than beech and maple which remain as a suppressed understory. Therefore, a special effort should be made in cuttings to protect beech and maple, if it is desirable to maintain a mixture of all three species. On the other hand, in cutting stands of the same composition on soils derived from siliceous rocks or calcareous shales, it is necessary to retard the reproduction of beech as much as possible, for it will suppress the other species, particularly oak. The oak may thus be entirely eliminated, since it cannot exist under a dense beech canopy.

(4) <u>Regeneration cuttings of spruce and hemlock on podzol loams</u>. A thick layer of matted raw humus as a rule prevents, or at least retards, the reproduction of even the saprophytic conifers. In order to promote the biological activity of soil

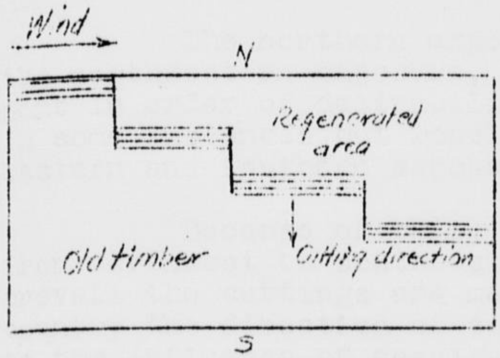
organisms and decomposition of organic remains, the amount of light and heat should be increased by a rather heavy cutting. In planning such cuttings, however, a great deal of skill and caution is required. Spruce and hemlock reproduction is liable to suffer injury from frost and sunscald if suddenly released. In addition, these two species, on strongly leached and cemented podzol soils, develop extremely shallow root systems and are subject to windfall. For these reasons a heavy selective cutting, over a large area is dangerous and, instead, the group selection method, or one of its modifications, is usually employed

In the group selection method, the old trees are removed in small patches where some reproduction is already present. The first trees are felled in a fan-like formation away from the reproduction. Dragging these trees in removal tends to break up the raw humus layer and encourage additional natural reproduction. In five or more years the cutting area is enlarged by a second concentric cut, or a cut extended in a direction which offers the best protection to natural reproduction. Similar cuts are made at intervals of several years depending upon the condition of young growth, until the entire block is regenerated.

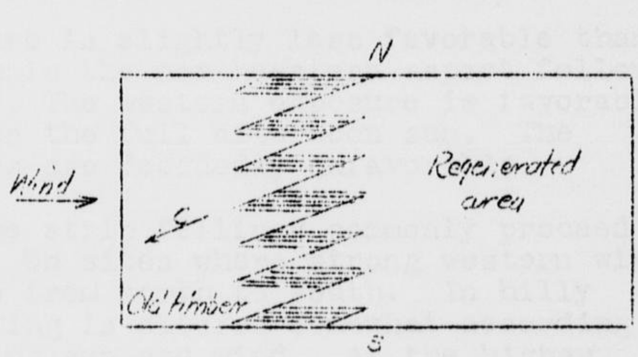
(5) Improvement cuttings and selective logging of mixed stands on poorly drained heavy soils. Improvement and reproduction cuttings of hardwood-coniferous stands on heavy soils with a high ground water level present one of the most difficult silvicultural problems. As a rule, such soils support a high percentage of inferior deciduous species which are often infected with heart rot. Consequently, the condition of the stand usually calls for a heavy cutting which may appear justifiable particularly in view of the slow decomposition of organic remains. However, heavy cutting on such sites may promote a vigorous growth of competing vegetation and inferior hardwood sprouts. Also a heavy logging may raise the ground water level and increase the soil moisture to an undesirable extent. This may be partly due to the larger amount of precipitation reaching the ground and partly to the decreased evaporating capacity of the forest stand. As a result, heavy cuttings may encourage the invasion of mosses, particularly Sphagnum, and may lead to the development of a swamp condition. The more moist and cool the climate, the greater is the danger of such a conversion and, hence, gley podzolic soils deserve especially careful handling.

Observations of the vegetation and humus on cut-over lands and on patches where windfall has occurred, usually serve as an invaluable guide to the establishment of a proper rate of cutting.

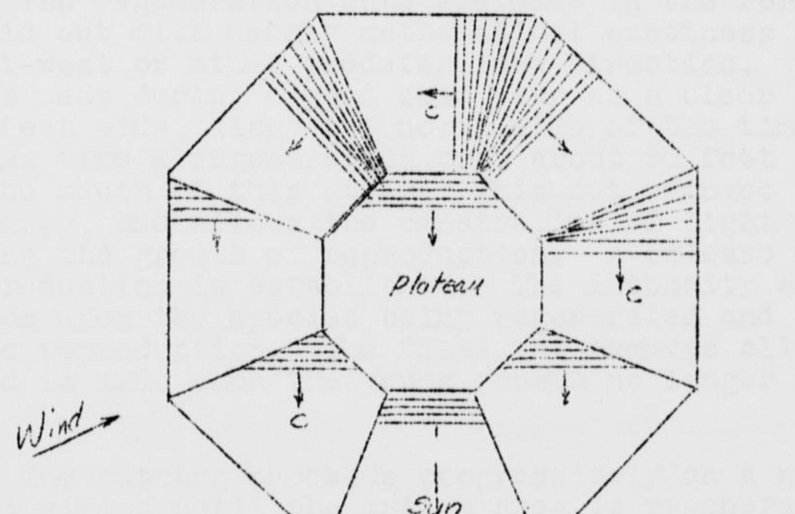
(6) Wagner's shelter-wood strip cuttings of spruce-fir stands. This method was originated in Bavaria, and may not be applicable in other regions. Nevertheless, it represents an example of silvicultural cuttings taking into account a great number of environmental factors, namely, wind, rainfall, frost, snow, dew and exposure to the sun. In Bavarian forests, the northwestern exposure is most favorable for securing natural reproduction of spruce and fir. The chief benefits of this exposure are as follows: complete protection from mid-day sun; free admission of the frequent, light western rains, which benefit shallow rooted spruce and fir; formation of dew; protection from the dry



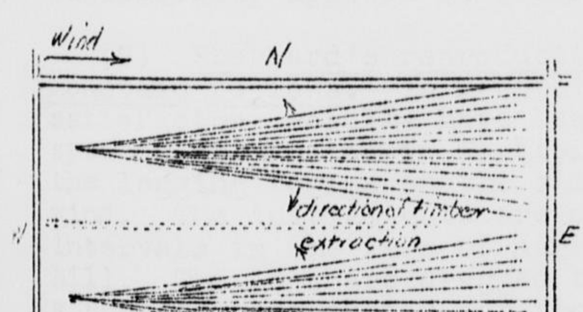
Step cuttings from north to south



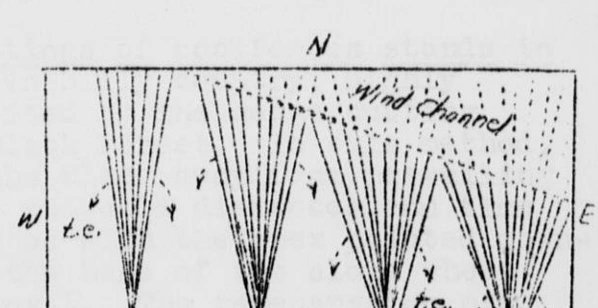
Cuttings advanced diagonally toward southwest



Cutting key showing arrangement of strips on different slopes with the view of protection against sun and wind



Wedge cuttings on level ground



Wedge cuttings on a southern slope

Figure 72

eastern winds; the accumulation of snow, which retards early growth of seedlings, reduces deer damage and provides moisture in the spring.

The northern exposure is slightly less favorable than the northwestern exposure, while the northeastern aspect follows next in order of desirability. The western exposure is favorable in some instances but receives the full afternoon sun. The eastern and southern exposures are decidedly unfavorable.

Because of this, the strip fellings commonly proceed from northwest to southeast. On sites where strong western winds prevail the cuttings are made from north to south. In hilly country the direction of cutting is altered somewhat according to the influence of dessicating sun and wind. At the higher elevations and in northern latitudes the protection from sun may be harmful due to excessive dampness and a rank weed growth. Under such conditions, best results may be obtained by cutting from south to north.

The regeneration cuts are made in the form of narrow strips laid out with nearly mathematical exactness and extending in an east-west or other predetermined direction. The first felling is made during a good seed year as a clear cut strip, 10 to 20 feet wide, along the north side of the timber block. At the same time a regeneration cut, about 50 feet in width, is made to the south of this strip. This cut removes about one-third of the canopy, and allows the penetration of light and heat, encouraging the growth of reproduction. A release cut is made after reproduction is established. The intensity of the second cut depends upon the species being regenerated and the condition of advance reproduction. The final cut removes all the remaining trees, and is made when the young growth no longer needs protection.

The cutting proceeds progressively on a number of individual strips until the entire area is regenerated. The side protection of natural reproduction is obtained by the arrangement of cutting in a step-like fashion as indicated on the attached diagrams.

Wagner's sys tem with various modifications may be successfully applied to other tree species.

(7) Eberhard's reproduction cuttings of coniferous stands in mountain regions. In mountains or in hilly country, highly satisfactory results have been obtained by the wedge cutting system, originated in Württemberg Black Forest. In this method, the logging begins on the side of the block away from prevailing wind. The initial cuts are made at suitable distances and time intervals in the form of narrow wedges with the apex pointed downhill. The logs are dragged toward the base of the slope where a road is constructed for their removal. The regeneration of the stand is achieved by progressive shelterwood strip cuts. The initial cuts begin in the center of the strip and extend outwards in both directions.

The principal aims of the system are: to minimize the danger of windfall; to obtain a longer regeneration front, and to protect reproduction from the damage in log skidding as well as from the adverse influences of the environment. On dry locations the position of wedges should be chosen so as to minimize the exposure of reproduction to direct sunlight.

In carrying out the reproduction cutting, frequent light thinnings are made to encourage the regeneration of tolerant species. The regeneration of the stand may be encouraged by increasing the intensity of thinnings and by reworking the raw humus layer. Old trees are removed as soon as regeneration is established. On sites where downward drainage of air occurs, the point of the wedge must be opened out, making a clear lane from top to bottom through which descending winds may pass.

The details of the technique of cuttings may be found in the attached references.

The few above outlined examples are but a small fraction of all the possibilities which may be encountered in silvicultural cuttings on different soils and sites. In fact, the multitude of conditions resulting from the combination of different tree species with soil, ground water, exposure and gradient, make it utterly impossible to prescribe cuttings in terms of standard recipes and formulas. Silvicultural cuttings are truly an art, but an art based on science. With a few exceptions, the cutting of each individual stand presents a problem of its own, the solution of which depends greatly upon the "Savior faire" of the forester. These are the reasons why the marking of trees for cutting in all well managed forests of Europe is traditionally done by the most experienced forester, often even by the "Herr Forstmeister" himself.

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Photo by Wisconsin Conservation Department

Figure 73. Silvicultural Cuttings: Top: A light improvement cutting in northern hardwoods; Bottom: A too heavy, nearly clear cutting of a woodlot; the number of remaining trees is by far insufficient to control the growth of grass and to obtain natural reproduction.

CHAPTER XXV

Problems of Forest Economics Related to the Productivity of Forest Soil

A knowledge of the productivity of forest soil is essential in the solution of the following problems in forest economics: construction of yield tables; relative advisability of growing either agricultural or forest crops on a specific type of soil; determination of annual cut; calculation of expected financial return on an investment in reforestation or drainage; evaluation of forest land for purchase, exchange or taxation; appraisal of damages to land productivity.

The Preparation of Yield Tables

Yield tables give the volume of timber per acre in cubic or board feet at various ages, usually at ten year intervals As a rule, they include information on total number of trees, total basal area, average diameter, and average height of the stand. This data is indispensible in the solution of many problems of forest management.

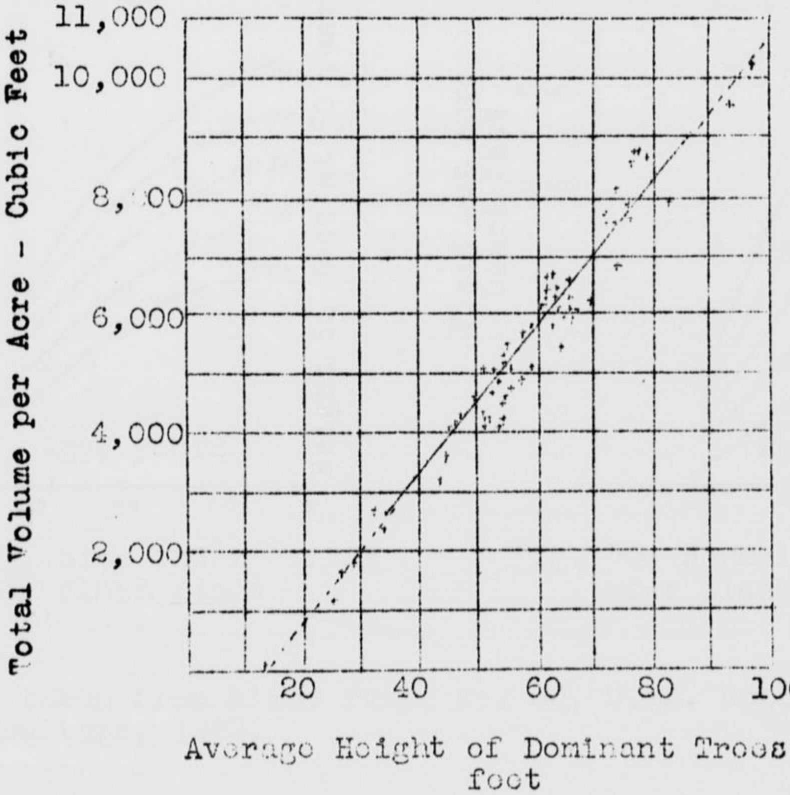

Fig. 74. Relation of the average height of dominant trees to total volume of timber

Since lands vary in fertility, they produce different yields of timber at a definite age. The productive capacity of the land is referred to as "site quality." As there is a fairly close correlation between the height growth of a stand and total production of timber (Figure 74) the sites are usually classified on the basis of the average height of the dominant trees at a certain age, such as 50 or 100 years. Thus, a stand of white pine of a high productivity, characterized by an average height of 70 feet at 50 years, is referred to as a stand of site index 70. The approximate yields of a normally stocked stand of this site would range from 3,000 cubic feet at 30 years to 14,000 cubic feet at 100 years.

It has been a common practice in the past to determine the yields on the most and the least productive sites by actual measurement of timber. The yields thus determined were related to age and expressed graphically. The yields of timber for intermediate sites were arrived at by drawing additional curves, equally spaced between the curves for the maximum and minimum productivity (Fig.75 and 76). As recent investigations showed, the actual production of timber on different soils does not correspond to these artificial sites established by empirical interpolation. Consequently, the general tendency of modern practice is to measure the grow th of representative stands on land types characterized by definite topography, soil profile, ground water level (Fig.77), and, quite often, typical ground cover vegetation. (Fig.78 and 79).

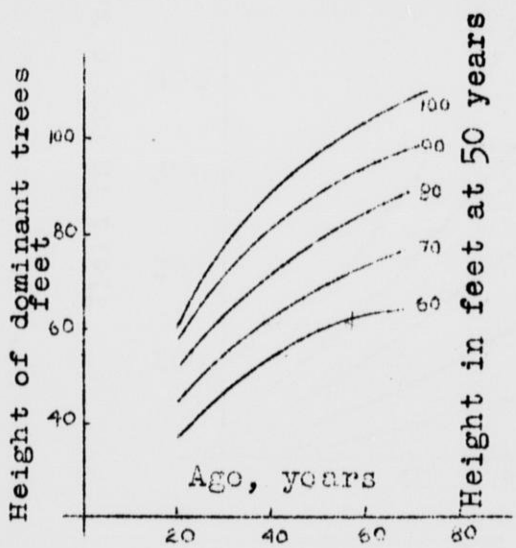

Fig. 75. Site index curves for slash pine*

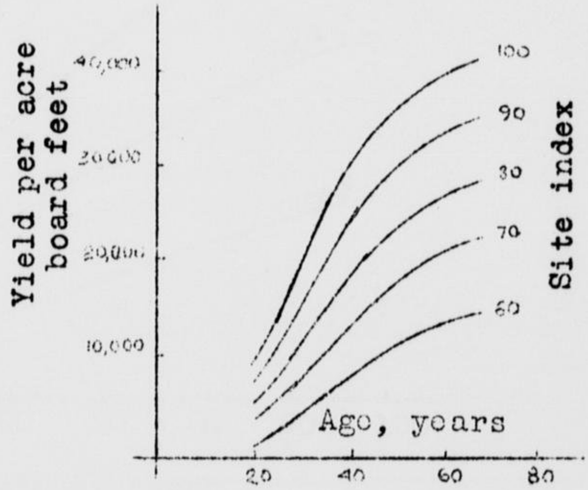

Fig. 76. Normal yield table for slash pine*

* Date taken from Misc. Publ. No. 50, U. S. Department of Agriculture, 1929.

In the construction of yield tables, a number of sample plats are selected to obtain statistically sound average data for all types and a sufficient range of ages. The size of the individual plats varies from 1/8 to 1 acre. On each plat the diameters of all trees are measured with a caliper or a diameter tape, heights of trees are determined with a hypsometer in sufficient number to construct the height-diameter curve, and age is determined by boring several trees or making stump counts. This information is usually supplemented by a number of complete stem analyses. The data obtained are treated statistically and abnormal plots are rejected. The site quality index and corresponding

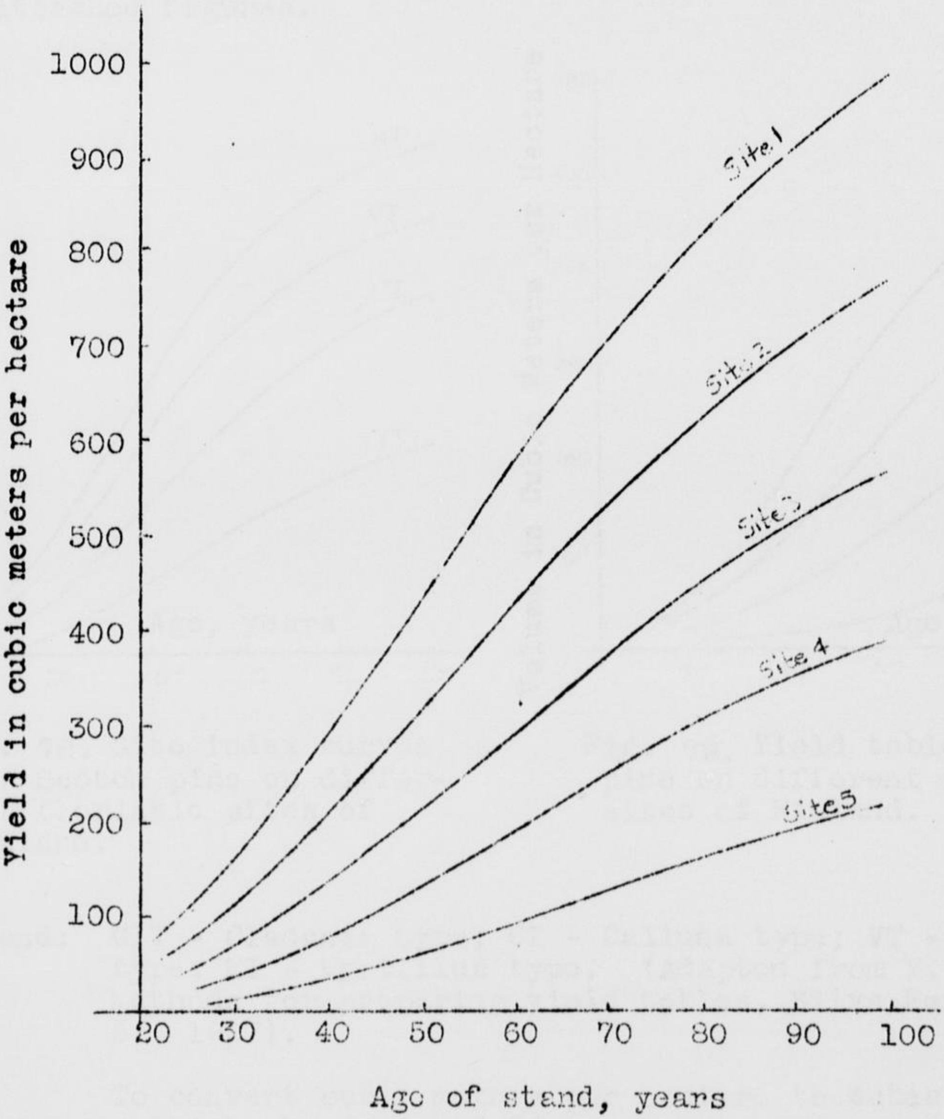

Fig. 77. Yield tables for Norway spruce of mountain regions by A. v. Guttenberg

Site 1. "Excellent." Deep humic loams on calcareous substrata in protected localities and at altitudes less than 1,000 meters above sea level. Site 2. "Good." Fairly moist sandy loams underlain by sedimentary rocks or schists at elevations less than 1,200 m. Site 3. "Fair." Shallow sandy loams on schists and shallow humic soils on limestone, at elevations from 1,000 to 1,400 m.; deep moist soils of higher elevations. Site 4, "Poor." Shallow stony soils or wet soils underlain by schists; shallow dry dolomitic soils of southern exposures at elevations from 1,400 to 1,600 m.; better soils of the higher altitudes. Site 5. "Very poor." Exposed areas of high altitudes, chiefly from 1,600 to 1,800 m.

yields for each soil type for ten year intervals are then presented in tabular form or in the form of diagrams as illustrated by the attached figures.

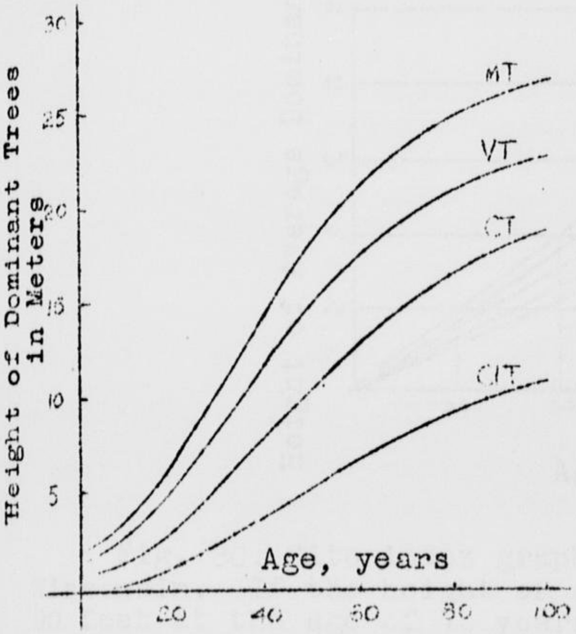

Fig. 78. Site index curves for Scotch pine on different floristic sites of Finland.

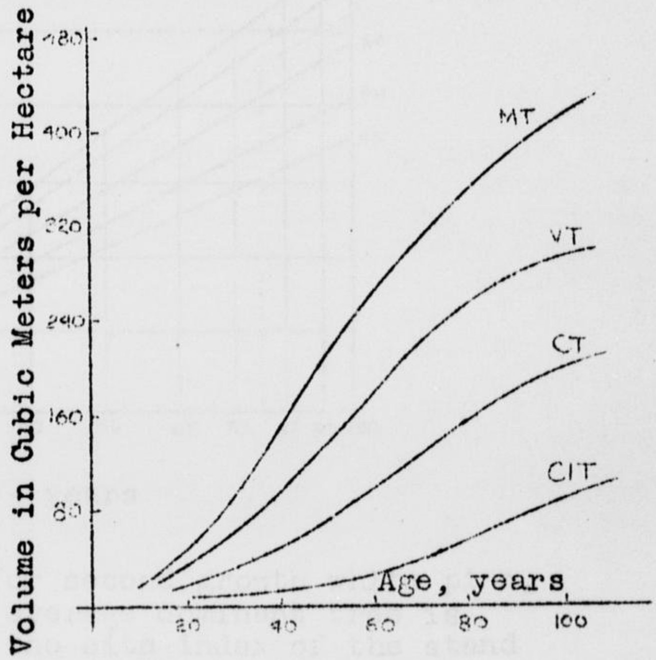

Fig. 79. Yield table for Scotch pine on different floristic sites of Finland.

Legend: ClT - Cladonia type; CT - Calluna type; VT - Vaccinium type; MT - Myrtillus type. (Adapted from Y. Ilvessalo, Methods for preparing yield tables, Silva Fennica, 5. 1927).

To convert cubic meters per hectare to cubic feet per acre multiply by factor 4.36.

With the aid of these yield tables, the volumes of growing stands are arrived at by determining the age of the stand and average height of the dominant trees on representative sample plots. The site index of the stand is found by referring to the site index graph (Fig.80), and the yields for this site index are interpolated from the yield table.

Since the volumes of timber shown by yield tables correspond to fully stocked stands, the volume of under-stocked stands are computed by multiplying the normal volume by a reduction factor. This reduction factor is obtained either by ocular estimate, or by the measurement of the basal area of the stand.

