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THE FOREST SOILS OF CONNECTICUT

HERBERT A. LUNT

CONNECTICUT AGRICULTURAL EXPERIMENT
STATION, NEW HAVEN, CONNECTICUT

CORRECTIONS

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Page 26: Under "Summary of Profiles Described" omit commas in "stony fine sandy loam" and "fine sandy loam".

Page 32, line 3: Reference (19) should read (24).

Page 47, line 2: For (pp. 00) read (pp. 21-25).

Page 73, 3d para., line 1: For page ... read page 7.

FOREWORD

The present bulletin supersedes Station Bulletin 342, "Profile Characteristics of New England Forest Soils," long out of print. Additional field and laboratory studies, made in Connecticut since that Bulletin was published in 1932, have added considerably to our knowledge of soils developed under forested conditions. It is advisable to make this material available to the people of the State and to others interested in forest soils.

CONTENTS

THE FOREST SOILS OF CONNECTICUT

HERBERT A. LUNT[1]

INTRODUCTION

About 61 per cent of the total land area of the State of Connecticut is in forest (46). For an area containing nearly 350 persons to the square mile and lying close to metropolitan markets, this is a high proportion of untilled land. The explanation lies in the fact that much of the land is unsuited to profitable agriculture because of its steep topography and stony, shallow, or coarse sandy soils. Another considerable area is taken up by summer homes and country estates of metropolitan residents who usually cultivate no more than a garden patch and seldom put products on the market.

Fortunately, the climate is favorable for tree growth, and most of the land will support a forest cover of some kind. Except on very shallow and very sandy soils, growth can be highly satisfactory and wood production a profitable enterprise, provided the forest is properly managed. Improvement in both quality and yield of present stands, and conversion of valueless brush areas into productive woodland obviously would enhance the wealth of the State. It has been estimated (15) that under intensive forestry practices wood production could be more than tripled in this region. Proper silvicultural management—knowing what and when to cut—hinges on an understanding of plant sociology and recognition of the role of the factors which go to make up a site.[2] One of these factors is the soil.

Prior to 1927, (the year the First International Congress of Soil Science met in Washington, D. C.), forest soils in this country were largely ignored by foresters and soil scientists alike. This was due largely to two facts: first, the lesser annual economic per acre value of the forest crop compared with farm crops, and second, the greater dependence of tree growth upon the other factors of site rather than primarily on the soil *per se* as is the case with farm crops. Contacts with foreign investigators stimulated interest in this hitherto neglected field with the result that investigations were begun in Connecticut and in several other states. These studies on forest soils in Connecticut have continued to the present time except during the war period of 1942-1945.

FACTORS AFFECTING SOIL FORMATION

Geologic and Topographic

Connecticut is the southernmost of the six New England States which occupy the extreme northeastern tip of the United States. The latitude of

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[1] The writer gratefully acknowledges the assistance of others in this investigation. Special recognition is given to the late M. F. Morgan who initiated and supervised much of the work; to Dwight B. Downs for assistance in the field and laboratory work; to Henry Hicock and Raymond Kienholz for providing opportunity for certain cooperative studies and for reviewing portions of the manuscript; to C. I. Bliss for advice on statistical analysis, and to C. L. W. Swanson for many helpful suggestions in preparing the final draft.

[2] The environment of the forest; equivalent to *habitat* as used by ecologists.

Connecticut ranges from 40° 54′ N to 42° 3′ N, approximately the same parallel as Chicago, Cheyenne, Mt. Shasta (in northern California), Barcelone, Rome, Istanbul, and Mukden. Its land area comprises 4,899 square miles.

The State is divided into three main physiographic regions, the Eastern Upland, the Connecticut Valley Lowland, and the Western Upland, with a fourth part in the extreme northwest portion known as the Taconic Section. The Eastern and Western Upland sections are areas of moderate relief, consisting of a mass of resistant crystalline rocks undergoing dissection by streams in the mature stage of the erosion cycle. The rocks consist mostly of very old granitic and dioritic gneisses and schists. The relief is greatest in the north where the floors of the major valleys lie at 500 to 700 feet above sea level, and the general level of the divides ranges from 800 to 1,400 feet.

The Connecticut Valley Lowland has a maximum width of about 20 miles and extends from Long Island Sound northward into Massachusetts. The rock consists of relatively weak, tilted, stratified red Triassic sandstones and shales from which project a number of conspicuous ridges of resistant lava flows and trap sills of basaltic rock commonly known as "trap". The tops of these ridges are almost flush with the eastern and western uplands and range in elevation above sea level from 200 feet in the south to about 1,000 feet in the north. The sandstones and shales vary from sea level to 400 feet.