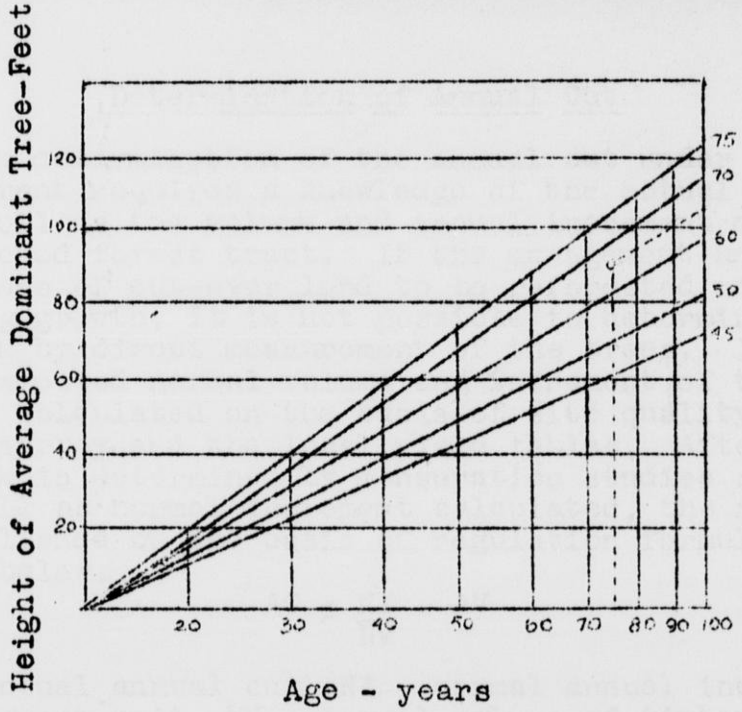

Fig. 80. Site index graph for second growth white pine, Wisconsin. If the height of an average dominant tree is 90 feet at the age of 75 years, the site index of the stand will be 65. (Adapted from S. R. Gevorkiantz and R. Zon, Second Growth white pine in Wisconsin. Res. Bull. 98; Wis. Agr. Expt. Sta. 1930)

In case the circumstances do not permit the determination of age and height in the field, the site quality may be established on the basis of soil examination or identification of ground cover association. While this method is applicable to the estimate of timber volume on extensive areas, it is less reliable in appraisal of individual smaller tracts because of the probability of a greater deviation from the mean.

The direct examination of soil is the only method of establishing the site quality of cut-over lands.

In numerous instances, it is possible to adapt available empirically constructed yield tables to the ecological basis by mensuration studies of representative sample plats on well defined types of soil. In case the volumes of timber on different soil types do not correspond closely with those given in the available yield tables, it is necessary to make the suitable interpolation on the basis of stem analyses.

It is relatively easy to construct yield tables for even-aged pure stands, particularly those of coniferous species, but several complications are involved in dealing with uneven-aged and mixed stands. Consequently, the prediction of yields for these stands are subject to considerable error. The technique of yield table construction is described in detail in the specific mensuration literature.

Determination of Annual Cut

The determination of the annual cut under sustained yield management requires a knowledge of the actual volume of timber, as well as the volume and annual increment of the normally stocked forest tract. If the management unit includes extensive areas of cut-over land to be reforested and areas supporting young growth, it is not possible to determine the future growing stock by direct measurement of the trees. In such cases, the expected normal volume and increment of the management unit must be calculated on the basis of site quality as inferred by the soil survey and the local yield tables. After the actual growing stock is determined by mensuration studies and the normal volume as well as normal increment calculated, the rate of annual cut is established on the basis of regulation formulas, as illustrated below:

$$AC = \frac{NI}{NV} \cdot AV$$

where AC - actual annual cut, NI - normal annual increment of the entire management unit, NV - normal volume of timber, AV - actual volume of timber.

Example: A forest tract of 10,000 acres supports a total volume of 120,000 m.b.f.; the normal volume and normal increment for the same tract are 200,000 and 5,000 m.b.f., respectively. The annual cut would be

$$AC = \frac{5,000}{200,000} \cdot 120,000 \text{ or } 3,000 \text{ m.b.f.}$$

Calculation of Expected Financial Return on Reforestation Investment

Before planting an area to a certain tree species, it is a dvisable to ascertain the expenses involved, the potential yields at various ages and the expected return on the investment. The expenses include value of land (L), cost of planting (C), and cost of protection, silvicultural care, and taxes or carrying charges (c).

The total cost including compound interest on the capital invested at accepted rate (p) up to the age when the plantation becomes merchantable (n) is then compared with the stumpage value of the plantation (V) as inferred from yield tables and estimated market prices according to the following formula:

$$V = L(1.0p^n - 1) + C.1.0p + \frac{c(1.0p^n - 1)}{0.0p}$$

Example: The value of land is \$2.00, cost of planting \$10.00 carrying charges 25¢ per acre, the rate of interest is 4 per cent, and the rotation is 40 years. The cost of production or minimum stumpage value at the end of the rotation will be:

$$V = \$2.00(1.04^{40} - 1) + \$10.00 \cdot 1.04^{40} + \frac{.25(1.04^{40} - 1)}{0.04} \text{ or}$$

\$7.60+\$48.00+\$23.50 or approximately \$80.00.

In case the soil in question is a well drained morainic loam, the expected yield of Norway spruce according to yield tables will be about 40 cords per acre. Consequently the minimum stumpage value of a cord will be $80.00 ÷ 40 or $2.00 which figure is low enough to promise a reasonable profit. If however, the soil is outwash sandy loam producing at 40 years only 16 cords per acre, the minimum stumpage value of a cord would be 80 ÷ 16 or $5.00 which figure indicates a possibility of losing money on the investment.

It must be borne in mind that the calculations on the basis of present cost of wood and the present value of money are only approximate. Even during a 40 year rotation period the stumpage value of the wood may be greatly modified by changes in the technique of wood utilization, transportation facilities and conditions of the domestic and international wood market.

The Evaluation of Land

A detailed soil survey is a necessary prerequisite to the land appraisal. The survey should take into consideration all of the factors important in forest production, such as topography, morphology of soil profile, ground water level, amount of humus, soil reaction and content of available nutrients.

After the survey is completed, a study of current land prices is made. The land of a certain soil type, most advantageously located with respect to transportation facilities and markets, is considered to have the maximum value for this particular soil type. The price of land of similar soil type located less favorably is computed by means of fractional coefficients, decreasing in proportion to the distance from market and passability of roads. The establishment of the reducing coefficients requires a great deal of general experience in evaluation of land, as well as the knowledge of local conditions.

Example: A tract of well drained outwash sandy loam situated on a state highway 5 miles from a pulp mill can be purchased for $6.00 an acre. A tract of similar soil located on a second class road 50 miles from the market center can be purchased for $1.50 per acre. Therefore, the reducing coefficient of such land is 0.25. Accordingly, the coefficient of similar land, located on county trunk road 25 miles from the market center will be, by approximate interpolation, 0.7 and the price of land $4.20.

The value of some particular tracts of the same soil type may also be depreciated because of fire damage, depletion by farming, abundant weed growth, overgrazing and other adverse conditions.

In some instances, the relative value of forest land (L) is estimated by the capitalization of a permanent periodic income represented by net profit from the sale of timber crops (Y) as follows:

$$L = \frac{Y}{1.op^n - 1}$$

where p is rate of interest and n age of stand.

Example: The value of standing timber at 40 years is $80.00 per acre and total expenses for the period at compound interest are $60.00. Hence, the net income is $20.00 per acre and the value of the land with interest at 4% is

$$L = \frac{\$20.00}{1.04^{40}-1} \text{ of } \$5.20 \text{ per acre}$$

If the area to be appraised is cut-over land, the expected yield of timber is determined by consulting yield tables for the species best suited to the soil. The value of land (L) is then estimated by subtracting the cost of planting (C) and raising (e) timber, from the expected total income (V) at the age of maximum merchantability, as follows:

$$L = \frac{V}{1.op^{n}-1} - \frac{C(1.op^{n})}{1.op^{n}-1} - \frac{e}{0.op}$$

Example: The yield of loblolly pine at the age of 60 years is 25 m.b.f., the stumpage price $8.00 per M., cost of planting $5.00 and annual expenses 20¢ per acre with accepted interest rate of 4 per cent. The value of land is as follows:

$$L = \frac{200}{1.04^{60}-1} - \frac{\$5.00 \cdot 1.04^{60}}{1.04^{60}-1} - \frac{.20}{0.04} \text{ or approximately } \$10.00$$

The calculations outlined give some idea of the land from a forestry point of view. The figures obtained in this way may serve as a theoretical basis for the evaluation of land in acquisition, exchange or taxation. However, it must be appreciated that the actual value of land may be strongly influenced by a number of factors other than soil productivity or the profit expected from the stumpage value. Among these factors the following are of prime importance: danger of fire and extent of fire protection measures, danger of injury by climatic factors and attacks by insects and fungi, stability of wood using industries, possibilities of future market developments and the individual interest of the purchaser.

Appraisal of Damage to the Productivity of Forest Land

Forest soils as well as forest stands may be damaged by a number of destructive agents, such as forest fire, damming of streams, drainage, disposal of waste products, toxic industrial fumes and grazing. Where it can be shown that a certain person or a corporation is responsible for the alteration of conditions, the owner of the damaged forest tract is entitled to a fair remuneration.

The appraisal of damage to the growing stock is accomplished according to the established principles of forest finance. The remuneration for the destruction of a mature stand amounts to the stumpage value of the destroyed timber. In the case of non-merchantable reproduction or plantations the allowable damages consist of the cost of planting or reforestation plus the compound interest on this investment computed from the time of initiation of the stand to the time of destruction.

In order to establish a basis for the evaluation of damages to the productivity of the soil, which will hold in a court of law, the facts must be supported by the data of soil analysis and competent profile descriptions of both the damaged and the normal soils. The damage must be also substantiated by evidence based on mensuration studies from adjacent localities or on the data of authoritative literature. If yield tables are available, they may be used as an index of the decreased production due to soil deterioration.

The extent of the damage is usually established empirically on the basis of current prices of the normal and deteriorated soil. Otherwise, the amount of remuneration (D) is calculated as the difference between the discounted stumpage price of the expected yields of timber for the original site (V) and deteriorated site (V_1), i.e.,

$$D = \frac{V}{1.op^{n}-1} - \frac{V_1}{1.op^{n}-1}$$

The species most suitable to the soil and the age of the maximum merchantability are assumed in this calculation. Ordinarily, the cost of planting and the carrying charges are the same on the normal and damaged sites, and, hence, the two values cancel out.

<u>Example</u>: A well drained mull loam soil supported a white pine stand of site 70 capable of producing 63,000 b.f. per acre at 70 years. This soil has deteriorated, due to the erection of a dam and subsequent change in ground water level, to a gley loam capable of supporting a white pine stand of site index 60, and a potential production of 52,000 b.f. at the same age. If the local stumpage value is $7.50 per m.b.f. and accepted interest rate 4%, the damages are as follows:

$$D = \frac{63 \times 7.50}{1.04^{70-1}} - \frac{52 \times 7.50}{1.04^{70-1}} = \$32.50 - \$27.00 - \$5.50 \text{ per acre.}$$

If cost of planting is higher on the damaged site, additional claim may be brought in.

The question of damages to soil productivity comes to attention particularly in the case of cut-over lands or young plantations.

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PART VII

MANAGEMENT OF FOREST NURSERY SOILS

"The soil lies on the twilight of life, a connecting link between the living and non-living, between material animated by vital forces and material subject to physical forces."

Curtis F. Marbut

Introduction

In the early days of reforestation planting was accomplished by broadcasting seeds on cut-over areas. However, the seedlings produced in this manner were seldom sufficiently vigorous to withstand frost, drought, sunscald, and the competition of grasses and shrubs. Birds and rodents were also often responsible for the failure of direct seedings. This led to the practice of raising seedlings in forest nurseries, i.e. protected areas with fertile soil, and sometimes with artificial irrigation (Fig. 81).

The seedlings remain in the nursery for one or more years, during which period they are supposed to attain the necessary vigor to succeed in the environmental conditions of the planting site. The characteristics which seedlings acquire in the period of their early development in the nursery are often transmitted to plantations. If the planting stock is grown in an unsuitable environment, if it is under-developed or over-developed, injured by chemicals or infested with parasitic organisms, one of two results may be expected. Either the seedlings will die immediately after being transplanted, or--what is even more unfortunate--they may struggle on for a number of years and finally be destroyed by fungi or insects. Such struggling plantations are the greatest danger in artificial reforestation, for they provide the breeding areas from which parasites may invade the sound forest stands throughout the region.

The aim of nursery soil management should be to provide vigorous and disease-free planting stock to reforestation agencies, and thus to reduce to a minimum the failure of plantations or their eventual deterioration. This objective is attained by fulfilling the following requirements:

(a) Maintenance of adequate moisture and aeration of nursery soil by careful watering, cultivation, and addition of organic matter;

(b) Maintenance of a proper amount and ratio of available nutrients by the addition of fertilizers and absorbing colloids, and by inoculations of the soil with beneficial organisms;

(c) Control of s oil parasites by application of acidifying agents, fungicides, insecticides, and other suitable means.

Among the problems of forestry, few are as difficult as the management of nursery soils, particularly those in permanent nurseries. In order to succeed in growing seedlings year after year on the same area, it is necessary to apply regularly considerable amounts of commercial fertilizers as well as toxic substances for the control of parasites. All of these chemicals enter into numerous reactions with the soil constituents, and cause a partial or complete destruction of the parasitic as well as the desirable organisms. It is evident, therefore, that under these conditions the productive capacity of a soil may be maintained only if all of the intricate chemical and biological reactions and inter-relationships are thoroughly understood and properly adjusted.

The problems of nursery soil management are often complicated by requests for stock of definite size and shape suitable for reforestation of various sites and by different methods. In the majority of cases such requests are justified and can be satisfied through modifications of the rate and manner of distribution of fertilizing materials. In adjustments of this kind, however, extreme care should be taken to preserve the proper ratio of nutrients, the disturbance of which would lead to the production of unbalanced stock, lacking in vigor. Also, a great deal of reservation should be exercised in regard to the amount of commercial fertilizers used, because heavy applications may result in chemical injury of the stock, or in production of over-developed, so-called "forced" seedlings which are likely to be destroyed by the unfavorable influences of the new environment after transplanting.

The expense involved in purchasing and applying disinfectants and fertilizers in some nurseries amounts to several hundred dollars per acre. This expense, however, is well justified considering the high value of the product. One acre of a forest nursery produces more than 1,000,000 two-year old seedlings. The minimum cost of two-year old seedlings, according to present price lists of private companies, is $4.00 per thousand. Thus, the gross income from one acre of nursery soil in two years amounts to at least $4,000, and the gross income of a nursery, forty acres in size, may easily reach $100,000 per year.

One acre of a forest nursery produces enough seedlings to reforest one thousand acres, and consequently, the care given to a forest nursery of average size may decide the future of forest stands worth millions of dollars.

CHAPTER XXVI

SELECTION OF FOREST NURSERY SITES

A forest management unit in European countries seldom exceeds 10,000 acres. With a common rotation of 80 years, the area to be reforested annually under management on a sustained yield basis is, therefore, 125 acres. The planting of this area requires about 250,000 seedlings, i.e. an amount of planting

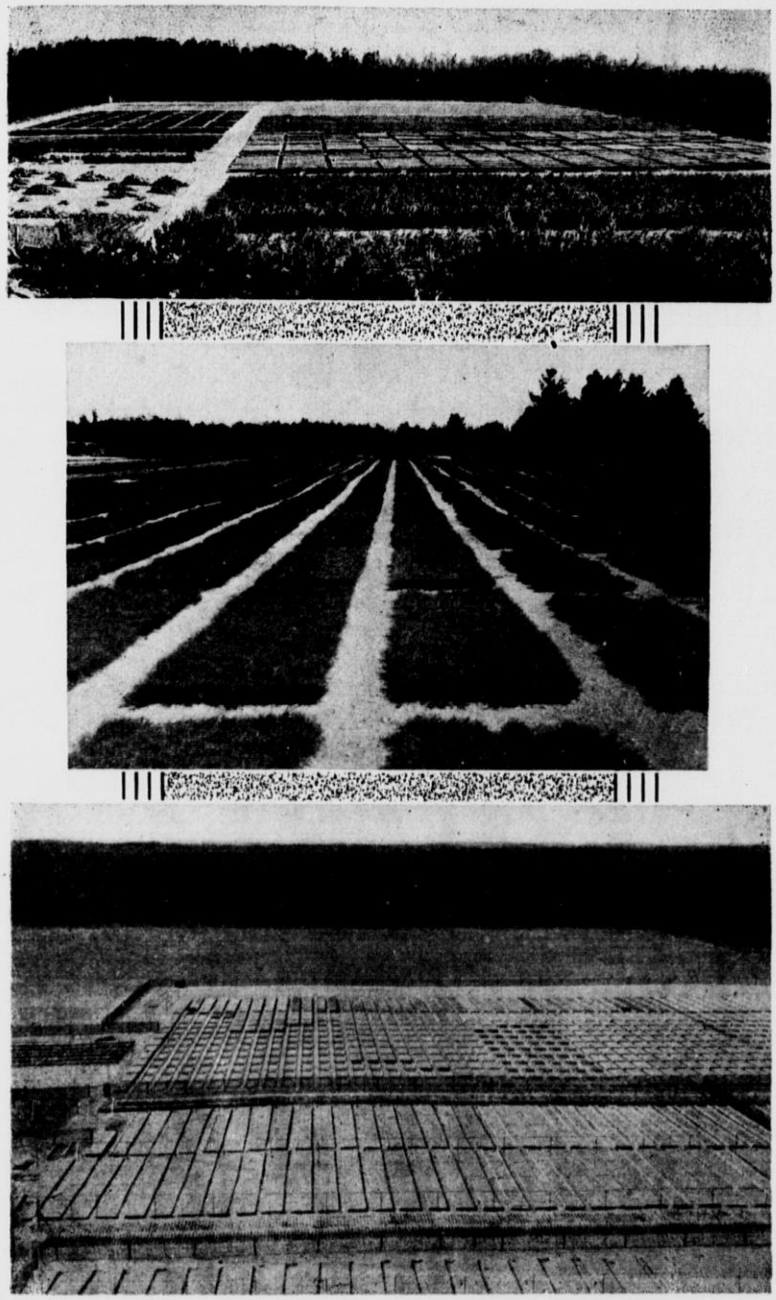

Photo by Wisconsin Conservation Department

Figure 81. General view of seed beds in Trout Lake and Wisconsin Rapids State **Forest Nurseries.**

stock which can be produced annually in a nursery less than one acre in size. This amount of planting stock can be successfully raised in a temporary nursery located on a recently cut-over area and maintained as long as the natural soil fertility is not exhausted.

The practice of temporary nurseries has many advantages, but it is not applicable at all to a large-scale American reforestation program. The need of this country for hundreds of millions of seedlings calls for the employment of mechanized mass-production methods and equipment, the full utilization of which is possible only in well organized permanent nurseries managed by highly trained personnel.

The establishment of a modern permanent nursery requires a considerable investment for grading, fencing, overhead watering system, office building, garages, and other equipment. Therefore a nursery once established cannot be moved to another place without the loss of many thousands of dollars. On the other hand, a poorly selected nursery handicaps reforestation because of the high production cost of seedlings or because of inferior planting stock.

A person who is appointed to select the nursery site should bear in mind that he is responsible, or may be held responsible, for the difficulties which may arise in raising stock. For this reason, it is well worthwhile to invite for advice and criticism experienced nurserymen and specialists in forestry, soils, plant pathology, etc. A written statement by these specialists is always more valuable than suggestions or opinions made by word of mouth.

The factors which should be considered in selecting the nursery site are outlined below.

(A) Physiographic factors:

(1) Climate. The localities of extreme temperatures, as well as those having late spring and early fall frosts, should be avoided. Often, the most suitable conditions are found in the proximity of large lakes and other bodies of water. The growing season and other climatic conditions of the nursery site should correspond with that of the region to be reforested.

(2) Topography. A level area is most desirable in the majority of cases. On the heavier soils a gentle slope may be beneficial because of the better surface drainage. The slopes of a larger gradient are subject to erosion or "washing off" of seed beds. The depressions, even slight ones, suffer from a periodic excess of water as well as from "heaving" of seedlings. Slopes of moderate gradient may be terraced. Small rough areas and depressions may be leveled by grading. However, both terracing and grading are not very desirable because they may expose the less productive subsoil and require additional expense. Narrow valleys and canyons should be avoided because of the scarcity of direct sunlight and danger of frost.

(3) Exposure. The area should be protected from wind to prevent injury to the seedlings by blowing sand, and by excessive evaporation during the snowless fall and winter periods. The action of wind may be reduced to some extent by planting shelter-belts or wind-breaks of rapid growing trees and shrubs or corn, sunflower and similar plants. In hilly or mountainous country, the northern exposure is usually preferable because of less danger of early frost. The relief of the area and arrangement of the protective cover should allow for the drainage of the cool air so as to avoid a "frost pocket" condition.

(4) Inundation. Whether or not the area is subject to over-flow should be investigated.

(B) Soil factors:

(1) Soil profile. The soil of recently cleared land with preserved forest litter is more desirable than a similar soil of cultivated, burned-over, or sodded areas. The soil should be at least four feet deep and rather uniform throughout the profile. A well developed dark humic layer commonly is a desirable feature. An excessively developed humic layer containing somewhat peaty material indicates a deficiency of drainage, and hence, an undesirable condition. An intensely colored subsoil layer usually indicates the presence of toxic substances and the soil should be carefully investigated by chemical or greenhouse tests. The soil profile must not include any of the following formations:

(a) Subsoil layers high in colloids, and especially impervious "claypan" layers.

(b) Iron concretions, or cemented "hardpan" layers as found in Podzol soils.

(c) Rusty or greenish mottlings common in Gley soils.

(d) Deposits of calcareous material common in Rendzina soils.

The undesirable properties of the lower soil layers will become especially pronounced in case the surface soil is removed for leveling.

(2) Ground water. The ground water should be not less than five feet from the surface so that there may not be danger of excessive moisture in the spring.

(3) Texture of soil. Sandy loam or loamy sand soil, containing from 15 to 25 per cent of silt and clay particles, is preferable. Lighter soils may be improved by the addition of organic matter or, in some cases, clay. Soils high in colloids are undesirable because of difficulty in cultivation, weeding, control of parasites, adjustment of reaction, etc. In cooler regions highly colloidal soils remain frozen late in the spring and in removing the seedlings for planting the roots are seriously injured. Also, on heavy soils the seedlings often suffer from "heaving" or "freezing out". The improvement of these soils by the addition of sand or charcoal is seldom practicable.

(4) Stoniness. Special attention should be given to the amount of gravel and stones imbedded in the upper one and one-half foot layer, since these materials will interfere greatly with cultivation.

(5) Reaction of soil. The optimum reaction for most species is between pH 5.0 and 6.0. Soils of a lower pH have a low content of available nutrients and some toxic agents; soils of a higher pH encourage the invasion of fungous diseases. The reaction may be corrected to a certain extent by the application of chemicals and organic matter. An increase in acidity may be produced by the application of acid solutions, ammonium sulfate, sulfur, or other acidifying agents. A decrease in acidity may be attained by the addition of alkalizing materials such as lime and wood ashes. This, however, is often objectionable because it encourages the invasion of damping-off organisms. Consequently, the improvement of the strongly acid soils may be more successfully accomplished through the fixation of the toxic substances by means of mineral or organic fertilizers. In general, alkaline soils present a much more difficult problem than the strongly acid soils.

(6) Organic matter. It is preferable to have at least 3 per cent of organic matter in the upper 6 inch soil layer.

(7) Plant food material. A desirable minimum content of nutrients in the upper soil layer is as follows: total nitrogen 0.1 per cent; available nitrogen (nitrates and ammonia) about 1 per cent of the total nitrogen; available phosphoric acid (P_2O_5) 100 pounds per acre; available potash (K_2O) 150 pounds per acre; total replaceable bases 3 to 4 milliequivalents per 100 gms. if the base exchange capacity of soil is about 10 m.e. per 100 gms. The amount of nutrients, however, varies greatly with the soil and climate and can be adjusted by the addition of fertilizers.

(8) Toxic agents. The soil should not contain a high content of total soluble salts, a high content of carbonates, ferrous iron, active aluminum, or other toxic substances. If the area has been used before as a forest or commercial nursery or for raising truck crops, it is desirable to determine the content of arsenic which might have been introduced by treatments for insect parasites.

(9) Peat deposits. In most regions, the productivity of a permanent nursery sooner or later will become dependent upon the supply of organic matter which is used for the improvement of the physical condition of soil and as a source of nitrogen, carrier of fertilizers, and as a buffering material after treatment with acid solutions. Therefore, it is important that some suitable deposits of acid peat, free from parasites and of a high base exchange capacity (80 milliequivalents per 100 gms., or higher), are located within a reasonable distance from the nursery.

(C) Biotic factors:

(1) Useful organisms. The upper soil layer should contain a sufficient number of nitrogen fixing, ammonifying, nitrifying, and cellulose-decomposing organisms, as is ordinarily the case with any fairly recently cut-over area. If the biological activity of the soil, for some reason or other, is unsatisfactory, it may be increas-

ed by the generous application of duff of leaf-mold from productive forest stands. Such stands should be located within a reasonable distance from the nursery so that the transportation cost is not exceedingly high.

(2) Parasitic organisms. The possible occurrence of parasitic fungi and insects should be investigated in the field and by greenhouse tests. The heavy infection of soil with parasites is especially common on abandoned fields.

(3) Weeds. If possible, the areas containing persistent weeds of the region should be avoided.

(D) Economic factors:

(1) Location. The nursery should be located as near as possible to the center of the planting region so that the transportation cost is low.

(2) Size of the area. There should be sufficient area to produce the seedlings and transplants required for planting. The possible expansion of the reforestation program should also be considered and the eventual enlargement of the nursery insured by the purchase of sufficient land at the start.

(3) Water supply. The source of water for irrigation should be carefully examined, the pumphouse located, and the length and cost of water pipes calculated. Also, a source of drinking water must be established, and the expenses connected with its supply estimated.

(4) Roads. Special consideration should be given to the condition of the roads in the spring in order that there may be no delay in delivering the seedlings during the planting season.

(5) Source of power and telephone connection. It is very desirable that power and telephone lines be in near proximity to the nursery site.

(6) Supervision. Since the most efficient management of a nursery demands the presence of the nursery superintendent and his assistants almost constantly, conditions should allow the possibility of permanently locating these officers and their families in the vicinity. The housing, accessibility to a populated center, and distance to a school are of primary importance.

(7) Labor. The availability of labor and distance to a settlement should be considered.

(8) Public relationship. Sites accessible to the public, especially those located on highways, are preferable. A well-managed

forest nursery may well serve for education and recreation of the general public.

Preparation of the Ground

If the area selected for a nursery site supports a forest stand, it is important to make an exact plan of the location of seed beds, roads and buildings before clearing. This must be done in order to preserve in proper places strips of trees and shrubs which would serve as windbreaks or hedges.

After the timber is logged, the slash is either removed and allowed to decay in compost heaps, or it is burned in small piles and the ashes carefully distributed over the area. The stumps are pulled with a tractor and used for fuel; stump holes are filled with the soil. The dry season is best suited for pulling the stumps as the soil is easily separated from the roots. The cleared land is plowed, disked and harrowed, or rototilled, and the seed beds are prepared. The cultivation or rototilling of the soil is particularly urgent on sites infested with white grubs or weeds.

Areas of irregular topography must be graded or terraced using a scraper-tractor unit. In grading, the fertile topsoil is moved to one side, the sterile subsoil is leveled and the topsoil is then distributed uniformly over the surface. A contour map, or series of level traverses are essential for the calculation of the cut and fill and the efficient grading or terracing of any extensive area. Utmost care must be taken to grade to a uniform level or slightly sloping surface. Even slight depressions are likely to accumulate water and cause either frost heaving or stagnant growth of stock due to lack of aeration. In soils with less pervious substratum provision should be made for establishing tile drainage.

Under conditions of nursery practice, soils of all textural classes are subject to erosion, and, hence, slopes with gradient exceeding five degrees, should be rigidly avoided.

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CHAPTER XXVII

REGULATION OF MOISTURE CONTENT IN FOREST NURSERY SOILS

Advantages and Disadvantages of Artificial Irrigation

Under proper management, artificial watering facilitates the preservation of stock during periods of prolonged drought and makes possible the maintenance of an adequate and uniform soil moisture content. However, the artificial irrigation system may adversely affect the quality of nursery stock if unnecessarily high amounts of water are applied.

Excessive watering leads to an anaerobic condition, leaches or renders unavailable plant nutrients, and may encourage the development of fungous diseases. Besides these direct detrimental effects, excessive watering may be harmful indirectly by developing succulent seedlings with a low resistance to drought and frost.

Rate of Watering

Most practical foresters believe that it is better to lose a few of the weaker specimens in the nursery than to bring up the stock on excessive moisture and have large-scale failures in the field following transplanting. However, as recent observations show, even nurserymen who intend to minimize watering, apply considerably more water than seedlings need. This fact is strikingly illustrated by comparing the amounts of water used in nurseries with and without artificial irrigation.

In order to get some idea as to the amounts of water being applied, it is very helpful to record the quantity of water used and to relate this quantity to the average monthly rainfall. For this purpose the nursery should be equipped with a number of rain gauges, properly placed, both inside and outside of the region of artificial irrigation.

In a conservative watering, the amount of water added to the soil each month should not greatly exceed the average monthly rainfall. A survey of this problem showed that in some nurseries, four to five times as much water as the average precipitation for the same period was added during the two dry months. Thus, in some instances, artificial irrigation has translocated the nursery from the prairie-border region of the central United States to an extremely humid condition as found on the Pacific Coast.

In fine-textured nursery soils, the establishment of a proper rate of watering may be materially facilitated by an analysis of the physical properties of the soil. A knowledge of soil aeration is particularly important since it is a function of two variable factors, the degree of water saturation and soil porosity. Consequently, soil aeration data have the same general significance for all soil types. As long as watering does not lower the aeration of soil below 20 per cent by volume for any considerable length of time, there is no danger of denitrification and other reduction processes. This means that satisfactory conditions for the growth of trees, on soils having a porosity of 50 per cent may be maintained with as much as 30 per cent of water in the soil. On the other hand, with soils having a porosity of 40 per cent, only about 20 per cent of water in the soil is allowable for satisfactory growth of seedlings. The aeration of coarse sandy soils practically never drops to an undesirable level.

In dry seasons it is advisable to dig into the soil periodically to about one foot depth in order to ascertain either by laboratory methods or ocular estimation the penetration of soil moisture and probability of drought. Studies following the severe drought of 1936 showed that the failure or survival of unwatered seedlings was directly correlated with the depth of root penetration. Table 36 presents some observations on the relation between drought resistance of seedlings and the length of root systems. In this particular case the drought injury was correlated with root length within each class of stock, but not with the top-root ratios.

Table 36. Average Top-Root Measurements of Survived and Drought-Killed Seedlings on Unwatered Nursery Plats; July, 1936 (After H. M. Galloway)

Class of stock	Survived			Drought-killed		
	Top (inches)	Root (inches)	T/R Ratio	Top (inches)	Root (inches)	T/R Ratio
2-0 Jack pine	8.07	8.02	1.01	4.64	5.99	.78
2-0 Red pine	5.53	6.64	.83	3.90	5.04	.77
3-0 Red pine	10.24	11.73	.87	5.38	8.40	.64

To aid in the maintenance of a proper water supply, several moisture-recording instruments have been devised.

The <u>tensiometer</u> type (Heath) of instrument consists of a porous clay vessel filled with distilled water and attached to a mercury manometer. When a soil is saturated it shows no attraction for water and hence no pull is exerted on the mercury column. As the soil becomes drier, water from the clay tube or jar is drawn out into the soil, and the vacuum created raises the mercury in the manometer column. This rise is related to the soil moisture content and is measured in convenient units of the manometer scale (Fig. 82).

In calibration, the instrument is placed in a saturated soil which is allowed to dry out until it reaches the wilting point. Throughout this period, the soil moisture is accurately determined on a number of samples, and a curve of soil moisture in terms of manometer units is thus constructed.

In nursery use the porous vessel should be placed in the critical region as determined by maximum root penetration, i.e. about 5 inches for one year old seedlings and about 10

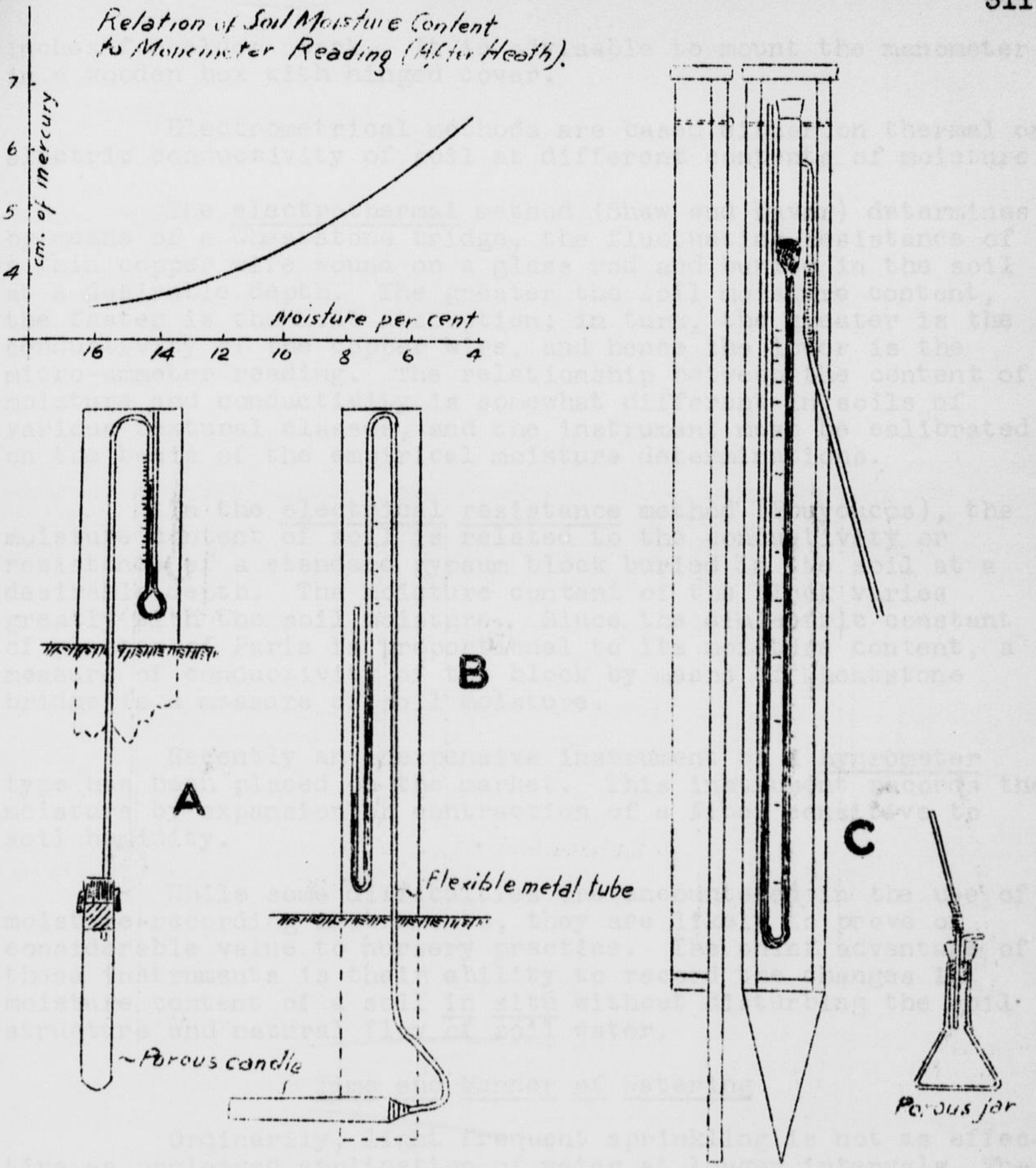

Figure 82. Types of soil moisture meters: (A) Heath's hygrometer adapted for use in forest nurseries; (B) Heck's modification; (C) Modification by the Lake States Forest Experiment Station.

inches for older stock. It is advisable to mount the manometer in a wooden box with hinged cover.

Electrometrical methods are based either on thermal or electric conductivity of soil at different contents of moisture.

The electrothermal method (Shaw and Baver) determines, by means of a Wheatstone bridge, the fluctuating resistance of a thin copper wire wound on a glass rod and buried in the soil at a desirable depth. The greater the soil moisture content, the faster is the heat absorption; in turn, the greater is the conductivity of the copper wire, and hence the lower is the micro-ammeter reading. The relationship between the content of moisture and conductivity is somewhat different in soils of various textural classes, and the instrument must be calibrated on the basis of the empirical moisture determinations.

In the electrical resistance method (Bouyoucos), the moisture content of soil is related to the conductivity or resistance of a standard gypsum block buried in the soil at a desirable depth. The moisture content of the block varies greatly with the soil moisture. Since the dielectric constant of plaster of Paris is proportional to its moisture content, a measure of conductivity of the block by means of Wheatstone bridge is a measure of soil moisture.

Recently an inexpensive instrument of a hygrometer type has been placed on the market. This instrument records the moisture by expansion or contraction of a fiber sensitive to soil humidity.

While some difficulties are encountered in the use of moisture-recording instruments, they are likely to prove of considerable value to nursery practice. The chief advantage of these instruments is their ability to record the changes in moisture content of a soil in situ without disturbing the soil structure and natural flow of soil water.

Time and Manner of Watering

Ordinarily, light frequent sprinkling is not as effective as prolonged application of water at longer intervals. The light sprinklings wet only the upper one or two inches of soil and a large amount of water is immediately lost through evaporation from the soil surface. This is especially true when watering is done during hours of high temperature. However, frequent sprinklings should sometimes be used on very young, short-rooted seedlings. Also, only a limited amount of water may be applied at a time on heavy soils when there is danger of denitrification. A certain amount of care is needed in watering soils of low colloidal content which have been treated with soluble commercial fertilizers since excessive watering may deprive the upper soil layer of nutrients. A careful periodic examination of the development of root systems and penetration of water on a given soil type is essential to the establishment of a proper rate of watering.

There has been a long, unsettled argument as to the effects of water applied on hot days under direct sunshine. While many practical foresters claim that this practice is harmful to seedlings, several scientists deny the validity of this belief.

Watering on days of scalding temperature decreases the air and soil temperature and often prevents the destruction of stock by heat. At the same time this practice is not economical since rapid evaporation prevents the penetration of water to a greater soil depth. The most efficient conservation of water is reached when it is applied late in the evening. Such practice allows percolation of water to a depth of 8 or 9 inches. Thus, when temperature becomes high in the middle of the day, the water is protected from evaporation by a soil layer of considerable thickness. The application of water in the early morning, i.e. from 3 to 5 a.m. is almost as efficient as evening watering. As observations showed, in nurseries where water was applied during the evening and early morning hours, including the nurseries without an overhead system, no losses of stock occurred in the extreme drought of 1936. In the same season, stock watered during the daytime was seriously damaged in several nurseries provided with an overhead system.

Watering in the daytime is decidedly harmful when the nursery is forced to use a supply of hard water. Because of rapid evaporation, the accumulation on the soil surface of a crust of calcium and magnesium carbonates results. Although such a crust may not reach a depth of more than 1/8 inch, it sometimes causes the deterioration of stock. One-year old seedlings are particularly susceptible to injury of this kind.

As a protection against frost injury, the operation of the overhead system may become urgent during late spring and early fall nights when the temperature drops suddenly toward the freezing point.

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CHAPTER XXVIII

COMMERCIAL FERTILIZERS

"I take it upon me to say, that to be a good husbandman, it is necessary to be a good chymist. Chymistry will teach him the best way to prepare nourishment for his respective crops, and, in the most wonderful manner will expose the hidden things of nature to his view."

Dr. A. Hunter, "Georgical Essays" Ed. 1777.

Irrespective of the original productivity of the soil selected for a forest nursery, in the course of time the content of nutrients and organic matter will be depleted because of leaching, activity of micro-organisms and nutrition of the seedlings. The fertility of soil may be reestablished in a safe and natural manner by the application of litter and duff, or humus from productive forest stands. These materials, however, are seldom available in large quantities and their procurement is very costly. In order to bring the nutrient content of a depleted sandy nursery soil to its original state it may be necessary to apply as much as 50 tons of forest duff. Therefore, natural fertilizing materials, as a rule, must be replaced by commercial fertilizers applied either broadcast, in the form of compost, or in solution.

The use of fertilizers requires a knowledge of their chemical composition, their reactions with the soil, and their effects upon the development of seedlings and soil organisms. Indiscriminate application of fertilizers may cause chemical injury to the roots of seedlings, encourage diseases, and lead to the production of unbalanced nursery stock, lacking in vigor.

The following outline contains a description of the more important commercial fertilizers with respect to their suitability to nursery practice.

A. Organic Nitrogen Fertilizers

This group of fertilizers includes dried blood, tankage, activated sewage sludge, castor meal, and similar materials containing from 5 to 10 per cent of ammonia nitrogen. Although these fertilizers are widely used in nursery practice, none of them are entirely satisfactory. The chief objections are, the high price, encouragement of parasitic organisms, and danger of chemical injury of seedlings. The chemical injury occurs under a condition of high temperature and abundant moisture which may lead to a sudden release of ammonia.

B. Mineral Nitrogen Fertilizers

(1) Nitrate of Soda, or "Chile saltpeter", $NaNO_3$, occurs as a natural deposit in South America. It is also produced in quantities in Virginia and Europe from synthetic nitric acid, synthetic ammonia, sodium hydroxide, and sodium carbonate. The refined salt contains about 16 per cent of nitrogen.

Sodium nitrate is soluble in water and readily available to plants. In regions not subject to late frosts, it has special value as an early spring fertilizer since it furnished the nitrogen to seedlings at a time when the nitrifying organisms are not active.

also, it may be virtually necessary on strongly acid soils, disinfected soils, soils high in raw organic matter, as well as on soils where upland hardwoods or other nitrophilous species are grown.

Continued applications of sodium nitrate may lead to a decrease of soil acidity because of assimilation of nitrate ion by the plants and accumulation of sodium in the form of the carbonate. This may be schematically represented by the following equation:

$$2\ NaNO_3 + H_2O + CO_2 = 2\ HNO_3 + Na_2CO_3$$

Actually the sodium nitrate probably reacts with the exchangeable ion to form the sodium exchange which eventually reacts with water and carbon dioxide, as follows:

$$NaNO_3 + B.x = Na.x + B.NO_3$$

$$2\ Na.x + H_2O + CO_2 \longrightarrow 2\ H.x + Na_2CO_3$$

The accumulation of sodium carbonate is detrimental to the seedlings of a majority of species, partially because of a decrease of acidity, and partially because of the direct toxicity of the sodium ion. Therefore, the application of sodium nitrate should be limited to cases when nitrate nitrogen is an urgent necessity. Since severe damping-off is a usual result of nitrate fertilization, nitrates should not be applied on seed beds. Adverse soil conditions resulting from the excessive application of sodium nitrate may be corrected by the application of acid fertilizers, particularly ammonium sulfate.

Because nitrate nitrogen appears as an acid radical and forms no insoluble compounds, it cannot be absorbed or fixed in the soil and is easily lost through leaching. For this reason, nitrate fertilizers are usually applied in a liquid form. The common rate of application varies from 100 to 200 pounds per acre at a time. Large amounts should not be applied particularly on pure sandy soils or on poorly aerated heavy soils. In the former case, the excess of nitrates will be leached away without producing much beneficial effect, while in the latter case, the nitrates will be reduced into undesirable forms. After the application of nitrates the treated beds should be watered rather conservatively so as to prevent leaching of the fertilizer and to avoid anaerobic conditions which would lead to denitrification.

The fertilizer should be obtained from a reliable source, since imperfectly purified salts may contain toxic potassium chlorate ($KClO_4$). "Arcadian" nitrate of soda is a synthetic American product of guaranteed analysis, which may be especially recommended.

(2) <u>Calcium</u> <u>Nitrate</u> or "Norwegian Saltpeter", $Ca(NO_3)_2$, is produced from lime water and synthetic nitric oxide. This fertilizer contains about 16 per cent of nitrogen and is readily soluble in water. It could be used to advantage on strongly acid nursery soils deficient in calcium. However, it is highly deliquescent and expensive. In other respects it is similar to nitrate of soda.

(3) <u>Ammonium</u> <u>Sulfate</u>, $(NH_4)_2SO_4$, is a by-product of coke or coal distillation. It is also manufactured from ammonia, calcium sulfate and carbon dioxide. It contains about 20 per cent of nitrogen. The salt is easily soluble in water and, under favorable conditions,

its ammonia is quickly converted into the nitrate form by nitrifying bacteria. This makes the nitrogen in ammonium sulfate available to the plants almost as readily as that in nitrate fertilizers. A great number of the coniferous species have ability to utilize ammonia nitrogen without its conversion to the nitrate form. Because the ammonia is energetically absorbed by the soil colloids, and used by plants, the sulfate ion accumulates and produces an acid reaction according to the equation:

$$(NH_4)_2SO_4 + 2\ H.x = 2\ NH_4.x + H_2SO_4$$

In most cases an acid reaction is beneficial to the seedlings, and hence, ammonium sulfate is, in general, a much more desirable commercial nitrogen fertilizer than sodium or calcium nitrate. This is particularly true when coniferous stock is grown. The acidification of a soil through the application of ammonium sulfate serves in a measure to control parasitic organisms. An especially valuable property of ammonia fertilizers is that the ammonia goes into the soil exchange compound where it may be retained for a long period.

Although ammonium sulfate contains more nitrogen per unit than the nitrate fertilizers, it is more slowly available, less toxic and may be applied at a rate as high as 300 pounds per acre. In some cases it is beneficial to combine sulfate of ammonia with nitrate of soda in a ratio, determined by soil conditions and composition of stock. Because ammonia is liberated by alkalies, ammonium sulfate should not be mixed with lime, potassium carbonate, wood ashes, or similar basic materials before application.

(4) <u>Ammonium</u> <u>Nitrate</u>, NH_4NO_3, is manufactured synthetically from nitrogen of the air. The pure salt contains 35 per cent of nitrogen of which 7 per cent is in the form of ammonia and 28 per cent is in the form of nitrate. This highly concentrated, double salt fertilizer may be of special value in liquid treatments. However, it is hygroscopic and expensive. One hundred pounds per acre at a time is a high application of ammonium nitrate.

(5) <u>Ammonium</u> <u>Sulfate-Nitrate</u>, "Leunasalpeter" or "Montansalpeter", $(NH_4)_2SO_4.NH_4NO_3$, is a double salt manufactured synthetically in Germany and containing 26 per cent of nitrogen. About one-fourth of the nitrogen is present in the nitrate form and three-fourths in the ammonia form. It may be considered as a mixture of about 165 pounds of ammonium sulfate with 100 pounds of ammonium nitrate. It is considerably less hygroscopic than ammonium nitrate and is a very popular fertilizer in Central Europe.

(6) <u>Calcium</u> <u>Cyanamid</u>, $CaCN_2$, is manufactured from calcium carbide through which nitrogen gas is forced at a high temperature. It contains from 20 to 25 per cent of nitrogen, and breaks down in the soil into ammonia and nitrates, according to the following equation:

$$CaCN_2 + 3\ H_2O = CaCO_3 + 2\ NH_3$$

$$NH_3 + 2\ O_2 = HNO_3 + H_2O$$

As by-products of these changes, there are formed some toxic compounds, and the fertilizer cannot be applied shortly before seeding or planting nursery stock. For this reason, calcium cyanamid is little desirable for use in nursery practice.

C. Phosphate Fertilizers

(1) Rock Phosphate, $CaF_2 . 3\ Ca_3(PO_4)_2$, occurs as apatite or phosphorite rock. It contains about 70 per cent of tri-calcium phosphate. This is soluble in strong mineral acids and is not directly available to the seedlings. In time, however, the water and carbon dioxide of the soil may convert the tri-calcium phosphate into available mono-calcium phosphate, as follows:

$$Ca_3(PO_4)_2 + 4\ CO_2 + 4\ H_2O = CaH_4(PO_4)_2 + 2\ Ca(HCO_3)_2$$

This process is very slow, especially in slightly acid soils and in soils with little organic matter. Fine grinding increases somewhat the availability of phosphorus. Nevertheless, even finely ground rock phosphates are slow acting fertilizer and are used for the permanent improvement of soils rather than for an immediate supply of phosphorus. In some exceptional cases, when the organic matter of compost is treated with mineral acid, rock phosphate may be advantageously added in a large quantity to the compost. Also, the rock phosphate may be used beneficially when strongly acid peat is applied in large quantities on nursery soils, as well as when the soil is treated with sulfur. Inoculation of soil with sulfur oxidizing bacteria, or an addition of duff of a raw humus nature, may speed up considerably the release of the available phosphorus.

Some rock phosphates may be toxic to forest seedlings because of their relatively high fluorine content.

(2) Superphosphate, $(CaH_4(PO_4)_2$, is essentially mono-calcium phosphate and is manufactured from rock phosphates treated with sulfuric acid, as follows:

$$Ca_3(PO_4)_2 + 2\ H_2SO_4 + 4\ H_2O = CaH_4(PO_4)_2 + 2\ CaSO_4 . 2H_2O$$

In the manufacturing process, besides the water soluble mono-calcium phosphate $CaH_4(PO_4)_2$, ammonium citrate soluble di-calcium phosphate $Ca_2H_2(PO_4)_2$, as well as insoluble tri-calcium phosphate $Ca_3(PO_4)_2$, are obtained. The commercial superphosphate contains from 14 to 20 per cent of available phosphoric acid (P_2O_5), partly in a form of mono-calcium and partly in a form of di-calcium phosphate. The 20 per cent superphosphate is the most common phosphate fertilizer in forest nurseries. Its rate of application varies from 100 to 500 and even more pounds per acre.

In case the nursery soil is strongly acid and does not contain a sufficient amount of active calcium, the superphosphate may be converted into insoluble ferric phosphate or aluminum phosphate, which is not available to the seedlings. This process is called "phosphate fixation" and it may be prevented by the addition of lime or wood ashes. On the other hand, in slightly acid or alkaline soils, the superphosphate may be converted back to unavailable tri-calcium phosphate. This may be counteracted by the addition of ammonium sulfate and other acid-forming materials. The presence of some gypsum, or calcium sulfate, is beneficial to the plants as a source of calcium and sulfur.

Sometimes the superphosphate is referred to as "acid phosphate". The Association of Official Agricultural Chemists, however, has recommended that the term acid phosphate be discontinued.

(3) Double Superphosphate or "Treble Superphosphate", known also under the trade name "Multiphos", contains from 40 to 50 per cent of available phosphoric acid (P_2O_5). It is prepared by treating phosphate rock with phosphoric acid instead of with sulfuric acid, as follows:

$$Ca_3(PO_4)_2 + 4\ H_3PO_4 = 3\ CaH_4(PO_4)_2$$

Thus, the double superphosphate may be regarded as ordinary superphosphate from which the gypsum has been removed.