A small area in the Pomperaug Valley, located in the towns of Woodbury and Southbury in the western part of the State, had a geologic and soil development history similar to the central lowland, and the soils are similar.

The small Taconic Section consists of two parts: (a) the northern end of the Housatonic Valley which at that point is quite broad due to its development in a belt of less resistant limestone, and (b) the highly resistant schists comprising the Taconic Range whose crest varies from 1,300 feet on the south to 2,355 feet on the peak of Bear Mountain (the highest point in Connecticut) located in the northwesternmost town in the State.

The entire State was glaciated, resulting in the deposition of a mantle of glacial till varying in thickness from a few inches to 20 feet or more. In the case of drumlins, the deposits range up to 130 feet. The average depth of till for the State as a whole is probably less than 10 feet. In most cases the greater portion of the till was derived from rock formations either directly underlying or within a mile or so to the north. The valleys often contain level sandy or gravelly terraces along their sides, and gravelly knolls and ridges are common in places.

Inasmuch as Connecticut lies wholly within one climatic and vegetative zone, the principal factors responsible for soil differences are geologic and topographic. The origin of the glacial till and its manner of deposition, and the forces of erosion, or of water or wind deposition which have taken place since the disappearance of the ice have all had an effect upon soil development. Man, through his clearing and cultivation of the land, has brought about a deterioration in the physical condition of the soil and, on sloping land, has hastened the erosion process. Erosion is not the serious problem here, however, that it is in the South and in many other parts of the country.

Climate

The climate of Connecticut is characterized by relatively long, cold winters and rather short, humid summers. The mean values for 18 widely distributed stations, based on Weather Bureau, U. S. Department of Commerce records ranging from 17 to 63 years are as follows:

Maximum temperature	105 °F
Minimum temperature	–29
January temperature, mean	26.7
Mean maximum	35.4
Mean minimum	17.9
July temperature, mean	71.1
Mean maximum	81.8
Mean minimum	60.4
Length of growing season	159 days
Annual precipitation	44.9 inches

On the average, the rainfall is well distributed throughout the year with monthly means of 3 to 4 inches. Rather prolonged dry periods are not uncommon, however, and may occur at any season.

Of the several classifications of climate proposed by different investigators, that of Thornthwaite (50, 51, 52) appears to be most useful in that it is based on the temperature and precipitation for each month of the year rather than on the annual means which is the basis of both Lang's rain factor[1] and Meyer's N-S Quotient[2] (21). Thornthwaite's *index of precipitation* (P-E index) rests on the assumption that evaporation and transpiration tend to increase with increase in temperature, hence the effectiveness of any given amount of precipitation decreases with an increase in temperature.

The climatic classes recognized by Thornthwaite are as follows:

Humidity	*Vegetation*	*P-E index*[3]
A Wet	Rain forest	128+
B Humid	Forest	64–127
B_8	"	112–127
B_7	"	96–111
B_6	"	80–95
B_5	"	64–79
C Subhumid	Grassland	32–63
D Semiarid	Steppe	16–31
E Arid	Desert	0–15

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[1] Precipitation in mm. divided by temperature °C.

[2] Niederschlagsmenge—Sattigungsdefizit Quotient = Precipitation in mm. divided by the absolute saturation deficiency of the air.

[3] P-E index is the summation of the 12 monthly indices each obtained by the formula $\left(\frac{P}{T-10}\right)^{\frac{10}{9}}$ where P = precipitation in inches and T the temperature °F.

Temperature efficiency type		*T-E index*[1]
A′	Tropical	128+
B′	Mesothermal	64–127
C′	Microthermal	32–64
D′	Taiga	16–31
E′	Tundra	1–15
F′	Perpetual frost	0

Seasonal rainfall distribution symbols:

r = precipitation abundant at all seasons
s = precipitation scanty in summer, abundant in winter
w = precipitation scanty in winter, abundant in summer
d = precipitation scanty at all seasons

In the foregoing classification, the climate of Connecticut is rated as $B_8C'r$, which means that it is quite humid and microthermal, with abundant rainfall at all seasons.

A comparison of Connecticut and Rhode Island with other areas in the North and East is shown in Table 1 (21, 52). As would be expected, there is a discrepancy between climatic classifications in the relative position of some of the areas. For the reasons previously mentioned, Thornthwaite's grouping is believed to be most reliable. The P-E indices given in Table 1 constitute the normal based on 40 years' data (52). However, marked departures from the normal are common in New England as elsewhere, and Thornthwaite has presented such data (52) which may be summarized for Connecticut as follows: During the 40 years (1900-1939), Connecticut experienced 17 years of wet climate A (P-E 128+), and 23 years of humid B climate. Considering only the crop season (March through August), Connecticut's climate was wet on two occasions, humid on 34, and subhumid on four.