Double superphosphate is particularly suitable for use on nursery soils well supplied with calcium, and when large quantities of phosphate are needed. A single application of this fertilizer may be as high as 500 pounds per acre, assuming that the fertilizer is thoroughly worked into the soil.

(4) Bone Phosphate. Bones contain about 50 per cent of tricalcium phosphate, and about 4 per cent of nitrogen. Bone phosphate is a rather favorite source of phosphorus in greenhouse and commercial nurseries, chiefly because it provides some extra nitrogen and because it produces no toxic effect upon the plants when applied in large quantities. However, it is an expensive fertilizer which cannot compete in forest nursery practice with the other forms of phosphate.

(5) Basic Slag, $(CaO)_5.P_2O_5.SiO_2$, is a by-product of the steel industry. It contains about 20 per cent of phosphoric acid, a large amount of calcium, and some amount of iron, aluminum, sulfur, and silica. The phosphorus is readily available to the seedlings and does not revert to an insoluble form. It is as active as superphosphate and may be of special value on strongly acid nursery soils. On the less acid soils, the superphosphate is usually preferable. Basic slag is largely a German fertilizer, and is on the market in the United States only to a limited extent.

The application of phosphate fertilizers in forest nurseries accomplishes triple purpose: it supplies the readily available phosphorus, it corrects the deficiency of calcium, and it counteracts the effect of the toxic agents, particularly aluminum. For this reason, the phosphate fertilizers are often applied to nursery soils in quantities considerably higher than those needed for the correction of deficient phosphorus. Also, the soils having a high fixation capacity may call for a systematic addition of large amounts of phosphates. Fortunately, the phosphoric acid is only slightly ionized and exerts considerably less toxic effect upon the seedlings as compared with other acid radicals, particularly with chlorine and nitrate ions. Due to this fact, in some nursery soils, as large amounts of 20 per cent superphosphate as 1000 pounds per acre did not produce an adverse effect upon the seedlings.

D. Potash Fertilizers

(1) Muriate of Potash, or Potassium Chloride, KCl, is manufactured by purifying the natural potash deposits of Germany and France. It contains nearly 50 per cent of potash (K_2O), is soluble in water, and is for the most part readily available to seedlings. In the soil it splits up into potassium and chlorine ions. The former are absorbed by the colloidal fraction of the soil and utilized by the plants, probably in the form of carbonate; the latter form hydrochloric acid. This may be schematically presented as follows:

$$KCl + H.x \longrightarrow K.x + HCl$$

$$2\ K.x + H_2CO \longrightarrow K_2CO_3 + 2\ H.x$$

The liberated hydrochloric acid is partly employed in converting calcium phosphates into available form, and is partly leached. In larger quantities chlorine ion is highly toxic to the forest seedlings, and where large amounts of potash are needed, potassium sulfate should be used instead of muriate of potash. Because potassium salts are easily washed from the soil in the absence of base exchange material, the need for large and repeated applications of potash fertilizer is to be expected on sandy soils poor in clay and organic matter.

The rate of application of muriate of potash varies ordinarily from 100 to 250 pounds per acre at a time. In purchasing potash fertilizers one should be sure that the salt does not contain borax which is injurious to the plants.

(2) Sulfate of Potash, K_2SO_4, is made by treating muriate of potash with sulfuric acid or magnesium sulfate. It contains about 50 per cent of potash (K_2O). It may be used in somewhat larger quantities than muriate of potash without injury to the roots of the seedlings. In other respects it is similar to muriate of potash.

(3) Crude potash salts. The crude sources of potash are kainit, sylvinite, and carnallite. Kainit is a mineral compound of muriate of potash and sulfate of magnesia with some sodium chloride and other impurities. It contains from 12 to 16 per cent of potash. Very often under this name is sold a mixture of carnallite and sylvinite with some rock salt. Sylvinite is essentially a mixture of potassium and sodium chlorides, containing about 16 per cent of potash. Carnallite is a double compound of muriate of potash and magnesium chloride with some sodium chloride. It contains about 9 per cent of potash.

The chemical composition of crude potash salts varies greatly according to the mine from which they come. Materials from some deposits may be highly toxic to seedlings, especially when applied in considerable quantities. Total destruction of the nursery stock has been reported due to the application of large amounts of crude potash fertilizers. The toxicity is directly related to the content of chlorides, especially those of sodium.

There is little information available as to the suitability of crude potash fertilizers for use in forest nurseries. However, on poorly buffered sandy soils crude potash fertilizers, when used in moderate amounts, may have some advantage over the purified materials because of their slower solubility.

E. Combined Fertilizers

This group of fertilizers includes largely synthetic products containing two or three essential nutrients. Combined fertilizers find their greatest use in forest nursery practice as liquid fertilizers. The most important fertilizers of this kind, which are suitable for nursery practice, are briefly discussed below.

1. Mono-Ammonium Phosphate, $NH_4H_2PO_4$, is made by treating pure phosphoric acid with ammonia and evaporating the solution. It contains about 11 per cent of nitrogen and 48 per cent of phosphoric acid. It is sold under the trade name "Ammo-Phos".

2. Di-Ammonium Phosphate, $(NH_4)_2HPO_4$, is essentially a mixture of mono-ammonium phosphate with ammonium sulfate in the proportion of about 800 pounds of crude ammonium phosphate with 1200 pounds of ammonium sulfate. The commercial product contains about 16 per cent of nitrogen and 20 per cent of phosphoric acid. It is called "Diammono-Phos".

3. Leunaphos is a concentrated fertilizer made in Germany from di-ammonium phosphate and ammonium sulfate. It contains about 20 per cent of nitrogen and 20 per cent of available phosphoric acid. About 90 per cent of the latter is water soluble. Except for the concentration of nutrients, this fertilizer is similar to Ammo-Phos.

4. Nitrophoska is a trade name for a group of highly concentrated synthetic fertilizers manufactured in Germany. These are made by bringing into contact, usually in solutions, diammonium phosphate, ammonium nitrate, and potash salts, and then precipitating the resulting salt out. The four grades of Nitrophoska, available on the American market, are as follows:

No. 1. N-15 per cent; P_2O_5- 30 per cent; K_2O- 15 per cent. Ten per cent of total nitrogen is in the form of nitrate, while 90 per cent is in the form of ammonia. Phosphoric acid is derived from di-ammonium phosphate. Potash is derived from muriate.

No. 2. N - 16.5 per cent; P_2O_5 - 16.5 per cent; K_2O - 21.5 per cent. Thirty per cent of the nitrogen is in the form of nitrate while 70 per cent is in the form of ammonia. Phosphoric acid is derived from di-ammonium phosphate and potash from the muriate.

No. 3. N - 15.5 per cent; P_2O_5 - 16.5 per cent; K_2O - 19 per cent. Twenty-nine per cent of the nitrogen is in the form of nitrate and 71 per cent is in the form of ammonia. The phosphoric acid is derived from di-ammonium phosphate and the potash from potassium sulfate.

No. 4. N - 15 per cent; P_2O_5 - 11 per cent; K_2O - 26.5 per cent. Thirty-five per cent of the nitrogen is in the form of nitrate while 65 per cent is in the form of ammonia. The phosphoric acid is derived from di-ammonium phosphate and potash from the muriate.

5. Potassium Nitrate, KNO_3, occurs in natural deposits and is manufactured from nitrate of soda and muriate of potash. It contains about 13 per cent of nitrogen and 45 per cent of potash. Although this salt is relatively little used in general fertilizer practice, it is well adapted for use in forest nurseries.

6. Potassium Ammonium-Nitrate is manufactured in Germany and is known also under the trade name "Kali-Ammon-Salpeter". It contains about 27 per cent of potash and 16 per cent of nitrogen, one-half of

properties of ammonium nitrate. It is well adapted for use in forest nurseries.

All of the combined fertilizers find their use in forest nursery practice primarily in a liquid form.

F. Lime

Lime, or different forms of calcium and magnesium oxide, encourage greatly the development of damping-off and other root rot diseases. For this reason the use of lime in forest nurseries is, as a general rule, avoided, especially when coniferous stock is grown. In some exceptional cases, however, an application of lime becomes imperative, either for the correction of acidity, for increasing the availability of phosphates, for counteracting the toxicity of accumulated aluminum, or for improvement of the physical condition of the soil. The use of lime is confined primarily to nurseries raising hardwood species. Even in these cases the application of lime should be very conservative. The deficiency of calcium and magnesium can be more safely corrected by the use of 20 per cent superphosphate (mono-calcium phosphate), magnesium sulfate, or leaf mold high in exchangeable bases.

The term "lime" is used in general to designate a number of compounds including the oxides, hydroxides, or carbonates of calcium and magnesium, viz.: burned lime or quick lime, air slaked lime, water slaked or hydrated lime, waste lime or by-product lime, marl, ground shell lime, and ground limestone. With few exceptions, forest nurseries use no other forms of lime except ground limestone. This is obtained by grinding calcitic or dolomitic rock. It is officially agreed that 75 per cent or more of the ground material should pass 100-mesh sieve, and should contain calcium and magnesium carbonates equivalent to not less than 45 per cent of calcium oxide, or mixed oxides of calcium and magnesium.

The rate of application of ground limestone on forest nursery soils may be as high as 5 tons per acre. Such a high application may be necessary on soils of rather heavy texture and having a reaction of about pH 4.0. On less acid and lighter soils the amount of lime is decreased proportionally. The general tendency in lime applic_ation on nursery soils should be to apply just enough lime to bring the soil reaction to a pH of 4.8 when growing conifers and up to a pH of 5.5 or 6.0 when growing hardwoods.

It is highly desirable that lime be applied as far ahead of seeding or transplanting as possible. When ground limestone is not available and burned or slaked lime must be used, the rate of application should be reduced to one-third. Transplanting or seeding immediately after an application of burned or slaked lime will result in chemical injury of the stock. The use of these latter forms of lime should be avoided as much as possible.

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CHAPTER XXIX

PREPARATION AND USE OF COMPOSTED FERTILIZERS

"Taking everything into consideration, Indore compost has about three times the value of ordinary manure."

A. Howard and Y. D. Wad, "The Waste Products of Agriculture".

General Characteristics of Compost

The term "compost" refers to a complete fertilizer made of peat, forest litter or duff, commercial mineral fertilizers, soil, and other available materials. All of these ingredients are mixed in a pile or special pit, and the organic matter is allowed to partly decompose and absorb the mineral salts during the storage period. By this procedure is obtained a safe and highly nutritive fertilizer which remains effective for a long period.

F. E. Weiss, University of Manchester, gives an interesting outline of the first experiments with compost. At some time early in the nineteenth century, an anonymous landed proprietor in Scotland found himself in difficulty when faced with the problem of disposal of peat moss obtained from the construction of a small artificial lake. Being of a shrewd and practical turn of mind, he tried a variety of experiments with a view of converting peat into manure. The experiments were undertaken in a truly scientific spirit, and in a period of six or seven years highly satisfactory results were achieved. "Peat", as the Scotchman tells us, "when taken out of a bog is certainly not manure. If dried, it becomes fuel, and so remains if kept dry. But if exposed to the vicissitudes of the atmosphere in our climate, it becomes in the course of years, a sort of vegetable mould, and, if mixed with the soil, raises good crops of potatoes and other vegetables."

In the first experiments the author tried the effect of mixing the peat with lime, but the mixture used as a top dressing did no good for several years. He next mixed the peat with various forms of decaying vegetable and animal matter, and found that the putrefaction of these substances was communicated to the peat, setting up fermentation activity indicated by the rise in temperature, and resulting in the production of a rich, very effective compost. Ten tons of the first successful compost he produced were made up from peat, shavings of timber, and the carcass of a horse.

In 1815 the experimenter has recommended, in a pamphlet to farmers, the stratification of peat with stable manure in alternate six-inch layers, using a proportion of seven cartloads of stable manure to twenty-one cartloads of peat. After the compost thus made up has undergone a period of putrefaction, the lumps of peat were found to be broken up, and when used weight for weight, compost proved to be quite as good as farmyard manure.

For a long time after the discovery of the composting process, the compost was looked upon only as a source of plant nutrients, and with the development of the fertilizer industry the importance of compost was temporarily decreased. Within the last two or three decades, however, studies of the biological and base exchange properties of soil have brought an entirely new light upon the importance of composted fertilizers. It is now realized that the chief benefit of compost does not lie in the content of nutrients released from peat, but in the inoculating and absorbing properties of the fermented organic matter. Both of these latter properties attain particular significance in the fertilization of forest nursery soils because the forest seedlings seldom feed on pure mineral salts in free solution, and because their sound development is intimately related to the useful soil organisms.

The main advantages of the composted fertilizers may be summarized as follows: (a) compost provides nutrients in the form of humates; they are readily available to the seedlings and do not cause chemical injury to the roots as do salts in free solution; (b) compost serves as an absorbent or a carrier of commercial fertilizers, and prevents their loss through leaching; (c) compost is the culture medium for numerous useful soil organisms which are introduced into the compost by the addition of duff or forest litter from productive forest stands; (d) compost provides all the essential plant nutrients, including rare elements, which may be of great importance in tree growth; (e) compost provides catalytic agents and, perhaps, some substances of unknown chemical and physical structure which are referred to as "auximones." These substances presumably perform the same functions in plant nutrition that the vitamins and hormones perform in animal nutrition; (f) compost facilitates a better distribution of fertilizer by disking or rototilling than can be achieved with mineral salts alone; (g) compost improves not only the chemical and biological properties of the soil but also its physical properties, such as water holding capacity, structure, and aeration.

. Compost Pits

Although compost may be stratified in a heap or in any natural depression, it has been found more economical to construct a special pit made of wood or concrete or a combination of these materials. The simplest form of pit is made by digging a rectangular hole in the ground and reinforcing the sides with planks and poles. More expensive types are constructed with the bottom and framework of concrete. The most permanent pits are built entirely of concrete, except for removable wooden gates.

A variety of structural designs are possible in the construction of permanent compost pits. In all of the concrete structures it is advisable to make the bottom of the pit somewhat channeled and inclined at about 5° gradient in order to allow for drainage of the percolating water. This water, saturated with fertilizers, is drained into a cistern or barrel by means of an iron pipe imbedded in concrete. The liquid thus collected is sprinkled again over the compost. At least one wall of the structure should be removable to facilitate the loading and unloading of compost. This wall is made of boards keyed into the concrete.

Sometimes the compost pit is provided with a roof to prevent excessive saturation, leaching of fertilizers, and summer dessication. A roof will not only protect the compost, but will provide an emergency storage space for fertilizers and other materials. If the construction of a roof is not financially possible, a one-foot surface layer of peat will furnish sufficient protection to the compost.

If possible, the pit should be cut into a slope of considerable gradient. If so located, gravity will assist in both loading and unloading the pit. When locating a compost pit it is necessary to have in mind the extra space which will be needed for the piling of peat and duff, and for the operation of the shredding machine.

The dimensions of a compost pit vary according to the number of acres to be fertilized annually and according to the rate of compost application per acre. At a fairly high rate of application, such as one cubic foot, or approximately one bushel, per 50 square feet, an area of one acre will require 870 cubic feet of compost. In case the area to be fertilized is five acres, the pit should have a volume of about 4500 cubic feet. Pits made to the dimensions of 100 x 15 x 3 feet, or 50 x 20 x 4½ feet, would satisfy this requirement.

Under ordinary conditions it is necessary to retain the compost in the pit for a period of two years so as to obtain a material of high quality. For this reason it is convenient to construct two pits, or one pit having two compartments, so that each year one can be emptied and refilled.

In some nurseries dealing with strongly acid and decay resistant peat it has been found desirable to keep compost for a three-year period, and, consequently, to construct pits having three compartments.

The following figure illustrates several types of pits used in forest nurseries.

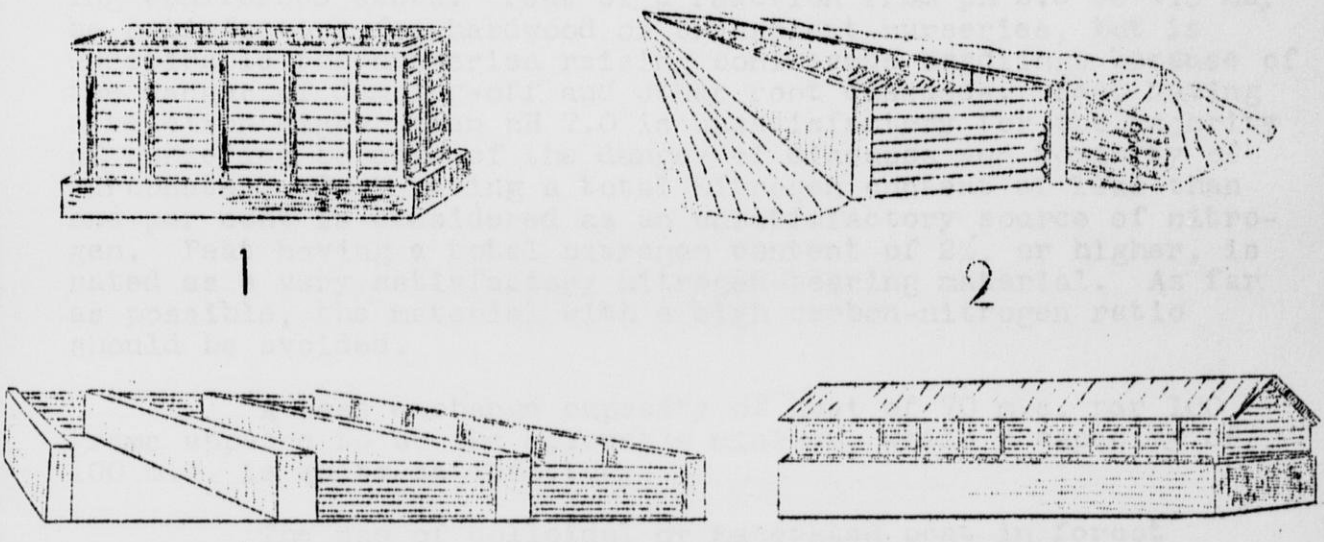

Figure 83

Types of Compost Pits. (1) Wooden pit with concrete floor, constructed above the ground. Wisconsin Central State Nursery. (2) Concrete pit with removable end wall, constructed on a side hill. U. S. Rhinelander Nursery. (3) Three compartment pit of concrete framework and removable wooden end walls. U. S. Manistique Nursery. (4) Two compartment concrete pit with a roof and removable wooden walls. Wisconsin Northern State nursery.

Obtaining and Preparing Organic Materials

The peat is dug either by hand or by means of a dragline or steam shovel. If wet, it is left to dry out at the place of excavation, so that a minimum amount of water is transported. The digging of peat, for that reason, should be done in the driest period of the year, if possible. The dry peat is transported to the nursery and shredded by means of a shredding machine run by a gasoline motor. The shredding machine is usually attached to the drive shaft or rear wheel of an old automobile. The machine best adapted for shredding peat is manufactured by Fred Franke & Co., Louisville, Kentucky, and is sold at a cost of about $150, F.O.B. In some cases the shredding of peat is accomplished by hand. This is a slow procedure and may be practiced only in small nurseries.

A thorough examination of the peat, to the depth of possible excavation, is necessary when considering peat for use in forest nurseries. Because morphological types of peat show a wide variation in chemical composition, the selection of satisfactory material may be made only with the aid of chemical analysis. Three chemical properties of peat, namely, reaction, total nitrogen content and base exchange capacity are of particular importance in the selection of peat.

Peat having a reaction of pH 5.5 or less was found to be most desirable for forest nurseries, particularly those raising coniferous stock. Peat of a reaction from pH 5.5 to 7.0 may be satisfactory for hardwood or transplant nurseries, but is undesirable for nurseries raising coniferous seedlings because of the danger of damping-off and other root diseases. Peat having a reaction higher than pH 7.0 is unsatisfactory for the majority of nurseries because of the danger of diseases and toxicity of carbonates. Peat having a total nitrogen content of less than one per cent is considered as an unsatisfactory source of nitrogen. Peat having a total nitrogen content of 2%, or higher, is rated as a very satisfactory nitrogen-bearing material. As far as possible, the material with a high carbon-nitrogen ratio should be avoided.

A base exchange capacity of peat of 70 m.e. per 100 grams appears to be the allowable minimum, while a capacity of 100 m.e. is quite satisfactory.

The use of colloidal or macerated peat in forest nurseries is not advisable since such materials tend to cement the soil particles.

The duff used for inoculation of compost is raked from the forest floor and packed into burlap sacks. It is transported either in these sacks or piled loosely in a truck, which is provided with canvas sidewalls. Since the removal of duff is rather detrimental to the productivity of the stand, it is not advisable to collect this material from large continuous areas. If possible, the collecting of duff should be confined to ditches, pits, roadside depressions, and to other localities where organic remains are accumulated in considerable quantities. The intention in collecting duff should be to take as little mineral soil as possible, since it has a lower value than pure organic matter. Well-rotted logs and slash debris may also be included as a portion of the duff material.

In the majority of cases it will be found desirable to examine forest debris by laboratory methods, or at least to secure the advice of a person familiar with soil conditions. If this is not possible, a few simple rules will assist in the selection of reliable material. (1) the duff should be secured from a productive upland forest stand, if possible, of tolerant species; (2) organic remains developed on soils of calcareous or siliceous origin should be avoided; (3) the duff should be of suitable reaction, which may be easily determined by a rapid field test; (4) the duff should have a thickness of at least 1½ inches. The duffs which throughout the area maintain a thickness greater than 3 inches should be investigated as to their inoculating value and content of nutrients; (5) the duffs from mixed stands, particularly from hardwood-coniferous stands, are usually superior to the duffs from pure stands.

The higher the proportion of duff or humus, the better compost is likely to be obtained. However, the nature of inoculating debris must be closely correlated with the reaction and other properties of composted organic remains. The use of true mull types may be satisfactory for the inoculation of slightly acid peats with a low carbon-nitrogen ratio, but not for inoculation of raw strongly acid peats in which the exacting mull population of bacteria, earthworms and insects rapidly degenerates. On the other hand, resistant to acidity fungi of raw humus forms may not find suitable conditions in peat of nearly neutral reaction. On the whole, the intermediate humus forms between the true mull and raw humus are the most desirable for inoculation purposes as they carry an abundance of active organisms having a high "acclimatization capacity" or ability to survive under a wide range of conditions.

In some instances, the inoculating humus or duff is partly or entirely replaced by manure. Such substitution is not very desirable because manure may encourage the development of parasitic organisms and may infest nursery soil with obnoxious weeds. The detrimental effects of manure may to some extent be reduced by prolonged composting.

Stratification of the Compost

A 1-inch layer of shredded peat is placed on the bottom of the compost pit. On top of this layer is broadcast a mixture of commercial fertilizers. The fertilizers are covered with a 1/8 to 1/4 inch layer of inoculating duff, which is followed by a layer of soil, if this is used. The materials are sprinkled with water to make them thoroughly moist. On top of the duff or clay is piled another 1-inch layer of peat, followed by the fertilizers and duff, as previously described. This is repeated until the pit is filled.

The amount of fertilizers to be applied to separate layers of the compost is calculated from the total amount of fertilizers used per acre, and from the amount of compost applied per 100 square feet of seed bed. Suppose that a soil needs 250 pounds of ammonium sulfate, 400 pounds of superphosphate, and 150 pounds of muriate of potash per acre, and that the intention is to apply one cubic foot of compost per 100 square feet of seed bed. Since one acre is about 40,000 square feet, the total amount of compost needed per acre is 400 cubic feet. Consequently, the entire amount of commercial fertilizer needed per acre should be distributed in 400 cubic feet of compost materials. If the compost pit is 48 feet long and 20 feet wide, a one-inch layer will hold 80 cubic feet of compost (48 x 20 x 1/12). Thus, a five-inch layer of material will be sufficient to fertilize one acre of seed beds. This means that one-fifth of the total acre application of fertilizer must be broadcast over a one-inch layer of organic matter. This application, then, would be 50 pounds of ammonium sulfate, 80 pounds of superphosphate, and 30 pounds of muriate of potash.

For a more exact calculation of the amount of each fertilizer (f) to be broadcast over a one-inch layer of organic material, the following formula may be applied:

$$f = \frac{F \times L \times W}{12 \times 435 \times C}$$

Where F is the amount of any one fertilizer to be applied per acre; L is the length of the pit; W is the width of the pit; C is the amount of compost in cubic feet to be applied per 100 square feet of seed bed.

According to this the amount of ammonium sulfate to be applied in the above case would be:

$$F = \frac{250 \times 48 \times 20}{12 \times 435 \times 1} = 46 \text{ pounds}$$

In place of stratification some nursery men feed the shredding machine by means of a conveyor, supplying peat, duff, mineral fertilizers, and clay in desirable proportions. The proper amounts of peat, duff, and commercial fertilizers are applied to the conveyor by means of shovels and scoop cups of known volume. It appears that the materials are mixed in this way just as effectively, or perhaps even better, than in stratification.

For maximum efficiency the shredding machine should be placed on the very edge or rim of the pit, so that the shredded material is discharged directly into the cavity.

The compost should be kept moist and reworked at least once, but better several times, during the year. Insufficient moisture inhibits the action of organisms and slows down the process of composting. On the other hand, excessive saturation with water produces anaerobic conditions which retard the biological processes and cause unfavorable changes in the chemical composition of the compost. Therefore, the maintenance of a proper water content and aeration in the compost is of primary importance. The compost attains its best quality when it becomes a uniform mass, so that the separate constituents can no longer be recognized.

Concentration of Fertilizers in Compost

In small nurseries as well as in nurseries with fertile soils an application of compost may correct both the deficiency of mineral nutrients and of organic matter. In large nurseries with soils low in organic matter, it is more economical to correct the deficiency of organic matter by direct application of peat. This makes it possible to reduce the quantity of peat used in composting to the very minimum amount necessary as a carrier of fertilizers and inoculating medium. Such practice leads to the use of highly concentrated composted fertilizers carrying as much as 50 pounds of mineral salts per cubic yards or less of organic matter. A concentration higher than 30 pounds of salts per cubic yard, however, is likely to be toxic to microorganisms.

Although concentrated compost offers a financial saving, it may cause chemical injury to the roots of the seedling. For this reason, utmost care should be taken in distributing the concentrated compost fertilizer to a minimum depth of seven inches.

Before application, concentrated compost may be mixed with raw peat in proportions such as 1:1, 1:2, or 1:3, depending upon the deficiency of soil organic matter. This mixing or "diluting", or compost with peat is usually done by forcing both materials through the shredding machine in the desirable proportion.

Rate of Application of Compost

The minimum convenient application of composted fertilizer is about one bushel per 100 square feet. Under exceptional conditions, however, as little as one-half bushel may be applied per 100 square feet, assuming that the compost is thoroughly mixed with raw organic matter.

Since different seedling species require different amounts of fertilizers, it is necessary to make applications of varying amounts of compost. The standard rate of application is established for the predominating conditions of the nursery soil and for species of average requirements. For instance, in a nursery raising jack pine, Norway pine, and Norway spruce, the average rate of application may be one bushel per 100 square feet. For jack pine it may be necessary to apply only one-half bushel of compost, while on Norway spruce it may be necessary to apply two bushels. The soil conditions may also essentially modify the standard rate of application, and, on poorer blocks of the nursery, even jack pine may require an application of one bushel, or even more, per 100 square feet.

The compost contains nutrients in a fixed ratio which is established to meet the predominant requirements of soil. This ratio, however, may not be entirely satisfactory for the sections of nursery which have an unbalanced ratio of nutrients. Under such conditions it is necessary to approach the desirable ratio by application of compost, and to correct the remaining nutrient deficiencies by the later application of liquid fertilizers. The requirements of different species may also call for additional corrections in the ratio of nutrients provided by compost. In the majority of cases available nitrogen is the factor which needs additional correction.

Distribution of Compost in the Soil

Poor distribution of composted fertilizer in soil may lead, in places, to chemical injury of the roots. A shallow application of compost, aside from the danger of chemical injury, leads to a production of seedlings with superficial root systems. This materially decreases the resistance of stock to drought. Adequate development of root systems is achieved by the distribution of compost to a depth of about 8 inches.

Unfortunately, harrowing, disking, and spading seldom distribute compost in the soil to a depth greater than four inches. For this reason, in many instances the satisfactory solution of this problem may be met either by alternate disking and plowing or by the use of recently devised machines of Rototiller type. Both of these methods are briefly outlined below.

The fallowed land or land supporting green manure crops is plowed to an eight-inch depth. This exposes comparatively sterile subsoil. About three-fifths of the total application of compost is broadcast over the area and worked into the soil by a thorough disking to a depth of about four inches. This fertilized layer is turned under by a second plowing to a depth of about eight inches. The remaining two-fifths of compost is broadcast, disked and harrowed. In case the green manure has been plowed previously, the first plowing should be omitted.

Rototiller is only recently finding its first use in forest nursery practice, but promises to replace in time the plow, disk, and harrow. In rototilling, the sharp-pointed tines are revolved like picks through the soil by a small motor. Each sharp point breaks its way through a small amount of soil instead of shearing out large chunks as do the shovel, plow, and disk. This revolving action helps to propel the machine and allows thorough mixing of compost fertilizer to a depth of eight, or even more, inches.

.. Compost Facilitates the Maintenance of Permanent Labor in Forest Nurseries

The success of a large forest nursery depends greatly upon the number of men permanently employed. Only such men have the necessary experience to perform the more responsible operations and occasionally help in supervision. The main objection to the maintenance of permanent men is the seasonal character of nursery work. Yet, experience in some nurseries shows that the permanent workers may be occupied during the winter months with carpentry work, repairing tools, fences, seed bed frames, etc. The hauling of natural fertilizing materials and the preparation of compost provide another important outlet for such emergency labor. The cash savings on commercial fertilizers and the greater income from the stock will repay, with interest, the money invested in the preparation of compost.

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CHAPTER XXX

THE USE OF LIQUID FERTILIZERS

The Place of Liquid Fertilizers in Nursery Practice

Ordinarily fertilizers are applied broadcast prior to seeding or transplanting. These fertilizers should provide enough nutrients for the entire two or three year period of seedling growth. If, for some reason, this has not been done, the treatment of nursery stock with fertilizers in liquid form is likely to become urgent. In some cases, even the fertilized soils may develop unexpected deficiencies and require an application of fertilizers in solution during the first or second year following seeding or transplanting. These deficiencies may result from a number of conditions, such as heavy rains, unexpectedly high germination of seed, and losses of nutrients through biologic or chemical fixation.

Choice of Fertilizers for Liquid Treatments

Because of high toxicity of salts in solution, particular care should be exercised in the selection of fertilizers for use in liquid treatments.

Available nitrogen compounds are readily soluble and are often lost from the soil through leaching. For this reason, only a few very fertile nursery soils can produce stock without the periodic addition of nitrogen in liquid form. The need for liquid nitrogen treatments may become especially urgent when the stock is grown under crowded conditions. Also, after the application of large amounts of raw organic matter, the consumption of the available nitrogen by microorganisms may cause nitrogen starvation of the seedlings.

A deficiency of nitrogen may be corrected by the application of 16% nitrate of soda, 20% ammonium sulfate, 35% ammonium nitrate (7% NH_3; 28% NO_3), 26% double ammonium sulfate-nitrate, or combined nitrogen-phosphate and nitrogen-potash fertilizers. The choice of either ammonium or nitrate fertilizer depends upon the reaction and biological activity of the soil, as well as upon the species grown. Under average conditions, it is advisable to supply about one-third of the available nitrogen in the form of nitrates, and two-thirds in the form of ammonia. In many cases, however, a high pH of the soil requires an application of acid-forming ammonium sulfate alone. On the other hand, strongly acid or disinfected soils deficient in nitrifying microorganisms may require an application of nitrate fertilizer. As a rule, the conifers readily utilize ammonia nitrogen, whereas hardwoods show a somewhat better response to nitrates.

A single application of nitrate of soda and ammonium sulfate usually varies from 100 to 300 pounds of salt per acre. Ammonium nitrate is used at the rate of 50 to 200 pounds per acre.

A need for the application of large amounts of phosphate fertilizers in liquid form may occur on soils having a high phosphate fixation capacity, i.e. a tendency to form insoluble iron, aluminum, or calcium phosphates. On soils treated with aluminum sulfate, heavy applications of phosphates may be needed to counteract the toxicity of accumulated active aluminum.

Most of the phosphate fertilizers are not readily soluble in water and require prolonged stirring to bring them into solution. However, nursery soils are seldom deficient in phosphorus without being deficient in the other two essential nutrients. For this reason, the deficiency of phosphorus is usually corrected by readily soluble combined fertilizers, such as Ammo-phos (11-48-0), Leuna-phos (20-20-0) or Nitrophoska (15-15-19 or 15-11-26).

The application of combined phosphate fertilizers varies greatly, depending upon the concentration of the ingredients, but seldom exceed 400 pounds of salt per acre.

The potash fertilizer in liquid form is applied chiefly on sandy soils poor in clay and organic matter. Even fertilized soils of this nature may become deficient in potash after a period of one year because of the high solubility and rapid leaching of potash in the absence of base exchange material. Since potash salts promote the hardening of seedlings or their resistance to frost, the timely application of this fertilizer may be of especial value in dealing with highly succulent stock grown on soils rich in nitrogen.

Potash in liquid form may be supplied either as 50% potassium sulfate or 50% potassium chloride. The former is preferable because of the lesser toxicity of the sulfate ion as compared to the chloride ion. Potassium nitrate or "Potnit" (13-0-44) and potassium-ammonium nitrate (16-0-27) are more expensive but valuable sources of potash on soils deficient in available nitrogen. Muriate or sulfate of potash may be applied at the rate of 100 to 300 pounds per acre at a time. A single application of potassium nitrate, may be as high as 400 pounds per acre.

In the majority of cases, the fertilizer for liquid treatments is prepared by mixing the individual salts in a proportion to satisfy the requirements of the seedlings on a given soil. The combination of ammonium phosphate, potassium nitrate, and ammonium sulfate gives about the most desirable fertilizer for the average nursery soils. The main advantages of this combination are: a slight acidification of soil, high solubility of all ingredients, and an absence of undesirable residues.

<u>Concentration of Fertilizer Solution and Rate of Application</u>

The amount of total fertilizer salts applied at one time in the form of solution should not exceed 600 pounds per acre, whereas the concentration of applied solution should not exceed 20,000 parts per million. The application of 600 pounds per acre of highly concentrated fertilizer under adverse climatic conditions may produce a marked depressing effect upon the seedlings (Fig. 84).

A suitable solution is made by dissolving one pound of the salt, or a mixture of salts, in 8 gallons of water; 8, 12, and 16 quarts of this solution applied per 12 by 4 foot seedbed or per 50 square feet correspond to 200, 300 and 400 pounds of fertilizer per acre, respectively.

The toxicity of a fertilizer solution depends upon both concentration of solution and relative degree of ionization of the salts. When the fertilizer mixture contains largely phosphate and small amounts of chlorides and nitrates, a greater concentration of solution can be used, such as one pound of salt to 6 gallons of water. On the other hand, when the mixture contains chiefly chlorides and nitrates, the degree of dilution should be increased and a desirable concentration of solution may be as low as one pound in 12 gallons of water or approximately 10,000 p.p.m. Sulfates occupy an intermedia te position, being somewhat less toxic than chlorides and nitrates.

The following example illustrates the method of mixing the fertilizers in proper amounts.

Suppose the analysis of a strongly acid soil growing coniferous seedlings showed a need for about 40 pounds of available nitrogen, to be provided partly as ammonia and partly as nitrates, 50 pounds of phosphoric acid, and 100 pounds of potash per acre. These amounts of nutrients may be had by using 100 pounds of ammonium phosphate (11-48-0) and 200 pounds of potassium nitrate (13-0-44), which combination will give 37 pounds of nitrogen, 48 pounds of phosphoric acid, and 88 pounds of potash per acre, or roughly per 40,000 square feet. If fertilizers are dissolved in 48 gallons of water and the rate of application is 6 gallons per 100 square feet, the following amounts of each salt should be used in the preparation of solution:

Ammonium phosphate: $\frac{100\times100\times48}{40,000\times6}$ or 2 pounds

Potassium nitrate: $\frac{200\times100\times48}{40,000\times6}$ or 4 pounds

As a general rule, the application of a balanced liquid fertilizer, including all three essential nutrients, gives much better results than the application of single ingredients. Especially, in the correction of nitrogen deficiency it is advisable to supplement nitrate or ammonia with some amounts of both phosphate and potash even on soils having a fairly high content of these two nutrients. The balanced solutions prevent possible discrepancies in nutrition which may result due to the higher availability of dissolved salts as compared with nutrients present in soil in the form of minerals or replaceable ions.

Distribution of Fertilizer Solution

In the treatments of smaller areas 50 gallon barrels are conveniently used for dissolving the salts and the liquid is

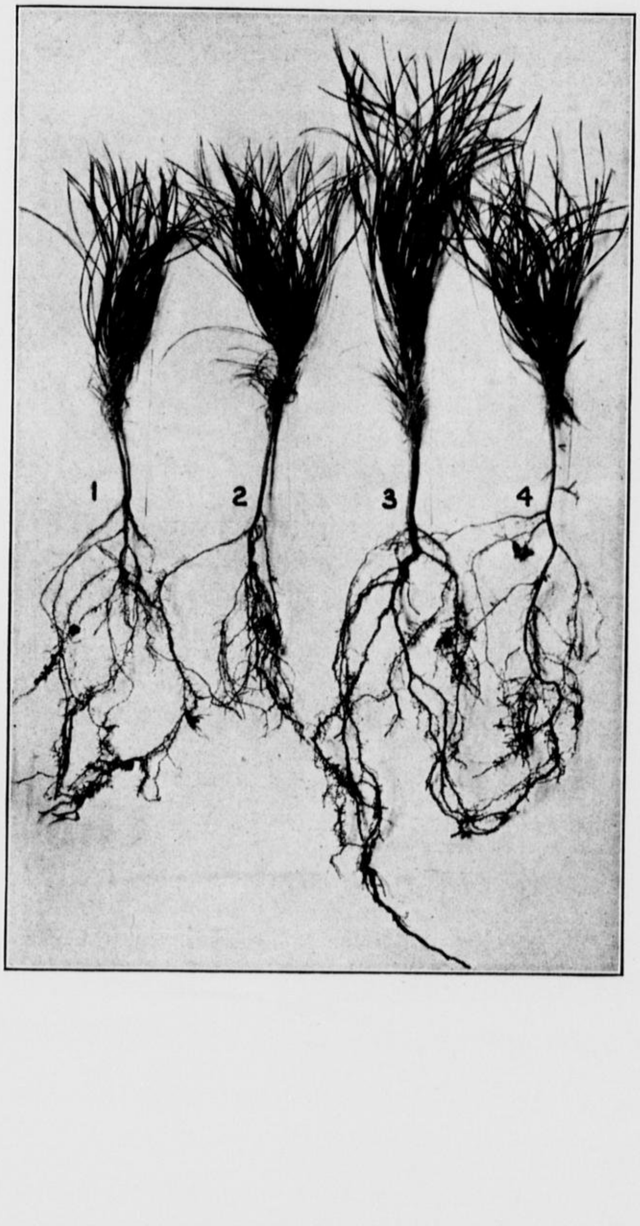

Figure 84. Effects of various rates of application of 20% ammonium sulfate (1 part), 11-48 ammonium phosphate (2 parts) and 50% potassium chloride (1 part) in solution on 2-year old red pine seedlings: (1) Check; (2) 200 pounds per acre; (3) 400 pounds per acre; (4) 600 pounds per acre. The depressing effect of the heavy treatment was in part due to unusually high temperatures during the period following application of the fertilizer.

distributed with 12 quart cans, one can per 4 by 12 foot bed. The amount of liquid in a 50 gallon barrel will thus suffice for a treatment of 800 square feet. The salts are added to the barrel by using measuring scoops cut from tin cans to the proper size, corresponding to the weights of individual fertilizers used.

Because the application by hand is slow and costly, small tanks or barrels mounted on wheels were used in some nurseries. However, this type of equipment fails to maintain a constant concentration of applied solution and does not supply the liquid at a sufficiently uniform rate.

In nurseries of a considerable size, the problem is satisfactorily solved by the use of a special sprayer or tank of 200 to 300 gallon capacity, mounted on one-and-half ton truck and provided with a pressure pump and a rotating agitator (Brener). The agitator facilitates the dissolving of chemicals, and prevents the formation of precipitate, while the pressure pump assures a uniform discharge of the liquid. The liquid is distributed through two horizontal spraying pipes with 1/16 inch nozzles. One of these pipes is mounted in a permanent position and the other on a long swinging rod to make possible the treatment of beds adjacent to an overhead system line (Fig. 85).

The sprayer is run in low gear following the paths between seed beds, with pressure pump working, and the liquid is sprayed over two rows of seed bed. The nozzles are arranged in such a position that the spray is delivered chiefly in between the rows of seedlings, thus minimizing the danger of "burning" the stock by chemicals and decreasing the amount of subsequent watering necessary for washing the chemicals off the leaves. The proper distribution of liquid is achieved by regulation of pressure, speed of the truck and, if necessary, size of nozzles. Ordinary rate of application is fixed to deliver 1 gallon per every 100 square feet traversed. At this rate it is necessary to make 4 trips to apply the required 2 gallons of solution for a 4 by 12 standard seed bed. Therefore, the capacity of the tank suffices to treat one hundred standard seed beds or about 5,000 square feet. The relatively slow discharge of the liquid with 1/16 inch nozzles is believed to be desirable as the repeated spraying covers the area more completely.

According to experience in the Wisconsin State Central forest nursery, the efficiency of such a sprayer, considering refilling of the tank, is 400 standard seed beds per hour or about 4 acres per day.

In some instances the solution of fertilizers is forced through the Skinner overhead system. In this method a stock solution is prepared in a large contained by dissolving the amount of salts needed for the area tc be irrigated. The stock solution is then fed gradually into the system at a sufficiently slow rate to prevent the undesirably high concentration of the applied solution. The chief objection to this method is the difficulty in obtaining a uniform distribution of liquid over the seed beds. Another disadvantage of this method is that the use of salts may plug or corrode the pipes of the watering system.

Time of Application

In the spring the fertilizers are most efficient, and should be applied as soon as the danger of the last killing frost is over. If necessary, the application of liquid fertilizers may be made in two or even three portions applied at two or three week intervals. The last application should be made at least six or seven weeks before the first killing frost, so as to give seedlings a chance to harden.

The application of liquid fertilizer should be made in the early morning, evening, or on a cloudy day. The treated beds should be washed thoroughly with water immediately after treatment.

In the majority of cases, liquid fertilizers are applied to 2-year old stock. Nutrient deficiencies in 1-year beds are often difficult to detect from appearance of the seedlings and fertilizer application to tender young stock requires a great deal of caution. Nevertheless, in many instances a light application of liquid fertilizers on 1-0 stock may be more beneficial than heavy applications on 2-0 stock. The seedlings treated during their first year of growth may be allowed considerable time for hardening, whereas the seedlings unreasonably forced during the second year, to meet planting specifications, are likely to be succulent and not adapted to adverse field conditions. If under-nourished 2-0 stock is far behind in its development, it is advisable to extend its recovery throughout another growing season, i.e. until the seedlings are 3 years old. An application of liquid fertilizers on transplants is confined to rare instances. The timely and appropriate applications of liquid fertilizers must be assured through periodic analyses of soil and careful observations of nursery stock. Frequent ana lyses are especially urgent in nurseries with poorly buffered sandy soils which are subject to great fluctuations in the level of their fertility.

Liquid Humate Fertilizers

"Liquid humate" is a term coined recently by nurserymen for a suspension of humus obtained by treating forest litter or duff with a fertilizer solution. Although this term is not strictly scientific, it is expressive and sufficiently accurate to serve the needs of practice.

Liquid humate includes essential nutrients, accessory foods and useful microorganisms. When prepared from suitable types of duff it has a remarkable beneficial effect upon the growth of forest seedlings. Humate suspension not only increases the rate of seedling growth but also the resistance of the stock to unfavorable environmental influences. Of special practical significance is a unique reviving effect of liquid humates upon stunted, weakened, chemically burned, and even mechanically injured seedlings. This effect to a great extent is due to the presence in humates of vitamin and hormone substances.

In preparation of humate for nursery use, enough duff or leaf mold is placed in a barrel or a tank to occupy one-half volume of the container. The required amount of mineral fertilizers is added, and the barrel is filled with water from a hose attached to the water system. While the water is being added, the mixture is stirred constantly and vigorously. After standing for several hours, the mixture is stirred again to bring fine humus particles into suspension. Then the suspension is siphoned into watering cans and applied to the seed beds in the manner usually followed in applying liquid fertilizers. After application, the soil is thoroughly soaked with water, using the hose or the overhead system. When fertilizer is applied on a large area, a battery of 12 or more barrels is employed to speed up the treatment. In order to shorten the carrying distance, the barrels are moved, as necessary, from one block of the nursery to another.

Fresh duff should be used, if possible, every time the barrel is emptied. The organic residue absorbs a considerable amount of fertilizers, and should be stored in a pit or other convenient place where the salts will not be lost through leaching. Such residues are utilized as an ingredient of compost or for the direct fertilization of seed beds. In the latter case the saturated duff should be thoroughly worked into the soil, since a local accumulation of concentrated material may be detrimental to seedlings.

Preparation of liquid humates requires readily soluble, high grade synthetic fertilizers, such as ammonium sulphate, ammonium nitrate, potassium nitrate, ammonium phosphate, potassium sulphate, and 15.5-16.5-19.0 nitrophoska. The concentration of salts should not exceed 20,000 parts per million, which is about 10 pounds of total salts per 50 gallons of water. The amount of each fertilizer to use in the preparation of liquid humate, as well as the rate of application of the suspension depend upon the content of nutrients present in the soil and nature of nursery stock.

A formula suitable to an average sandy soil raising pine species, may be given as an example: $1\frac{1}{2}$ pounds of 11-48-0 ammonium phosphate, 3 pounds of 13-0-44 potassium nitrate, and 2 pounds of 20 per cent ammonium sulfate added to 50 gallons of suspension and applied at a rate of 6 gallons per 100 square feet.

Because of the buffering action of humus, the danger of chemical injury of seedlings in application of liquid humates is greatly reduced. Yet, if circumstances permit, it is advisable to make repeated applications of fertilizer, thus avoiding the strongly concentrated suspensions.

The following materials should be avoided in preparation of liquid humates: alkaline or nearly alkaline duffs, because of the excess of calcium and the danger of encouraging root-rot diseases; duffs and litter of pioneer species, such as jack pine, pitch pine, and scrub oaks, because of a low exchange capacity and a low content of nutrients; peat, muck, and perhaps some types of raw humus, because of their lack of useful organisms, low content of nutrients, and a too high exchange capacity. The most suitable sources of humus are acid duffs derived from productive mixed hardwood-coniferous stands of tolerant species.

Some nursery men have used the same organic residues for three or more extractions with fairly satisfactory results. If such repeated treatments are practiced, it must be realized that after the first extraction the organic matter will be nearly saturated with bases and ammonia, and, therefore, a much higher proportion of the fertilizers will come through in the solution. Consequently, in preparation of suspension the content of salts must be proportionally decreased.

The application of liquid humates is a very expensive treatment and should be limited primarily to the stock seriously upset by malnutrition or injured by chemical, climatic, or biotic agents. On the other hand, liquid humate treatment is the most efficient means of stock recovery available at present to the nursery manager.

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CHAPTER XXXI

GREEN MANURES

Selection of Crops Suitable for Nursery Purposes

The practice of raising transitional crops of rapidly-growing species is used in forest nurseries for a triple purpose: to enrich soil in organic matter and nutrients by plowing under the succulent tissue of green-manure crops; to prevent the loss of soluble salts by leaching by incorporating them into the tissue

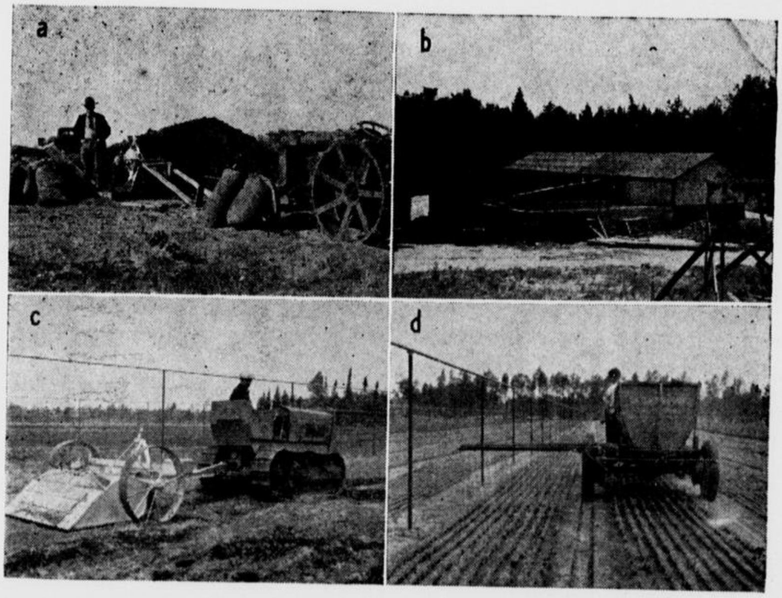

Figure 85. Preparation and application of fertilizers in forest nurseries: (a) Shredding of peat and duff for compost; (b) Concrete pit provided with conveyor to facilitate the stratification of compost; (c) Distribution of fertilizer by rototiller; (d) Application of liquid fertilizer by means of the Wisconsin multiple-use sprayer.

of catch crops; to protect exposed soil from erosion and weeds by cover crops. Both cover and catch crop are usually used as green-manure.

Whenever the conditions permit, green-manuring is accomplished with leguminous plants which enrich soil in nitrogen. Various species of lupine, soybeans, and cowpeas are commonly used. Satisfactory results have also been reported with a number of other leguminous crops, particularly vetch, beans, clover, serradella, Lathyrus clymenum, and Medicago lupulina. If high cost of seed or soil acidity do not favor raising legume crops, they may be replaced by less exacting non-legumes. The choice of these latter crops is largely limited to rye, oats, and buckwheat.

The selection of suitable green-manure crops is usually dictated by local conditions, but in general preference is given to rapidly-growing species having abundant and succulent tops. In most nursery soils the pH value confines the selection of crops to soybeans, yellow lupine, and non-legumes.

Advantages and Short-Comings of Green-Manuring

The use of green-manures has a strong appeal to a nurseryman. This method of soil fertility maintenance does not involve particular difficulties or danger of burning the stock. However, among many beneficial effects that have been attributed to green-manuring only few are undisputable under conditions of nursery soils.

Green-manuring improves physical properties of the soil, especially its structure and water-holding capacity. It exerts a conserving influence on the soil nutrients, and, in case of legume crops, augments the supply of nitrogen. The liberation of carbon dioxide and organic acids by decomposing tissues are said to increase the availability of nutrients, such as phosphorus, potassium and calcium.