TABLE 1. CONNECTICUT CLIMATIC FACTORS IN COMPARISON WITH THOSE ELSEWHERE IN NORTHERN AND EASTERN UNITED STATES

	Lang's Rain Factor	Meyer's N-S Quotient	Thornthwaite's P-E Index
Maine	166	600-800	B_8 (112-127)
New Hampshire and Vermont	141	500-600	B_7 (96-111)
Conn. and R. I.	**118**	**400-500**	**B_8 (112-127)**
Pennsylvania (major portion)	94	300-500	B_7 (96-111)
Virginia (major portion)	79	300-400	B_6 (80- 95) B_5 (64- 79)
Ohio (major portion)	85	300-400	B_6 (80- 95)
Michigan central & northern	168	500-600	B_5 (64- 79)
southern	104	400-500	B_6 (80- 95)
Wisconsin	107	400-600	B_5 (64- 79)

Vegetation

The natural vegetation of the State may be classified in broad terms as mesophytic or deciduous. More specifically, Connecticut lies at the

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[1] T-E index is the summation of the 12 monthly indices $\frac{T-32}{4}$ where T is the mean monthly temperature °F.

northeastern edge of the upland oak forests, which is part of the northern forest region. It is bounded on the north by white pine (*Pinus strobus*)[1] forests and, in the western Berkshire Mountain section, by northern hardwoods forests. Connecticut forests ". . . are characterized by varying mixtures of oaks, hickories, maples, and birches, with some yellow poplar [tulip-tree (*Liriodendron tulipifera*)] and other species on the better sites. Upland hardwood stands, most of which would be classed as belonging to the oak type, constitute about 85 per cent of the forested areas" (53).

The remaining 15 per cent is made up of three principal types: Red cedar (*Juniperus virginiana*)—gray birch (*Betula populifolia*), hemlock (*Tsuga canadensis*)—hardwoods, and swamp (33).

Time

In point of time Connecticut soils are relatively recent and, therefore, immature. None of them existed prior to the glacial period. Probably the oldest are the upland soils derived from glacial till[2], followed by the glaciofluvial deposits[3] and the glaciolacustrine deposits[4]. In some areas, the glacial till, glaciofluvial deposits and glaciolacustrine deposits may have occurred concurrently, in which case all of the forementioned soils would be the same age.

Stream terraces[5] were built up after the disappearance of the last glacier but long before the arrival of man; while the youngest soils of all have developed from recent stream deposits[6] and wind-blown materials[7], processes that are still going on.

HISTORY OF LAND USE

The original forests which white men found when they came to southern New England consisted of oak (*Quercus* spp.), chestnut (*Castenea dentata*), and other transitional hardwoods with scattered hemlocks and pines (3, 4). Undoubtedly there was a higher proportion of hemlock and, on sandy soils, of pine (*Pinus* spp.) than now, but pure pine stands of any one species were probably rare. Local variations in composition occur continually, of course, due to such factors as fire, windstorms, cattle grazing, and cyclic increases in destructive insects. For example, cattle prefer soft-foliaged trees like ash (*Fraxinus* spp.), basswood (*Tilia americana*), and sugar maple (*Acer saccharum*), to oak, beech (*Fagus grandifolia*), chestnut, and elm (*Ulmus* spp). According to Baldwin (4), ash seems to be on the increase today in ungrazed forests.

In the pioneer period the first task of the settlers was to clear enough land for their buildings and crops. This was done largely by burning the forests. The woodashes were used in making soap or were left to enrich the soil.

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[1] A list of the common and scientific names of species mentioned in this bulletin is given in Part I of the Appendix.

[2] See the catena key in the Appendix, lines 0 to 32.

[3] *Ibid.* lines 33 to 41.

[4] *Ibid.* lines 46 to 49.

[5] *Ibid.* lines 42 to 45.

[6] *Ibid.* lines 50 to 52.

[7] *Ibid.* line 54.