On the other hand, the gains in organic matter and base exchange capacity due to green-manuring are too small to satisfy requirements of most nursery soils. At best, on sandy soils with artificial irrigation green-manure crops may help to maintain the level of these basic fertility factors. Consequently, the practice of periodic rotations of nursery blocks with green-manure as a transitional crop is seldom justified.

The toxicity of green-manure crops to the seedlings, danger of white grub infestation, and encouragement of damping-off disease appear to be greatly exaggerated. In most instances these ill effects are brought about by untimely seeding or plowing under of soiling crops, or seeding of nursery stock. The high carbon-nitrogen ratio of non-legume crops is likely to be the condition responsible for inhibited growth of seedlings under unskilled management.

Catch Crops

As recent studies have indicated, green-manures attain their greatest importance in forest nursery practice serving as "catch crops" for commercial fertilizers (Cady; Brener and Wilde).

A comparison of available nutrients determined by analysis with growth data and the results of plant tissue analyses has shown that a considerable fraction of applied commercial fertilizers is temporarily fixed by green-manure crops as difficultly soluble organic compounds. These compounds, however, become gradually available in the course of plant tissue decomposition and benefit the growth of forest seedlings or transplants. From the standpoint of nursery stock production, this conversion of mineral fertilizers into slowly acting and less dangerous organic compounds is just as important as the reduction of fertilizer losses through leaching.

In localities where peat is not available, a catch crop is about the safest and most suitable method of fertilization. Under average conditions, 200 to 300 pounds of 20 per cent superphosphate and 100 to 200 pounds of 50 per cent muriate of potash per acre may be suggested as suitable applications ahead of seeding legume crops. In raising non-legumes, these fertilizers should be supplemented with 100 to 200 pounds per acre of ammonium sulfate. The state of available nutrients in soil, however, may considerably modify the amount of fertilizers required.

Tables 37 and 38 illustrate the effect of non-legume green-manure upon the state of fertility of a sandy nursery soil and the development of white ash seedlings. Table 39 presents data on the development of red pine in sand cultures with and without green manure.

The most serious objection to the use of catch crops is the loss of one growing season.

Table 37. Effect of Buckwheat Green-Manure upon the Fertility of a Sandy Nursery Soil as Determined by Chemical Analysis. Fertilized Plats Receive 2,000 Pounds of a 4-4-10 Mixture per Acre. Fertility of Soil One Year after Application of Fertilizer and Green Manuring. (Central State Forest Nursery at Wisconsin Rapids, Wisconsin)

Treatments	Reaction pH	Base exchange capacity m.e./100 g	Organic matter per cent	Total N per cent	Available P_2O_5 lbs./acre	Available K_2O lbs./acre	Replaceable Ca m.e./100 g.
Untreated soil	5.46	4.73	3.28	.063	43.5	112.4	2.08
Fertilizer alone	5.32	4.67	3.21	.060	60.7	139.0	2.45
Green manure alone	5.24	5.27	3.47	.067	52.0	110.4	1.87
Fertilizer and green manure combined	5.17	5.39	3.59	.070	77.5	154.6	2.15

Table 38. Effect of Buckwheat Green Manure "Catch Crop" upon the Content of Nutrients in the Tissue of One-Year Old White Ash Seedlings

Treatments	Weight of an average seedling gms.	N	P_2O_5	K_2O	CaO
		per cent			
Check	0.94	1.72	0.40	0.69	0.94
Fertilizer alone	1.43	1.77	0.41	0.92	0.98
Green manure alone	1.17	1.72	0.40	0.66	0.89
Fertilizer and green manure combined	2.02	1.84	0.43	1.22	0.98

Table 39. Effect of Non-legume Green-Manure upon the Development and Chemical Composition of Red Pine Transplants Grown for Five Months in Quartz Sand Cultures

Treatment	Average weight of transplants grams	Root-top ratio	Ave. stem dia. mm.	Average size of buds mm.	Analysis of tissue per cent N	P_2O_5	K_2O
Sand treated with 1,000 lbs. of 4-6-10 fertiliz er per acre	1.37	0.69	2.1	5.8	0.80	0.39	0.45
Sand treated with 1,000 lbs. 4-6-10 fertilizer per acre and green-manure	2.43	0.77	2.9	9.0	1.28	0.67	0.69

Cover Crops

When conditions require a temporary decrease in the production of nursery stock, the fallowed area should be kept under a cover crop or be used as farming land for raising corn, potatoes, or other agricultural products. Such practice helps to protect the soil from water and especially wind erosion, excessive oxidation, leaching, and infestation with obnoxious weeds. The beneficial effect of cover crops is unquestionable.

Seeding and Turning Under Soiling Crops

As a general rule, green-manure crops are seeded in the spring shortly after the nursery stock is lifted. In the years when a large flight of June beetles is expected, seeding must be delayed until the egg-laying period is nearly over.

The success of green-manuring with legumes depends greatly upon careful inoculation of seed with the proper culture of nodule bacteria. Some nursery soils have been inoculated by broadcasting surface soil from a field which previously supported a productive stand of legumes. One hundred pounds of soil is sufficient to inoculate one acre of nursery according to Tillotson. This method, however, is not as reliable as seed inoculation.

The plowing under is done before the crop matures or the tops lose their succulent character. Allowing green-manure to mature may infest nursery beds with an undesirable volunteer crop; this is especially true in raising buckwheat. The decomposition of the hardened tissues with their high carbon-nitrogen ratio may bring about a shortage of available nitrogen.

In plowing under green-manures, the furrow slice should not be thrown entirely over, but rather against and on the adjacent furrow-slice. In this way of plowing the green manure is distributed evenly throughout the whole layer of surface soil. Deep plowing, however, is recommended in nurseries which do not use artificial methods of damping-off control.

The turned under green-manure is left to decompose until the plant remains do not interfere with the preparation of seed beds. Forest seed is planted in fall of the same year or in the following spring. In some instances two crops of green-manure are raised during the same growing season, or green-manure crop is followed by a catch crop of non-legumes, usually rye. The second crop is plowed under two or three weeks before the preparation of seed beds. If cover crop is left over winter, at least two weeks should elapse in the spring between plowing under green-manure and planting of forest seeds or seedlings; otherwise germinating seeds and young plants may be injured by toxid by-products of plant tissue decomposition.

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CHAPTER XXXII

ADJUSTMENT OF NURSERY SOIL FERTILITY

The Problem of Fertility Maintenance in Nursery Soils

Although the relation of the chemical composition of soil to tree growth was a subject of many investigations in the course of the past hundred years, little reliable information has been obtained (zu-Leiningen). In most of the earlier experiments a number of important conditions were overlooked or misinterpreted. The chemical analysis of soils was performed by the use of strong solutions which extracted not only easily soluble or available nutrients, but also difficultly soluble compounds unavailable to plants. No regard was paid to the distribution of nutrients in different soil horizons. The reactions between the nutrient salts, colloids, and other soil constituents were not considered. The studies dealt largely with specific constituents and disregarded the influence of numerous other chemical and biological factors. The production of dry matter alone was studied in fertilizer trials, but the anatomical and physiological development of the seedlings was ignored. Particular attention was given to the encouragement of luxuriant vegetative growth, but not to the development of vigorous seedlings resistant to diseases and unfavorable conditions of environment. In many instances, one-sided fertilization and disruption of nutrient balance led to the deterioration of nursery stock or to the eventual failure of plantations.

As a result of this, until recently there has been no agreement among the leaders in silviculture on the problems of nursery soil fertility and the use of fertilizers. Even in Germany, the country with the oldest silvicultural practice, the importance of nursery soil fertilization has only been fully recognized during the past few years. A quotation from Dengler's modern text on silviculture (p. 420) may help to visualize the confusion which existed in German nursery practice: "The earlier, often expressed idea that the planting stock for poorer sites should not be encouraged by fertilization led so far that the commercial nurseries were offering stunted seedlings as being especially well suited for reforestation of the poorer soils."

In a great measure, the opposition to the use of fertilizers in forest nurseries had developed due to a number of misconceptions introduced by the early students of silviculture, especially the theories which discounted the importance of nutrients for the growth of forest plantations and nursery stock. These ideas were based on the misinterpreted observations of some productive forest stands growing on soils with an apparently low content of nutrients.

The trees of older stands, growing in a wide spacing, are able to utilize nutrients from an enormous volume of soil; they store plant food in their leaves, and return it to the soil as leaf litter. In this way, a forest stand with its revolving fertility not only maintains an adequate supply of nutrients, but over a long period may convert barren wastes into productive land. Nursery stock, on the other hand, is grown at a great density; its roots seldom penetrate below a 10-inch depth; no crop residues are left in the soil of the nursery because even the root systems are removed. As recent investigations have shown, the maintenance of a satisfactory fertility level in nursery soils often requires applications of fertilizers at much higher rates than is common in farming practice.

Fertility Standards

Before the technique of soil analysis had been perfected, there was only one way to study the relation of plant growth to the content of soil nutrients, i.e. by empirical greenhouse or sample plat trials. Such purely inductive method proved to be of little value in studying the variable and mutually interrelated factors of nursery soil fertility. Moreover, the increase in the size and weight of seedlings, used as a criterion of the fertilizers' influence in empirical trials, is not a measure of the quality of planting since the stock vigor may be lowered by an unsatisfactory root-top ratio, succulent tissue, and inferior physiological makeup. For this reason, the entire experimental technique based on Mitscherlich's concept of "optimum" growth is not applicable to the study of nursery problems. As a rule, stock having the maximum dry weight is too expensive to raise and difficult to plant.

The study of the complex problem of nursery soils fertility would have made slow progress had not Hilgard shown a short cut to its solution. In his text on soils, this scientist warned against "futile attempts to deduce practically useful results from the chemical analysis of soils long cultivated, without first studying the less complex phenomena of virgin soils." As the key to the solution of fertility problems Hilgard advocated the investigation of soils under various types of native vegetation which he considered to be the concrete expression of all productivity factors. The success of such a deductive approach was made especially possible by the recent progress in analytical determinations of soil reaction, exchange properties, and available nutrients.

Following Hilgard's line of reasoning, several thousand soil-horizon samples were collected under productive stands of representative tree species throughout the Lake State region. These samples were analyzed for pH value, base exchange capacity, total nitrogen, nitrates, ammonia, available phosphorus, available potassium, and replaceable bases using standard procedures of the Wisconsin Experiment Station. The analysis of soil was not extended beyond a depth of 8 inches since the soil at greater depths does not affect the nutrition of young seedlings in the nursery. The average fertility of the 8-inch surface layer was arrived at by considering the thickness, volume weight, and chemical composition of the separate soil horizons, viz. litter, duff, humic layer, and leached layer.

The mean values obtained by statistical treatment of the results of analyses are given in Table 40.

Table 40. Standards of Nursery Soil Fertility for Several Representative Tree Species

Species	Reaction pH	Base exchange capacity M.E./100 g.	Total N per cent	Approximate level of avail. N	Available P_2O_5	Available K_2O	Replaceable Ca	Replaceable Mg
				pounds per acre	pounds per acre	pounds per acre	M.E./100 g.	M.E./100 g.
Jack Pine	5.6	5.0	0.10	20	40	100	2.0	0.5
Red Pine Scotch Pine*	5.4	8.0	.12	30	50	150	3.0	1.0
White Pine	5.4	10.0	.14	35	80	200	5.0	1.5
White Spruce Norway Spruce*	5.2	15.0	.25	45	100	250	6.0	2.0
Yellow Birch	5.3	12.0	.16	35	60	175	5.0	1.5
Hard Maple, Amer. Elm, Basswood	5.8	14.0	.20	45	150	275	8.5	2.5
White Ash	6.2	16.0	.22	55	185	300	11.0	3.0

*Standards extended on the basis of practical nursery experience.

These values, representing the average fertility levels of natural seed beds of different species, may well serve as standards in the management of nursery soils. Such fertility levels appear to give the closest approach to the physiological optimum of growth conditions; they provide not only the amount of nutrients, which may be somewhat variable, but the constant ratio of various constituents which is of great importance in the balanced nutrition of seedlings. The results thus far obtained show that the nitrogen-phosphorus pentoxide-potash ratio of available nutrients approach 1-2-5 for all conifers and yellow birch, and 1-3-5 for the remainder of hardwoods studies. Experience in nurseries and greenhouse has repeatedly demonstrated that natural fertility standards prevent both the starvation of nursery stock and the unreasonably rapid growth or abnormal one-sided development.

While the present list of tree species investigated is far from complete, it may be safely extended to a number of other species either on the basis of practical nursery experience, or on the basis of similarities in the natural conditions of growth. Both nursery experience and typological investigations of European students have indicated that the standards established for red pine and white spruce may be applied to Scotch pine and Norway spruce.

General Directions for Adjustment of Soil Conditions

Reaction. The adjustment of the pH value of soil has received considerable attention in both agricultural and phytopathological literature, and only a few specific points need to be emphasized. The acidification of soil may be accomplished by the application of acid organic remains, sulfur, aluminum sulfate, or acid-forming fertilizers, such as ammonium sulfate. The need for a decrease of acidity very seldom occurs in nursery practice, being usually limited to blocks with hardwood stock. It may be accomplished by the application of lime, wood ashes, organic remains high in bases, and alkali-forming fertilizers, such as sodium nitrate.

Both decrease and increase in acidity are accomplished on the basis of soil analysis and calculation of the amount of material needed, or on the basis of empirical trials. Utmost care should be exercised in the adjustment of the pH value of soil since the introduction of acidifying or alkali-forming agents may be toxic to seedlings (Al, H_2S) or may encourage the development of damping-off and root-rot fungi ($CaCO_3$).

Base-exchange capacity. The correction of the base exchange capacity, as a rule, is achieved through an addition oforganic remains, particularly peat. Suppose the exchange capacity of a nursery soil is 7 m.e. per 100 grams, the desired capacity is 10 m.e., and the available peat has a capacity of 120 m.e. per 100 g. Assuming the furrow-slice of soil weighs 2,400,000 pounds, the following amount of peat must be applied to correct the deficiency:

$\frac{2,400,000 \times (10 - 7)}{120}$ or 60,000 pounds, or 30 tons of air-dry peat per acre. This corresponds roughly to 120 cubic yards of peat, or 20 large truckloads.

When there is a suitable deposit of clay in the proximity of the nursery, it may be used instead of peat. In case the base exchange capacity of available clay is 40 m.e. per 100 g., the following amount will be necessary to correct the deficiency of 3 m.e. in 2,400,000 pounds of soil.

$$\frac{2,400,000 \times 3}{40}$$ i.e. 180,000 pounds or approximately 90 cubic yards.

The chief advantage of using clay instead of peat is that the clay will remain in the soil indefinitely, while peat will decompose in time. However, clays of high exchange capacity and suitable reaction are of rare occurrence.

Total nitrogen. The adjustment of the base exchange capacity by application of organic remains usually brings the content of total nitrogen to a desirable level. If not, the content of total nitrogen is increased by the addition of suitable peat or duff.

Suppose the total nitrogen content of the nursery soil is 0.07 per cent and the desired content is 0.12 per cent. The deficiency of 0.05 per cent in 2,400,000 pounds of the surface soil is 2,400,000 x 0.0005 or 1,200 pounds of nitrogen. If the peat to be applied analyzes 2.5 per cent of total nitrogen, the necessary amount of peat is

1,200 x 100 ÷ 2.5 or 48,000 pounds, or about 100 cubic yards per acre.

Available nitrogen. Under favorable conditions, the activity of microorganisms provides a sufficient amount of available nitrogen by converting protein compounds into nitrates and ammonia. The usual content of nitrate and ammonia nitrogen together in a nursery soil amounts to about 1 per cent of the total nitrogen i.e., about 40 pounds per acre, if the nursery soil contains 0.2 per cent of total nitrogen. Under such well-balanced conditions there is no need to apply available nitrogen in the form of commercial fertilizers.

In many instances, however, the amount of available nitrogen released by soil organisms may not be sufficient for seedling growth. This may be due to crowded seed beds, presence of raw organic matter high in carbon, or a soil unfavorable for microbiological activity. The latter condition particularly may be expected in nursery soils which have been disinfected with toxic substances. In such cases, the content of available nitrogen should be increased by application of ammonia or nitrate fertilizers.

There is at hand no simple procedure for the determination of the exact amount of mineral nitrogen fertilizer to apply, since this depends upon a great variety of factors. Fortunately, deficiency of nitrogen is readily manifested by discoloration of foliage, and consequently, the application of nitrogen fertilizers is usually dictated by the appearance of the stock. A good rule to follow in nitrogen fertilization is to apply too little rather than too much of the salt. A deficiency may be corrected by a second application. An excess produces planting stock lacking in vigor. The periodic determination of nitrates and ammonia in nursery beds may be of help in determining the amount of nitrogen fertilizer needed. Also, the determination of nitrifying capacity of soil by chemical tests, or total available nitrogen by biological tests, may assist in arriving at the proper rate of application of available nitrogen.

As analyses of virgin soils and nursery experience indicated, the state of available nutrients should approach the ratio of 1-2-5 or 1-3-5, if vigorous, well-balanced stock is to be produced. This means that in soil with 100 pounds of available phosphorus pentoxide and 250 pounds of available potash, the maximum single application of nitrogen fertilizer should not exceed 50 pounds of elemental nitrogen, or 250 pounds of 20 per cent ammonium sulfate, or an equivalent amount of any other nitrogen fertilizer. An application higher than 60 pounds of elemental nitrogen would seldom be justified.

Available phosphorus. The deficiency of available phosphorus is corrected by application of phosphate fertilizer. If a soil analyzes 30 pounds per acre of available phosphorus pentoxide (P_2O_5) and the desired content is 80 pounds, the deficiency of 50 pounds may be supplied by an addition of about 100 pounds of 45 per cent treble superphosphate or 250 pounds of 20 per cent superphosphate. Higher amounts of phosphate fertilizers than those demanded by nutrient requirements of seedlings may be needed on soils with a high phosphate fixation capacity on soils treated with toxic substances, or on soils deficient in calcium. If the analysis is reported in terms of elemental phosphorhs (P) the results must be multiplied by 2.3 to give the amount of phosphorus pentoxide (P_2O_5).

Available potash. Deficiency of available potash is corrected by a method similar to that for phosphorus. For instance, if the soil content of available potash (K_2O) is 100 pounds and the required amount is 200 pounds per acre, the deficiency of 100 pounds is taken care of by the addition of 200 pounds of 50 per cent muriate of potash or sulfate of potash.

Replaceable bases. Deficiency of calcium and magnesium is seldom experienced in nursery soils. If the content of bases is too low it may be gradually built up by the addition of organic remains high in bases. Organic materials with a high base content are not necessarily alkaline in reaction, and hence not dangerous in nursery use. Also, the application of low-grade phosphate fertilizers and magnesium salts may contribute to the correction of deficiencies.

Behaviour of Fertilizers in Soil and Soil Improvement Program

Ordinarily, soil improvement involves a period of several years, and follows a definitely outlined program. Few nurseries may be improved by means of a single application of absorbing and fertilizing materials. The time element is particularly important when a nursery soil has a low content of exchange material and total nitrogen, or a considerable deviation of pH value from the desired state. Even the correction of potassium and phosphorus deficiency may require a period of several years. This is because the problem of nutrient requirements of seedlings cannot be solved by mere addition of fertilizers, but only through complex physico-chemical and biological processes. The grow th of seedlings in a soil containing unabsorbed fertilizer salts is different from the growth in a medium in which the salts have become incorporated into organic matter by means of chemical and biological reactions. In the first case, the nutrient medium is characterized by equal amounts of cations and anions, great periodic changes in concentration of soil solution, due to fluctuations of soil moisture, and a number of other conditions which are not favorable to the normal nutrition of forest trees. In the second case, most of the nutrients are present as complex organic compounds, and the absorbed cations predominate in the soil since the anions are largely eliminated by leaching. It is evident, therefore, that the soil-building process is completed only when peat and mineral fertilizers have undergone a certain period of "composting" and have become incorporated with the soil through microbiological activity and exchange reactions.

In outlining a soil improvement program it is important to keep two conditions in mind. The first, is the undesirability of introducing large quantities of raw organic remains and mineral fertilizers, because such introduction may bring about a deficiency of available nitrogen and a toxicity of soil solution due to a high concentration of salts. In order to avoid this condition it is necessary to prolong the soil improvement program over a number of years. On the other hand, undue delay in attaining full productive capacity of the nursery soil is also undesirable. It will result in financial losses caused by waste of unabsorbed fertilizers, and it may lead to the production of under-developed stock. The length of time needed for the soil-building program depends on a number of factors, such as present condition of soil in relation to the desired state, species of trees being grown, and availability of funds. Experience has shown that most soils, including those of sandy texture, can be brought into a fully productive state in the course of three 2-year rotations.

It is important in the adjustment of fertility and the management of nursery soils to keep in mind the relationship that exists between the total soil fertility, the fraction of nutrients in the soil solution, and the content of nutrients actually required by seedlings during their 1- or 2-year period of growth.

The amount of nutrients which is necessary for actual annual metabolism of forest seedlings constitutes, as a rule, but a small fraction of the total available supply of this nutrient present in a productive nursery soil. For example, the amount of calcium annually taken up by the growth of even calciphilous hardwood seedlings is less than 1 milliequivalent per 100 gm., or 400 pounds per acre. Nevertheless, a productive hardwood nursery soil must contain at least 5 milliequivalents per 100 mg. of replaceable calcium, or 2,000 pounds per acre. The presence of this high amount is vital because calcium fulfills numerous functions in soil besides that of a plant nutrient; it promotes aggregation, regulates reaction, counteracts the toxicity of other ions, and stimulates the activity of micro-organisms.

In nursery soils, exposed to rainfall and artificial irrigation, the nutrients in solution are subject to frequent changes. During a period of abundant rainfall, the readily soluble salts are leached away and the soil is saturated with nearly pure water. After the rains have stopped, additional nutrients are gradually released into the soil solution, by hydrolysis and the activity of microorganisms, from the more soluble minerals, exchange material, and organic compounds, i.e., from the storehouses of the plant nutrients. The higher the reserve supply of nutrients, the more stable is the level of the readily available fraction, and the greater is the assurance of an uninterrupted and balanced nutrition of seedlings.

If, in spite of all precautions, prolonged rainfall, severe leaching, or intensive feeding of densely planted stock decrease greatly the content of certain available nutrients, the deficiency must be corrected by the application of liquid fertilizers. Careful observations of stock and periodic soil analyses should serve to prevent any serious disruption of the normal nutrient balance.

Adjusted Soil Fertility as a Prerequisite to the Success of New Developments in Plant Nutrition

In recent years, the science of plant nutrition has been broadened by a number of remarkable achievements: Nearly dead plants were revived by colloidal suspensions of certain metals; the growth of roots on twigs of conifers was promoted by the use of hormones; high yields were produced in soilless cultures; many improvements were obtained through the use of vitamins and rare elements, and inoculations with nitrogen-fixing bacteria, mycorrhizal fungi, and earthworm cultures. Unfortunately, not all of the new developments enjoy as yet a full success under actual nursery conditions. To a great extent this is because the applications of new treatments are not always preceded by a careful adjustment of related soil fertility factors. It is obvious that no vitamins, hormones, or colloids can improve the growth of stock if the soil is deficient in phosphates, potash, or any other nutrient.

Effect of Nursery Soil Fertilization upon Survival and Growth of Seedlings in the Field

In farming or gardening the results of fertilizer applications are judged on the basis of general development of plants or weight of the crop produced. In nursery practice the success of fertilization is measured by the survival and the rate of growth of seedlings after they are transplanted in the field.

The information accumulated during the past decade has shown conclusively that the under-developed or "starving" seedlings, grown on nursery soils depleted in nutrients, do not produce satisfactory planting stock. On the other hand, the vigor of planting stock may be upset by either application of fertilizers in injuriously high concentrations, or by unbalanced treatments which produce physiological and anatomical abnormalities of seedlings.

Tables 41, 42, and 43 present some results obtained under field conditions with variously fertilized nursery stock.

Table 41. Effect of 15-30-15 Nitrophoska Applied in Solution and Hardwood-Hemlock-Nitrophoska Liquid Humate upon Survival of 2-0 Red Pine Seedlings (Adapted from Technical Notes of the Lake States Forest Experiment Station, No. 162, 1940).

Nursery treatment	Classification of nursery stock*			Green weight of ave. 2-0 seedling	Field Survival	
	Plant-able	Good	Excel-lent		First year	Second year
	Pct.	Pct.	Pct.	Grams	Pct.	Pct.
None	64	14	4	1.55	71.6	54.7
200 lbs. nitrophoska	76	16	10	1.79	72.8	62.2
400 lbs. nitrophoska	94	48	24	2.73	80.4	58.9
800 lbs. nitrophoska	94	54	36	3.14	72.4	57.7
200 lbs. liquid humate	68	6	6	1.77	70.9	57.1
400 lbs. liquid humate	86	30	18	2.45	75.6	65.1
800 lbs. liquid humate	92	40	22	2.37	77.7	62.3

Table 42. Effect of Complete N-P-K Fertilizer and Acid Peat Applied Broadcast upon Survival of 1-0 Jack Pine Seedlings. (Adapted from Technical Notes of the Lake States Forest Experiment Station, No. 162, 1940).

Nursery treatment per acre	Classification of nursery stock*			Field Survival
	Plant-able	Good	Excel-lent	
	Pct.	Pct.	Pct.	Pct.
No treatment	60	12	7	69.6
400 lbs. 20% Amm. Sulfate, 600 lbs. 20% superphosphate, 160 lbs. 50% potash	95	22	12	70.7
Ditto, plus 20 tons of peat (oven-dry basis)	100	67	47	77.0

* In classifying nursery stock, trees 4/64 inch caliper and over are considered plantable; those 5/64 inch and over are good; those 6/64 inch and over are excellent.

Table 43. Survival and Height Growth of 2-Year Old Jack Pine Raised on Beds of an Average Fertility and Those Treated With a High Rate Application of Complete Fertilizer. Results Recorded 3 Years After Planting Seedlings in the Field. (Adapted from Wilde, Wittenkamp, Stone and Galloway)

Plat	Unfertilized stock		Fertilized stock	
	Survival Per cent	Height Inches	Survival Per cent	Height Inches
A	73	24.9	91	37.0
B	83	22.7	87	27.4
C	92	20.9	89	26.6
D	63	25.9	86	25.0
Average	77.8	23.4	88.3	29.4

Average increase in survival: 88.3-77.8 = 10.5 per cent.
Average increase in height growth: 29.4-23.4 = 6.0 inches.

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CHAPTER XXXIII

CONTROL OF PARASITIC ORGANISMS IN SOILS OF FOREST NURSERIES

"It is not the pathogenic microbes, but the state of the infested organisms that counts."

Claude Bernard

Introduction

Records of over one hundred years of forest nursery practice include but very few cases in which seedlings on recently cleared land were attacked by parasitic organisms. This suggests that in many instances the invasion of the nursery by parasites is simply a manifestation of exhausted soil fertility, unskilled fertilization, inadequate or excessive watering, and other unforseen eventualities. Therefore, careful management of the nursery soil appears to be the first requirement in protection of nursery stock from diseases and insects.

If preventative measures fail and parasites invade the nursery, all possible efforts should be made to suppress them by means of disinfection treatments. In carrying out these treatments it should be kept in mind that the welfare of the seedlings is just as important as the destruction of the parasites. Usually, measures of control destroy not only the parasitic organisms but also the useful population of the soil. Very often such measures materially decrease available plant food and leave toxic residues. For these reasons, the re-establishment of the ruined fertility, through application of "antitoxins", fertilizers, and inoculating materials, forms an essential sequel of the disinfection treatments.

The phytopathological literature of today includes numerous methods for the control of soil parasites. Unfortunately, in devising various treatments sufficient consideration has not always been given to the effect of disinfectants on the forest seedlings under different soil conditions and in the presence of various fertilizers. As a consequence, the application of such treatments without a thorough examination of soil may either not eliminate the parasites, or may produce a condition fatal to nursery stock. Reaction of soil, content of colloids, organic matter, amount of carbonates and exchangeable bases, mineralogical origin of soil, and composition of soil solution are among the important factors which modify the kind, quantity, and concentration of the chemicals used in the control of parasites.

The most common and most dangerous parasites of the nursery soil are the damping-off fungi, which cause the destruction of seedlings in the early period of growth (chiefly species of Fusarium, Rhizoctonia, and Pythium). There is evidence that the destructive activity of these fungi is supported by mites (Arachnida) and eel-worms or nematodes (Rhabditis spp.) which have been found in large numbers within the roots of injured live seedlings. Less conspicuous, but perhaps not less important are the fungi which cause the root rot of older seedlings (Fusarium, Phytophthora, etc.). Among the insect parasites the white grub (Phyllophaga) and root weevil (Brachyrhinus) should especially be mentioned.

The following outline includes a brief review of the methods of parasite control commonly used in nursery practice. The chief purpose of this outline is to give a cross-section of various approaches to the problem, and hence, it includes methods of dubious value in forest nursery practice.

Surface Firing

The burning of brush, wood, or straw is the oldest and most primitive method of soil sterilization. Twenty centuries ago Virgil in his Georgics said, "Often you will find it well to burn the garnered field and set the flimsy straw a-cockling in the flames. Whether perchance the land in this wise finds some unknown force, or that every fault thereby is purified by fire and all the useless humours purged....."

Until recently, surface firing has been widely used in agricultural and horticultural practice as a means of damping-off control, but has been almost abandoned because of the scarcity of wood. Although in some trials surface firing proved to be satisfactory in forest nurseries, no conclusive results have been reported. Since wood ashes and the decreased acidity following burning may encourage the development of survived damping-off fungi, this method requires a careful investigation of its reliability under local conditions before it is used on a large scale. The chief advantage of surface firing in forestry practice is that it requires no cash outlay, since the slash from thinnings is usually available and the treatment may be done by a few men permanently employed in the nursery.

The brush or other combustible material is burned over dry, spaded seedbeds for two or more hours, depending on conditions. Wood ashes are removed as far as possible, and the remainder is thoroughly mixed with the soil. The soil after treatment is abundantly watered for several days to leach out the excessive potash, which may injure the germinating seedlings. As the burning destroys useful organisms and nitrogen compounds, soil after sterilization must be treated with acid peat, leaf litter, and commercial fertilizers. In the majority of cases, the need for the latter will be limited to ammonium sulfate.

Steaming of Seed Beds

While sterilization by steam may be found practicable under special conditions, there have been but few experiences with this method in forest nursery practice. The destruction of weed seeds appears to be a decided advantage of steaming in comparison with other methods of soil disinfection.

In one method, steam is applied by means of a set of 1½ inch perforated pipes, with the holes one foot apart and not larger than ¼ inch in diameter. With a medium boiler capacity of 50 horse-power, the pipes should be about 30 feet long and not more than 7 in number. The pipes are buried at a depth of 8 inches in a level position and about 16 inches apart, being connected with a 2-inch cross-head by means of T connections. Before steaming, the soil is leveled and covered with canvas or sacking to check the escape of steam. Potatoes are placed in the soil near the surface and the treatment is completed when they are well cooked. The cost of treatment depends upon the size of the area treated, availability of men permanently employed, and availability of second-hand material to be used.

Another method of sterilization by steam is the use of an inverted pan. A galvanized iron pan 4 x 12 feet and 6 inches deep, with sharp edges, is inverted over the spaded seedbed. The pan is pressed one or two inches into the soil, thus forming a compartment into which the steam is run for 20 to 40 minutes from a boiler having 100 pounds pressure. A pressure less than 100 pounds introduces an excessive amount of water into the soil and may result in puddling. The pressure under the pan is seldom greater than 1 or 2 pounds. A one-inch steam hose is used to connect the pan with the boiler. A traction engine, such as is used for threshing, may be conveniently used to furnish the steam. Sandy soils require a shorter time for sterilization than heavy soils.

Sterilization of the soil by steam lowers the fertility, because of the destruction of some useful organisms, breaking down of soil colloids, and excessive accumulation of soluble salts, including toxic ammonium carbonate and manganese. Consequently, the sterilized soil should be thoroughly soaked or "washed" with water, treated with peat and commercial fertilizers, and re-inoculated by a generous application of leaf mold.

Quite often in steam treatments some portions of the soil are left unsterilized because of insufficient pressure or too wide a space between the pipes. In such cases, the surviving parasites within a short time after treatment invade the treated areas with increased intensity. This may be due to the destruction of the hyper-parasites in the treated areas. For this reason, steaming requires very careful attention under the direction of a skilled person.

Sulfuric Acid

A dilute solution of sulfuric acid is about the cheapest and most commonly used means for the control of damping-off disease. However, this method is primarily adapted to non-calcareous soils of sandy texture.

The dilute solution is prepared in a barrel or other large container by the addition of concentration commercial acid to water with constant stirring. Water must never be poured into the acid as this may cause an explosion. The solution is transferred from the barrel by means of a hose or spigot into watering cans and sprinkled uniformly on top of the seeded nursery beds. A fertilizer sprayer may be successfully employed in treatment of larger areas. As soon as the acid has soaked into the soil, the soil is thoroughly watered and is kept in a fairly moist condition throughout the period of germination and early growth of seedlings. Allowing the soil to dry out will result in the high concentration of acid and chemical injury to the seedlings. The success of disinfection depends greatly upon a correct estimation of the suitable concentration of applied solution and the rate of its application.

Although plant pathologists have long emphasized the importance of adequate dilution of acid used in control of damping-off organisms, nurserymen have often applied acid on the basis of ounces per square foot, disregarding strength and volume of solution. The concentration of applied solution, ranged in different nurseries from 0.5 to 12.5 per cent by volume, whereas the rate of application varied from 3 quarts to 24 gallons per hundred square feet.

The treatments with strong solutions in small quantities were based on the assumption that the acid is diluted by water applied later on. However, on soils having even a small amount of base exchange or absorbing material, the bulk of the H-ions is instantly fixed at the points of their first contact with the soil; these ions can be released only slowly by hydrolysis and replacement with bases and do not undergo immediate dispersion either horizontally or vertically. Consequently such treatments are likely to result either in incomplete control of parasites or in chemical injury to the seedlings. On the other hand, treatments with weak solutions in larger quantities eliminate only hyperparasites and competing organisms and not the damping-off fungi. Such treatments also lead to saturation of soil to an unnecessarily great depth and subsequent greater deterioration of fertility. As a result, the treatments with weak solutions may increase the virulence of the disease and cause the starvation of surviving seedlings. Thus, any considerable deviation from the desirable optimum of either concentration or rate of application of solution causes unsatisfactory results, as outlined in the following summary:

(a) Too strong concentration: chemical injury of seedlings;

(b) Too weak concentration: increase in virulence of disease due to destruction of hyperparasites;

(c) Too small volume of solution: partial control of parasites due to patchy distribution and insufficient penetration of the liquid;

(d) Too large volume of solution: deterioration of soil fertility to an unnecessarily great depth.

The work in Wisconsin nurseries, located on non-calcareous sandy soils, showed that the adequate quantity of solution, needed to saturate the surface soil layer containing the seed, ranges from 6 to 7 gallons per 100 square feet. These observations were confined to soils derived from granitic and other crystalline rocks, characterized by an exchange capacity of 5 to 8 milli-equivalents per 100 grams and an original reaction of pH 5.0 to pH 6.5. On soils having a higher content of colloids or bases a greater amount of solution may be needed. Ordinarily, 12 gallons per 100 square feet is the maximum amount of solution to be applied. If this amount is not sufficient, the soil should be thoroughly investigated as to its suitability for acid treatments.

Observations over a number of years have indicated that 2 per cent* is the maximum concentration of sulfuric acid required in the control of damping-off fungi on non-calcareous sandy soils. This concentration is usually not injurious on such soils when applied in the fall at the rate of 7 gallons per 100 square feet. In some nurseries the concentration of solution in the fall treatments may possibly be reduced to 1.5 per cent. The use of the same amount of 2 per cent solution in spring treatments involves danger of chemical injury. A 1.5 to 1.2 per cent solution appears, therefore, to be safer for the treatment of spring sown beds. A further decrease of concentration is not advisable because of the low disinfecting efficiency of weak solutions.

The excess of a cid should be removed from treated seed beds by periodic watering so that the reaction of the soil approaches a pH of 5.0 at the time of germination. The speed with which the acidity of treated soil decreases depends upon its mineralogical composition and colloidal content. The affinity of some soils for acid is so great that watering will not raise the reaction to a value higher than pH 3.0 before the seedlings germinate, and the seedlings may suffer from chemical injury or malnutrition. Other soils have such a small affinity toward acid or such a high neutralizing capacity that watering will nullify the effect of acidification, thus making possible the reinvasion of the surface soil by parasites from the deeper untreated layers.

The results of laboratory treatments of various soils indicate that granitic sand tends to maintain a sufficiently acid reaction after many washings (Fig. 86). Siliceous sand is inert to acid treatment and rapidly recovers its original neutral reaction. For this reason soils of this nature should be watered very carefully after application of acid, especially when they are treated in the fall. Calcareous sand reaches neutral reaction after the first washing, and after three more washings attains the original alkaline reaction of pH 8.0. This condition indicates that the use of sulphuric acid for the control of damping-off in calcareous soils is impracticable, and that some other chemicals, such as formaldehyde, should be employed. The treatment of soils of different colloidal content derived from granitic rocks shows tha t the decrease of acidity after washing is inversely proportional to the colloidal content of these soils. The decrease in acidity of a fine sandy loam is so slow that the acid treatment of such soils may exert an adverse influence on the seedlings. This may be particularly true in regard to spring treatments.

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*The expression "per cent of solution" refers to a solution prepared by diluting a certain number of cc. of concentrated commercial acid in 100 cc. of water.

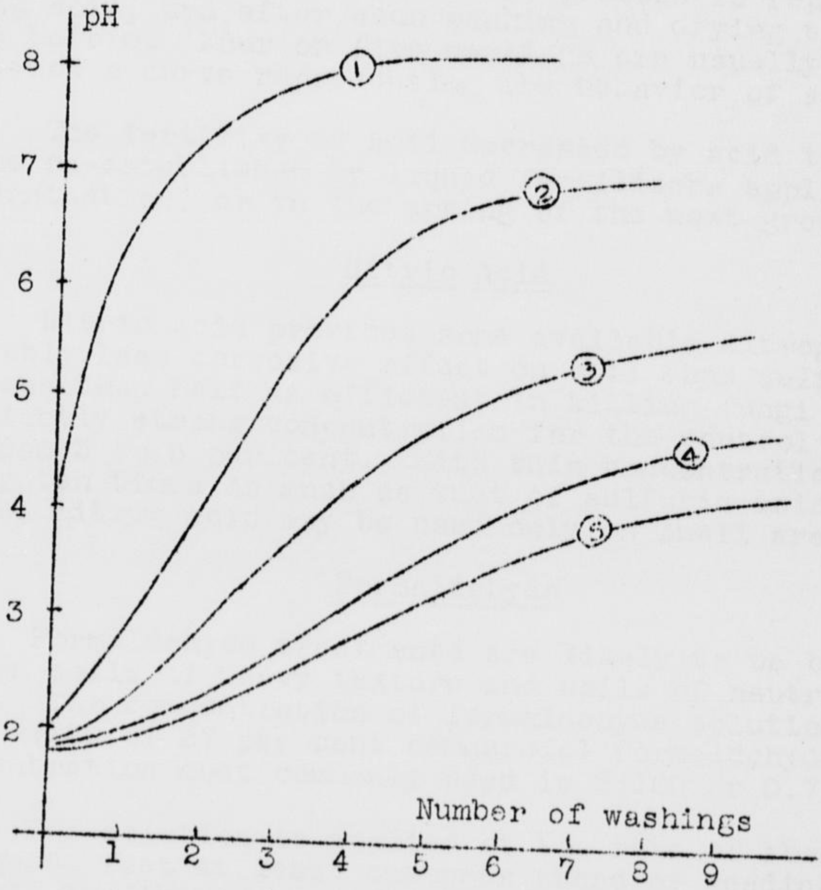

Figure 86. Effect of washings upon different soil materials treated with 2 to 100 solution of sulfuric acid. (1) Calcareous sand; (2) Siliceous sand; (3) Granitic sand; (4) Granitic sandy loam; (5) Granitic fine sandy loam.

The effect of organic matter upon acidification of soil was found to be similar to that of mineral colloids, except that organic matter has a much higher absorbing capacity per unit of weight.

Most soils are composed of varying amounts of quartz, alumino-silicate minerals, calcareous particles, coarse and fine material, and organic matter. Because of this complexity, the behavior of soils toward acid can be more easily established by the experimental treatment than through a consideration of the different constituents. The following procedure may be employed.

One hundred grams of a 20-mesh sample are placed in a 400 cc. beaker, saturated with 50 cc. of 2 per cent sulphuric acid and allowed to stand for 2 hours. The contents of the beaker are filtered on a Buechner funnel. The soil is transferred to a beaker and stirred thoroughly for 1 minute with 200 cc. of distilled water, using a rubber policeman. The suspension and the coarse soil are filtered again on a Buechner funnel and allowed to dry in a steam or electric oven a t 60° C. Upon drying, the soil is thoroughly mixed and the pH is determined electrometrically on a 10 gram sample. The process is repeated on the remaining soil, and after each washing and drying the pH is taken as before. Four or five washings are usually sufficient to construct a curve representing the behavior of soil.

The fertility of soil decreased by acid treatments should be re-established by liquid fertilizers applied six weeks after germination, or in the spring of the next growing season.

Nitric Acid

Nitric acid provides some available nitrogen, and has considerably less corrosive effect on soil than sulfuric acid, but is less than half as efficient in killing fungi as the latter. A sufficiently strong concentration for the control of parasites ranges from 3 to 5 per cent. With this concentration the cost is nearly ten times as much as that of sulfuric acid, and, therefore, nitric acid may be used only on small areas.

Formaldehyde

Formaldehyde treatments are likely to be best adapted for use on soils of heavy texture and soils of neutral or alkaline reaction. The concentration of formaldehyde solution varies from 1:100 to 4:100 of 37 per cent commercial formaldehyde in water. The concentration most commonly used is 2:100 or 0.75 per cent.

The solution is applied at the rate of about 6 gallons per 50 square feet at least one week ahead of seeding. Under unfavorable conditions a period of two weeks may be needed for evaporation of the formaldehyde. The covering of the treated soil with oil-treated paper to prevent the escape of the fumes does not increase the effectiveness of the treatment. It is important that soil disinfected with formaldehyde be disturbed as little as possible at the time of seeding, and especially should not be contaminated by applications of untreated soil as a top dressing.

The greatest drawback in the use of formaldehyde is the difficulty in establishing the proper length of time which must elapse between treatment and seeding. Too short a period results in chemical injury to germinating seedlings, whereas too long a period may decrease the effectiveness of formaldehyde and may result in more severe damping-off than on untreated areas. The delay of spring seeding interferes seriously with the nursery program and decreases the length of growing season. Another decided disadvantage of formaldehyde is its low efficiency in control of weeds. The cost of formaldehyde may be prohibitive when the area in need of treatment is of considerable size.

The use of paraformaldehyde in dust form has been suggested but needs thorough trial in forest nurseries under different conditions before it can be recommended.

Carbon Disulfide Emulsion

Carbon disulfide is used for the control of animal parasites and insects, particularly Japanese beetle larvae, but does not control the fungous diseases unless it is combined with formaldehyde. The emulsion is prepared from water, rosin-fish oil soap, carbon disulfide, and other substances. These constituents are agitated in special mixers. The stock solution obtained is diluted with water. Commercial 37 per cent formaldehyde is added to this emulsion in case the control of fungous parasites is desired. The emulsion is applied by means of pails or hose. The composition of the emulsion and its rate of application varies with conditions and satisfactory disinfection requires the supervision of an expert.

Pure carbon disulfide is highly inflammable and explosive. Prolonged exposure to the gas causes dizziness. The cost of treatments is very high. Carbon disulfide does not satisfactorily control white grubs which are the most destructive pests in forest nurseries. All of these limitations make the use of carbon disulfide in forest nurseries seldom justified.

Chlor-picrin

Chlor-picrin is a heavy liquid, made by interaction of bleaching powder and picric acid, which gives off a suffocating vapor. It destroys eelworms and insect parasites, but no information is available as to its value in control of damping-off fungi.

In treating nursery beds, holes are made from 5 to 6 inches deep, and 14 inches apart. Approximately 2.5 ml. or 1/12 oz. of liquid is inserted into the hole by means of special pipette. The hole is immediately closed by pinching the soil together with a thrust of the heel. The entire bed then is covered with oil-treated paper, which is tucked down on the edges of the bed to a depth of 3 to 4 inches. After three days the paper is removed, and the bed prepared for seeding. Treatment is extremely dangerous to growing nursery stock.

Sulfur Powder

Sulfur powder has been applied extensively in forest nurseries as a means of damping-off control, but has not always proven to be wholly efficient. Nevertheless, sulfur in moderate quantity is desirable on all nursery soils which are less acid than pH 6.0. It acts as a preventative against damping-off fungi by acidifying the soil, and also acts as a fertilizer both directly and by rendering available other soil nutrients. The usual rate of application varies from 100 to 300 pounds per acre depending upon the reaction and texture of the soil. <u>Even this light application must be made well ahead of seeding, as the intermediate products formed in sulfur oxidation are extremely toxic to plants</u>. A thorough distribution of sulfur powder in the 8 or 9-inch layer of soil is essential.

An addition of sulfur may be advantageously supplemented by a generous application of duff of raw humus nature which will increase the number of sulfur oxidizing bacteria and speed up the oxidation process. The sulfur most commonly used in forest nurseries is the grade, of which 90 per cent will pass through an 80-mesh sieve.

Aluminum Sulphate

Recently this salt has been used extensively for acidification of soil and damping-off control. It has proven to be only partly efficient as a fungicide, even when the rate of application on sandy soil was as high as 500 pounds per acre. In order to attain more thorough control of the damping-off disease, some recommendations call for applications ranging from 1200 to 3000 pounds per acre. While such applications may be justifiable on highly calcareous soils, they are harmful in the great majority of forest nurseries because of the high toxicity of the aluminum ion. The application of as high as 2,000 or 3,000 pounds per acre of even nutrient salts, not to mention toxic compounds, is likely to bring about chemical injury of the nursery stock. The repeated application of aluminum sulphate at the biannual rate of 400 pounds per acre on poorly buffered sandy soil led to a general deterioration of the stock in several forest nurseries.

It appears, therefore, that aluminum sulphate may be used only in moderate quantities, purely a s a preventative measure for deep acidification of soils, especially those of heavy texture. Care should be taken in these treatments to distribute the chemical in the soil to a minimum depth of 8 inches. The amount necessary for acidification of a particular soil is usually found by treating small amounts of soil with different quantities of aluminum sulphate and measuring the resulting pH values.

The toxicity of the accumulated aluminum ions may be counteracted by applications of low-grade phosphate fertilizer or organic matter high in exchangeable bases.

Lead Arsenate

Lead arsenate powder is applied for poisoning white grubs. The efficiency of this chemical in reducing the injury is questionable, since there have been reported instances when the seed beds were destroyed in spite of heavy applications of the insecticide. In a larger quantity and especially on strongly acid soils lead arsenate is extremely toxic, causing either immediate death of the seedlings or serious injury to the roots, which later become subject to the attack of Fusarium and other fungi. The application of 200 pounds per acre on a sandy loam soil of a moderately acid reaction seems to be the maximum that can be used.

Attempts were made in some nurseries to dip the roots of seedlings into a semi-fluid mixture of clay and an arsenic compound. Such treatments, however, interfere with the nutrition of the seedlings and lead to the production of inferior planting stock. Direct spearing with a board studded with knitting needles and rototilling are used now in the majority of nurseries in preference to poison. A three-field rotation system may be of help in reducing grub injury if green manure is planted after the egg-laying season of the beetles.

Organic Remains

A number of observations in greenhouse and on extensive areas of several nurseries have indicated that addition of acid peat and raw humus has a tendency to reduce fungus diseases. This effect of organic remains may be attributed to a variety of conditions, viz. increase of soil acidity (Fig. 87), buffering action preventing the injury of roots by salts in solution, and supply of plant food in the form of humates which may increase the strength of root tissue of germinating seedlings and thus decrease their susceptibility to disease. Moreover, application of suitable organic remains may increase the number of hyperparasites and other organisms responsible directly or indirectly for reduction of parasites. Numerous other conditions related to organic matter may be expected to play an important part in the reduction of parasitic organisms.

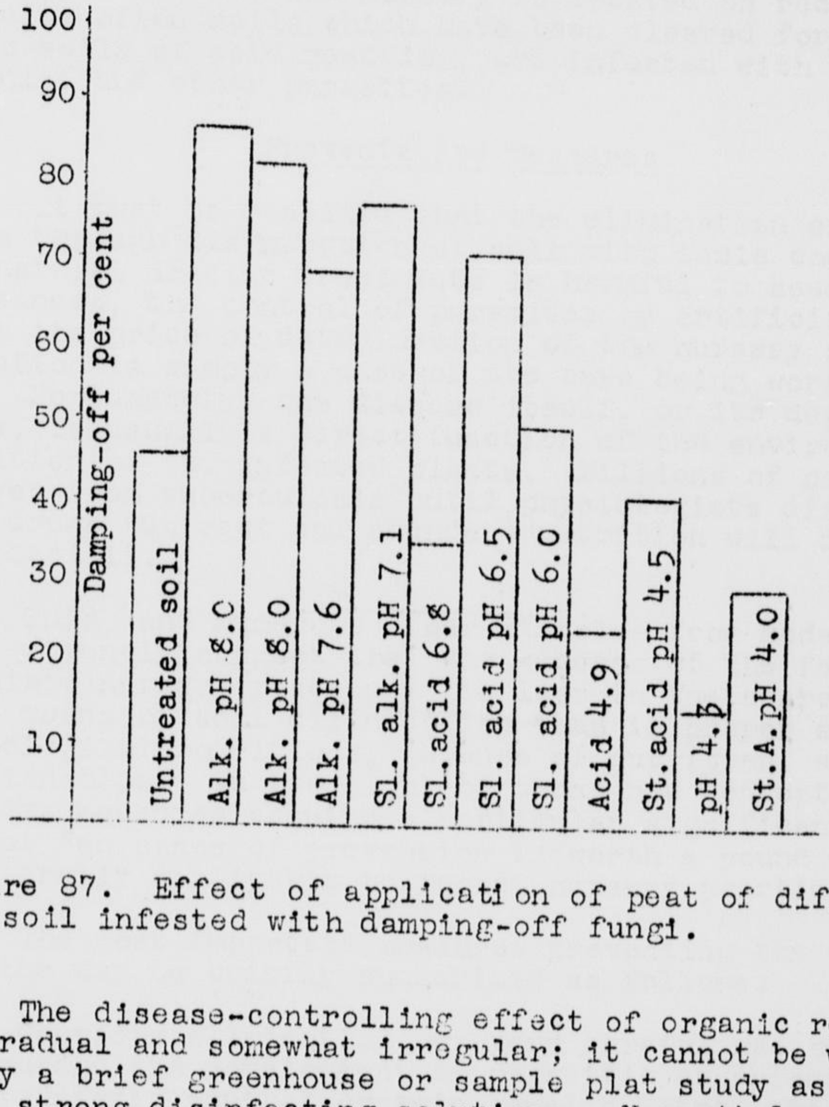

Figure 87. Effect of application of peat of different pH value to soil infested with damping-off fungi.

The disease-controlling effect of organic remains is usually gradual and somewhat irregular; it cannot be well demonstrated by a brief greenhouse or sample plat study as may be the effect of strong disinfecting solutions. Nevertheless, in the course of several years suitable organic remains appear to produce a lasting control of fungous diseases. At least the observations in many forest nurseries of the Lake States region made during the last ten years, lead to this conclusion.

Other Means of Parasitic Control

Glacial acetic acid, pyroligneous acid, phosphoric acid, organic and inorganic mercury compounds, zinc salts, copper sulfate, Bordeaux mixture, and numerous other compounds have been proposed for the control of soil-inhabiting parasites. However, none of these has found extensive use in forest nurseries because of low efficiency, high cost, or corrosive effect upon the soil. Treatment of seed beds with boiling water has been tried, but the results were not satisfactory. The addition of charcoal has been advocated as a means of damping-off control, but there is little information available in regard to this method.

Some foresters avoid disinfecting the soil by abandoning the nursery and selecting a new site as soon as the parasites become troublesome. This practice, however, may not always be successful, unless the new nursery is located on recently cleared land. Quite often soils which have been cleared for some time, including soils of acid reaction, are infested with Pythium, Rhizoctonia, and other parasites.

Preventative Measures

It must be realized that the elimination of parasitic organisms through disinfection of soil with toxic chemicals or other unnatural drastic treatments is harmful to seedlings. In many instances, the control of parasites by artificial means is bought at the price of deterioration of the nursery stock, and the situation is simply a case of the cure being worse than the disease. Fortunately, the disease itself, or its degree of virulence, is usually a direct function of the environment and the condition of the infested plants. Millions of people lost their lives from tuberculosis until physiologists discovered that not drugs but rest and abundant nutrition will defeat the tubercle bacilli.

This, and numerous other examples from modern medical practice, strongly suggest that the success of the forester's fight against nursery pests may lie less in the search for more efficient means of soil disinfection than in proper adjustment of the ecological conditions, balance of nutrition, and biological relationships. In the light of these new conceptions the preventative measures acquire a particular significance. The saying that "an ounce of prevention is worth a pound of cure" may be literally applicable to forest nursery practice.

The most important measures preventing the development of parasites may be briefly summarized as follows:

1. Complete elimination, or very careful use of materials which encourage the development of parasitic organisms, namely, alkaline or nearly neutral organic remains, lime, wood ashes, and commercial fertilizers decreasing the acidity of soil, such as nitrate of soda and calcium cyanamide.

2. Maintenance of an acid reaction of nursery soil by careful applications of suitable acidifying agents, especially acid peat.

3. Maintenance of an adequate and balanced supply of available nutrients and organic matter through addition of suitable fertilizers and organic remains.

4. Regular additions of suitable duff and litter in order to assure an abundance of useful organisms, as well as a supply of available nutrients for their sustenance.

5. Restriction of the use of unbuffered fertilizers or any other unbuffered soluble salts.

6. Maintenance of an adequate content of soil moisture and an adequate degree of soil aeration by carefully regulated artificial watering.

7. Protection of seedlings from extremes of climate by shading, windbreaks, mulching, watering, and other means.

8. Rotation, careful use of green manure crops, sparse seeding. Fall seeding, if possible, or at least early spring seeding.

9. Periodic examinations of nursery stock and nursery soil and immediate eradication of parasites as soon as they appear. Weed control and other forms of sanitation.

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APPENDIX

Selected Review Questions

The purpose of the following selected questions is merely to aid in a crystallization of the subject matter. It should not be assumed that the ability to answer these questions assures one of the knowledge of the entire course.

PART I: GENESIS OF FOREST SOILS

1. Enumerate some of the more important contributions to soil science made by foresters.
2. Name outstanding students of forest soils.
3. Outline development of the subject of forest soils in Central European countries, Russia, Scandinavia, and the United States.
4. Name a few outstanding works on forest soils that appeared in the nineteenth century.
5. Describe the part played by forest soils and the knowledge of their management in general program of land utilization, conservation, and social development.
6. Compare a silvicultural definition of forest soil with the concepts introduced by agronomists, geologists, and pedologists.
7. Outline the composition of a forest soil including physical, chemical, and biological characteristics.
8. Discuss the concepts of "embryonic" and "mature" forest soils; "zonal" and "intra-zonal" forest soils.
9. Outline major divisions of the subject of forest soils.
10. Classify parent material of soils on the basis of its origin and composition.
11. Explain the meaning of the following expressions: mantle rock, bed rock, inherited soil, and talus.
12. Outline the principal characteristics of various types of morainic deposits and soils formed upon them.
13. Discuss fluvio-glacial deposits.
14. Describe briefly lacustrine deposits, marine deposits, alluvial deposits, and deluvial deposits.
15. Outline the characteristics of aeolian deposits and soils originating from them.
16. Name the main types of cumulose deposits.
17. Describe the composition and appearance of a few of the more important soil-forming minerals.

18. Name the more important rocks of igneous, sedimentary and metamorphic origin.

19. Describe the composition of the important members of one of the following groups of rocks: (a) Granitic rocks; (b) ferro-magnesian rocks; (siliceous rocks, (d) calcareous rocks.

20. What are the principal compounds constituting soil-forming organic remains?

21. Explain the meaning of the term "weathering" and give some of the chemical reactions typical of weathering processes.

22. State the approximate composition of the weathering material indicating primary and secondary minerals and the soluble products.

23. What are the principal stages in biological weathering?

24. Outline the course of "mineralization" of organic remains and name the important end-products of this process.

25. Describe three principal types of weathering taking place under different climatic conditions.

26. Is laterization a geological or a soil-forming process? What are the principal processes of the profile development of forest soils?

27. Describe briefly three processes of forest soils development, viz. melanization, podzolization, and gleization.

28. Discuss the principal horizons of forest soils and indicate their designation according to one of the generally accepted methods.

29. Outline the distribution of zonal forest soils in relation to climatic factors. Give a graphical or a tabular scheme.

30. Outline principal morphological and chemical features of the profiles of the four zonal groups of forest soils.

31. Present in a tabular form climatic conditions, vegetation, and profile characteristics of the four zonal groups of forest soils.

32. Discuss the influence of topographical features upon the development of forest soils.

33. Discuss the influence of parent material upon the development of forest soils.

34. Discuss the influence of vegetation upon the development of forest soils.

PART II: THE GREAT SOIL GROUPS OF THE WORLD

1. What significance has zonal groups of soils in silviculture?

2. State the conditions of development of podzol soils, their distribution, and profile characteristics.

3. What are the properties of the morphological varieties of soils belonging to the podzolic group? Indicate the predominant forest cover of these soils, and discuss their productivity from silvicultural and agricultural viewpoints.

4. What difficulties may be encountered in reforestation of fully-developed podzols?

5. State the origin and conditions of development of grood or prairie-forest soils, their profile cha racteristics and predominant forest cover.

6. Compare the fertility of podzol and grood soils from silvicultural and agronomical viewpoints.

7. What difficulties may be encountered in reforestation of prairie-forest soils?

8. State the conditions of development of melanized or humus-incorporated soils, their morphological features and predominant forest cover.

9. Discuss the meaning of the term "Brownearth" and its shortcomings.

10. State the conditions of development of lateritic soils, their distribution and morphological features.

11. Outline morphological varieties of soils belonging to the lateritic group; state their predominant forest cover and productivity.

12. What difficulties may be encountered in reforestation of lateritic soils?

13. Outline the principles of the vertical zonality of soils and the outstanding characteristics of soils of high mountains.

14. Classify soils of high mountains stating their morphological features, physical and chemical composition, and predominant forest cover.

15. Name the major groups of intra-zonal soils.

16. State the origin and evolution of rendzina soils considering morphological features, chemical composition, and vegetation.

17. Discuss the conditions of development of gley soils and their morphological features.

18. Classify gley soils from an ecological or silvicultural standpoint.

19. State the predominant forest vegetation, productivity, and silvicultural adaptation of different morphological varieties of gley soils.

20. Classify organic or moor soils on the basis of their origin and composition.

21. Explain the meaning of the following terms: "quagmire", "sapropel", and "marl".

22. What are the morphological characteristics of high moor soils and their predominant forest cover.

23. Outline morphological characteristics of the principal varieties of low moor soils, their predominant forest cover, productivity, and adaptation.

24. Compare the content of organic matter and nutrients, C/N ratio, base exchange capacity, and reaction of the more important types of peat.

25. Discuss the properties and forest cover of the more important types of immature or embryonic forest soils.

26. Give an outline of soil-forest provinces of the United States.

27. Give an outline of soil-forest provinces of Eurasia.

28. What are the main characteristics of tundra soils, heath soils, mountain meadow soils and skeletal soils?

29. Discuss briefly the origin and properties of chernozem soils, prairie soils and savanna soils.

30. Discuss briefly the origin and properties of alkali soils stating the principal morphological varieties of these soils and their evolution.

PART III: SOIL AS A MEDIUM FOR TREE GROWTH

1. Outline the geographic, biological and sociological relationships upon which modern silviculture is based. Discuss the following concepts: "biocenose", "life zones" and "biological equilibrium".

2. Discuss the relationship that exists between the light requirements of trees and their adaptation to soil. Name a few of the more important light-demanding and shade-tolerant species of forest trees.

3. Classify forest trees according to their temperature requirements and relation to soil.

4. Into which three groups, based on moisture requirements, are forest trees divided?

5. Illustrate the relationship of soil and forest vegetation by a few examples of folk terminology.

6. Discuss obvious and concealed relationships of forest and soils.

7. Explain the role played in the natural distribution of forest vegetation by ecological amplitude of tree species, competition, moss action of the forest, and occidental disturbances.

8. Discuss the local and the general succession of forest vegetation. Indicate the importance of forest succession in silvicultural practice.

9. Outline the dynamic principles of soil fertility. Compare the potential and the actual productivity of forest soils.

10. How would you proceed to establish a correlation between the composition of soil and the rate of forest growth?

11. Explain the meaning of "soil skeleton" and "soil protoplasm".

12. Discuss the relation of tree growth to textural composition of soil under conditions of virgin forest and cut-over lands.

13. Discuss planting possibilities of various coniferous and deciduous tree species in relation to soil texture under different climatic conditions.

14. How would you proceed in sampling a soil for textural analyses?

15. Outline the significance of soil texture in silvicultural cuttings.

16. Discuss the significance of soil texture in nursery practice; indicate the advantages and shortcomings of light and heavy soils. Give an approximate optimum content of silt and clay particles in nursery soils.

17. Define soil structure and discuss its significance in forest growth and reforestation practice; name the more important types of soil structure.

18. Give approximate data on porosity, and contents of water and air ordinarily found in forest soils of sandy, loamy and clay texture.

19. Discuss gravitational, capillary and hygroscopic forms of soil water.

20. Discuss the meaning of the following terms: "ground water table", "capillatum", and "dead horizon of dryness".

21. Outline the influence of ground water upon the properties of soil and growth of forest vegetation.

22. Discuss the nature of acidity and alkalinity of the soil solution and the meaning of "pH".

23. Outline the influence of soil reaction upon the distribution and the growth of forest trees.

24. What is the significance of soil reaction in the selection of planting sites?

25. Why may the planting of trees fail on soils of a strongly acid or alkaline reaction?

26. How does soil reaction affect the growth of forest seedlings in nurseries?

27. What influence does nitrogen exert upon the growth of trees? State approximate contents of total and available nitrogen in the A_1 horizon of an outwash sandy soil supporting a mature stand of red pine.

28. How does phosphorus affect the growth of trees? What are approximate contents of available phosphorus in the A_1 layer of a weakly podzolized loam supporting hardwoods and in a lateritic clay supporting longleaf pine?

29. How does potassium influence the growth and vigor of forest trees? Give a range of available potassium found in virgin forest soils.

30. State briefly the function of the following nutrient elements: calcium, magnesium, sulfur, and iron.

31. What are the minor elements essential to the growth of trees? Discuss their functions.

32. Discuss availability of nutrients and nutrient balance in relation to the growth of forest trees.

33. Which properties of nursery seedlings would you consider in the evaluation of their vigor?

34. Enumerate the most important toxic agents occurring in forest soils and give methods for counteracting their effects.

35. What are the principles of exchange reactions? Discuss the "replacing power" of different ions and "the law of mass action".

36. Give a few typical exchange reactions taking place in soils of forest nurseries.

37. Outline the significance of the base exchange material in management of nursery soils.

38. Compare the exchange capacity of the mineral and organic fractions in a virgin pine soil of sandy texture.

39. Into what two broad groups determined by the mode of nutrition are bacteria divided? How may silvicultural treatment of sands or management of nursery soils affect the balance of soil microorganisms?

40. What are the principal stages in the decomposition of protein compounds? What is the importance of microorganisms in nitrogen transformations?

41. Discuss nitrogen fixation in forest soils.

42. How does the decomposition of carbohydrates proceed in forest soils and composts?

43. What is the function of sulfur and iron bacteria in forest soils?

44. Name the more important genera of fungi occurring in forest soils and discuss their effects upon the soil and tree growth.

45. What are mycorrhizae? State the part which mycorrhizae presumably play in growth of trees and distribution of the forest.

46. Describe the morphological features of Actinomycetes and state the function of these organisms in forest soils.

47. Classify the algal flora of the soil and outline its part in soil development.

48. What are the important effects of soil protozoa?

49. Describe nematodes, name a few more important genera, and state the role which these organisms play in soils and growth of forest trees.

50. Discuss the importance of earthworms in soils; what is their effect on the growth of forest vegetation?

51. What beneficial and adverse influences upon the forest are exerted by different groups of insects?

52. Discuss the meaning of the following terms: "forest humus", "litter", "duff", and "leaf mold".

53. Describe the two principalmorphological groups of forest humus and explain their mode of development.

54. Discuss mull and mor humus in regard to their effects upon the fertility of soil, growth of trees, and silvicultural management.

55. Enumerate the principal types of humus belonging to the mull group.

56. Enumerate the principal types of humus belonging to the mor group.

57. Outline the principles of biological and chemical analysis of humus.

58. Discuss the nutrient content, reaction, and base exchange capacity of humus in relation to its origin and morphological features.

59. What beneficial and adverse effects upon the growth of forest seedlings in nurseries and in natural stands have different types of humus?

60. What significance has soil organic matter in nursery practice and reforestation?

61. Outline the relation of soil organic matter to nitrogen, phosphorus and replaceable bases in forest soils.

62. Give approximate minimum contents of organic matter in the 7-inch surface soil required for successful growth of several important conifers and hardwoods.

PART IV: SOIL-FOREST TYPES

1. Why is the study of forest vegetation of major importance in the development of ecology?

2. Describe several outstanding eco-types of Sub-Arctic forest.

3. Outline the principles of the soil-forest relationship established by Morozov and Kruedener.

4. What are the principles of the soil-forest relationship established by Cajander.

5. Review the ideas on the soil-forest relationship introduced by Hilgard.

6. Compare the most important soil-forest types of northern Russia with those of the Lake States region of America.

7. Give a general scheme of the soil-forest relationship existing in the prairie-forest region.

8. Describe the principal soil-forest units of the southern Coastal Plain of the U.S.A.

9. Give a general scheme of the soil-forest relationship observed in the mountains.

10. Compare the predominant ground cover vegetation of podzolic sandy soils in the Old and the New Worlds.

11. Compare the predominant ground cover vegetation of podzolized loams in northern United States and northern Europe.

12. Name tree species occurring on Sphagnum moss peat in the United Stated, Finland, and Manchuria.

13. Draw a parallel between the major forest types of the western and the eastern portions of the United States.

14. Describe the principal forest types of the southern Rocky Mountains and state their relation to the soil.

15. Could you apply the knowledge of soil-forest types of the Carpathian Mountains to the Adirondack region?

PART V: ANALYSIS OF FOREST SOILS

1. Discuss the technique of soil sampling.

2. Outline the procedure for the determination of soil texture using the hydrometer method.

3. Outline the procedure for the determination of the water and air contents of the soil using steel cylinders.

4. Describe a method for the determination of the moisture equivalent of soils.

5. Discuss the relationship between the wilting coefficient and moisture equivalent.

6. What significance has the composition of the soil profile in the chemical analyses of soils?

7. Give an outline of the different methods of chemical analysis of soils.

8. Discuss equivalent weights and normal solutions.

9. State the principles of titration and the main types of reactions upon which it is based.

10. How would you proceed in the preparation of standard solutions? Give a concrete example.

11. Outline the procedure for calculating milliequivalents of replaceable ions. Give a concrete example.

12. What advantages has the presentation of replaceable bases in terms of milliequivalents instead of pounds per acre?

13. Discuss the meaning of the term "buffer".

14. What complications may arise in diluting concentrated solutions?

15. Indicate rapid tests for determination of soil texture, soil reaction, and the content of soil organic matter.

16. Indicate rapid methods for the determination of availa ble nutrients and replaceable bases.

17. Outline the procedure for the determination of available nutrients using lower organisms.

18. What are the principles involved in the determination of total nitrogen by means of the Kjeldahl method?

19. Outline a procedure for the determination of nitrates in soils.

20. Discuss the determination of ammonia in soils.

21. State the procedure for the determination of available phosphorus by the Truog method.

22. Discuss the determination of available potash using the Volk-Truog method.

23. State the principles involved in the determination of base exchange capacity and replaceable bases in soils.

24. Outline the technique of plant tissue analysis.

25. How would you determine the nitrifying capacity of the soil?

26. Discuss the method for the determination of carbon dioxide evolved from soils.

27. State the procedure for the determination of the number of organisms in soils and composts.

PART VI: FOREST SOILS IN RELATION TO SILVICULTURE AND FOREST MANAGEMENT

1. In which phases of forestry practice is it essential to have a knowledge of forest soils?

2. State the purpose and technique of the forest soil survey.

3. Discuss the use of soil survey reports and maps prepared by the state and federal agencies in reforestation practices.

4. State the degree of accuracy and the cost of forest soil survey.

5. How would you approach the delineation of soil types in surveying forest soils?

6. Elaborate on the problem of nomenclature used in surveys of forest soils.

7. Give an outline of a report on a forest soil survey.

8. How are the soil survey data used in forest management?

9. What specific conditions are of prime importance in surveying forest soils in mountain regions?

10. Discuss the ecological importance of topographic factors.

11. How would you classify topography on the basis of gradient and exposure?

12. Review different methods of forest subdivision.

13. Discuss the relation of topography to ground water table.

14. What are the major phases constituting the reforestation program?

15. Which properties of tree species should be given a consideration in their selection for planting?

16. Discuss the problem of acclimatization and the establishment of silviculturally homogenous regions.

17. Enumerate the more important factors to be considered in the selection of planting sites.

18. Outline planting possibilities of several important tree species in relation to ground water level, pH value, soil texture, and content of soil organic matter. Give due consideration to the climatic conditions of the region in which the reforestation is to be carried on.

19. Discuss the relation of the geological origin of soils to their productivity and planting possibilities.

20. Discuss planting possibilities of various tree species in relation to the content of soil nutrients.

21. Review the importance of ground cover vegetation as an indicator of planting possibilities. Give some concrete examples.

22. Which methods of planting would you use in reforestation of well drained sandy soils?

23. Which method of planting would you recommend for reforestation of soils having a close ground water table or hardpan layer?

24. On which soils is the use of slit planting method prohibitive? On which soils is mount planting prohibitive?

25. State the advantages and shortcomings of the furrowing.

26. Discuss planting on top of the furrow slice.

27. What are the advantages and shortcomings of the inverted V and cone methods of tree planting.

28. Enumerate the more important factors which must be considered in making a diagnosis of the causes responsible for the failure or stagnant growth of plantations.

29. How would you reduce the losses of water by run-off?

30. Outline methods of artificial drainage applicable to forestry practice.

31. How would you proceed in planting trees on peat soils?

32. Outline the technique for stabilization of aeolian sands.

33. Describe the procedure for reclamation of ortstein soils.

34. Discuss the method of gully planting.

35. Discuss tree planting in prairie regions.

36. How are field crops used in reforestation practice?

37. State the advantages and disadvantages of cultivation of forest plantations.

38. What are the effects of burning forest floor?

39. Discuss the use of fertilizers in reforestation.

40. Give an outline of various methods of fertilizer application used in forestry and landscape practices.

41. Define thinning and selective logging; state their respective purposes.

42. Outline the general principles of silvicultural cuttings; discuss cuttings of different intensities.

43. Discuss selective logging of different species on upland sandy soils.

44. Compare the technique of selective logging on humus-incorporated and on podzol soils.

45. Discuss the problem of selective logging on soils with a high ground water level.

46. Describe the principles of Wagner's shelter-wood strip cuttings.

47. Describe the technique of Eberhardt's production cuttings.

48. Outline different methods of preparation of yield tables; discuss the use of yield tables in forestry.

49. How would you determine the annual cut under the sustained yield management.

50. How would you calculate the expected financial return on a reforestation investment?

51. Outline the principles of land evaluation.

52. Discuss the problem of appraising the damages to the productivity of forest land.

PART VII: MANAGEMENT OF FOREST NURSERY SOILS

1. What are the different phases involved in the mana gement of nursery soils?

2. Enumerate the important factors to be considered in the selection of a nursery site.

3. How would you proceed in the preparation of ground for nursery beds?

4. Discuss the regulation of moisture content in soils of forest nurseries.

5. Give a brief description of different types of soil moisture meters.

6. Discuss time and manner of watering.

7. State the advantages and shortcomings of the various mineral and organic nitrogen fertilizers in relation to their use in forest nurseries.

8. Discuss the suitability of the various phosphate fertilizers for use in forest nurseries.

9. Discuss the suitability of the various potash fertilizers for use in nursery soils.

10. List the common combined fertilizers and state their importance in the management of nursery soils.

11. Discuss the use of lime in forest nurseries.

12. What are composted fertilizers and what are their chief advantages?

13. How would you proceed in the construction of a compost pit for a large size forest nursery?

14. Discuss the suitability of organic materials for use in the preparation of fertilizer composts.

15. How would you calculate the amounts of commercial fertilizers to be used in the preparation of a compost?

16. Discuss the effect of salt concentration upon the quality and cost of fertilizer composts.

17. Discuss the rate of compost application and the problem of the maintenance of a proper content of nutrients in the soils raising stock of different species and age classes.

18. How would you distribute a composted fertilizer in the soil?

19. Under what circumstances should liquid fertilizers be applied?

20. Which fertilizers would you use for liquid treatments?

21. State the suitable concentration of liquid fertilizers in parts per million or in pounds per 100 gallons of water. What are the common rates of application?

22. How would you calculate the amount of different fertilizers for liquid treatments?

23. Outline the technique of application of fertilizers in solution.

24. Discuss the application of liquid fertilizers in relation to the time of the year and kinds of nursery stock.

25. What are liquid humate fertilizers and what are their chief advantages?

26. How would you prepare and apply liquid humates?

27. Outline the benefits and shortcomings of green manuring.

28. Wha t is the effect of catch crops?

29. Discuss the seeding and turning under of green manure crops.

30. Discuss the problem of fertility maintenance in soils of forest nurseries.

31. What are the different approaches in establishing standards for the maintenance of fertility in nursery soils?

32. How would you adjust the pH value of a nursery soil?

33. Outline the adjustment of the base exchange capacity of nursery soils.

34. Discuss the correction of deficiency of the total and available nitrogen.

35. How would you correct the deficiency of phosphorus, potassium, and other replaceable bases in a nursery soil?

36. Discuss the major steps in a soil improvement program.

37. Outline the relationship that exists between the total soil fertility, the fraction of nutrients in the soil solution, and the content of nutrients required by seedlings during their annual growth.

38. Discuss the importance of the adjusted fertility for a successful inoculation of the soil, use of growth-promoting substances, and development of rapidly-growing hybrid varieties.

39. How does nursery soil fertilization affect the survival and the rate of growth of seedlings in the field?

40. Name the most important parasites inhabiting nursery soils.

41. Outline the control of parasites by surface firing and steaming of seed beds stating the dangers involved in the use of these methods.

42. Discuss the disinfecting efficiency of acid applied in different concentrations and at different rates of solution.

43. Which soil factors are likely to modify the effect of acid treatment.

44. What acids other than sulfuric can be used in soil treatments?

45. Outline the method of damping-off control by the use of formaldehyde.

46. What methods are used for the control of animal and insect parasites inhabiting forest soils?

47. Outline the use of the carbon disulfide emulsion.

48. How does chlor-picrin affect the composition of soil, soil organisms, and growing stock?

49. What is the affect of lead arsenate upon the chemical properties of soil?

50. Discuss the acidification of soil by the use of sulfur and aluminum sulfate.

51. How would you reduce the toxic effect of aluminum sulfate?

52. Name some of the recently introduced fungicides and insecticides.

53. What affects may an application of organic remains have upon the parasitic soil organisms?

54. State the principles of the biological method of parasite control.

55. What agents are instrumental in the transmission of diseases?

56. List measures for the prevention of diseases in nursery soils.

57. Discuss the problem of parasite control in relation to the maintenance of soil fertility.