"By 1818 the virgin forests had almost entirely disappeared. Reduction in the supply of wood for fuel was one of the causes leading to the abandonment of mining. In 1819 Connecticut still exported a considerable quantity of wood, timber for building and ship timber, but attention was being called to the depletion of the woodland and the need for restriction of waste. Economy was being used in the consumption of wood. Burning over woodlands for the sake of pasture had ceased; improvements in houses and fireplaces and the introduction of stoves decreased the quantity of wood required for fuel in the home. Suggestions were also made as to the best method of reforestation. But a steady demand for timber and, in later years, for railroad ties brought continued cutting of such virgin forests as still remained and of the woods which had grown up where cutting had taken place in previous years. In 1819 there were 406 sawmills in the State; in 1840 there were 673. In 1845 Connecticut was preparing for market about twenty-two million feet of lumber, 206,463 cords of firewood, over three million shingles, four million bushels of charcoal, and about five thousand cords of bark. Railroad ties were purchased for prices ranging from thirty cents to seventy-five cents apiece" (19).

The 1870 census revealed the beginning of a downward trend in the acreage of farmed land with a corresponding increase in woodland; this trend gained momentum after 1880. This change was brought about chiefly by the decline in the sheep and beef industries and the westward migrations of people (6, 9). The increase in industrial building, and shifts in population from farms to towns drew heavily on local lumber supplies. Cutting was generally selective, taking sawlog material and leaving younger stock. Through heavy cutting, basswood, black walnut (*Juglans nigra*), white ash (*Fraxinus americana*), and tulip-tree were greatly reduced in number. In 1877, in an address to the Connecticut Board of Agriculture, Brewer (6) stated that " . . . much of our land which paid well as agricultural land forty years ago, is now of *relatively* vastly less value, and I verily believe that we have much land in the State which would today be three, four, or even five times more valuable as *timber* land, than it is now as nominal 'cleared' or 'improved' land."

In the present century, four catastrophies have markedly influenced the forests by changing the stand composition or by reducing the amount of standing timber, or both. The chestnut blight disease (*Endothia parisitica* [Murr.] Ander. and Ander.), completely wiped out that species between 1911 and 1925. The 1938 hurricane[1] ruined many stands, particularly the older white pine forests; and the two world wars made serious inroads upon the merchantable wood supply.

At the present time woodland ownership may be grouped somewhat as follows:

(a) farm woodlots, generally grazed; many are clearcut periodically for posts and cordwood;

(b) privately owned woodland, generally not grazed; in some cases clearcut periodically, in other cases left untouched, with neither help nor hinderance by the owner aside from fire protection;

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[1] The 1944 hurricane was destructive in spots but, for the State as a whole, the damage was slight.

(c) woodlands maintained or plantations developed on watersheds to protect public water supplies, (these are usually handled by silvicultural methods to a greater or lesser degree);

(d) tracts owned by industrial concerns for present or future use which frequently involves clearcutting;

(e) recreational areas;

(f) state and town forests in which approved forestry practices are more or less followed.

Brushland is generally grazed. Where grazing is heavy, trees cannot get established and the land may remain in brush permanently. Otherwise, it gradually becomes stocked with trees.

SOIL AND HUMUS TYPES IN CONNECTICUT

Soil Classification

The upland soils of Connecticut belong to the Brown Podzolic great soil group. Formerly included with the Gray-Brown Podzolics (36), the soils of this State, together with a considerable portion of the coastal regions of Massachusetts, New Hampshire and Maine; the Connecticut River Valley extending well into Vermont and New Hampshire, and the extreme western section of Massachusetts and Vermont have recently been recognized (5) as a separate group called Brown Podzolic.

"Essentially the Brown Podzolic soil is an imperfectly developed Podzol having, in timbered areas, an organic mat on the surface and a very thin gray leached horizon just below it—usually less than an inch thick. The B horizon is largely yellowish brown in color and has only the beginnings of a dark-brown orterde just below the gray A horizon. The total depth of the solum is usually less than 30 inches although it exceeds that depth in places (48)."

The boundary line between Brown Podzolic (BP) and Podzol (Po) soils appears to be governed to a considerable degree by elevation (23), the Podzols occurring for the most part at altitudes in excess of 1,000 feet above sea level. In Connecticut it may be safer to raise that figure by 300 or 400 feet, as the occurrence of true Podzol profiles (in which the leached A_2 horizon equals or exceeds one inch in thickness) is limited to the high elevations, or to strictly local situations.

Contact between Brown Podzolic and Gray-Brown Podzolic (GB) soils has been observed on the Connecticut-New York border which is on the eastern edge of the Gray-Brown Podzolic area extending up the Hudson River Valley (23).

In most of the Brown Podzolic profiles in this State, no leached A_2 is visible. Where it does occur, it is light-gray or pinkish-gray in color and varies in thickness from a trace to ½ or ¾ inch. It is found in small discontinuous areas, generally less than an acre in size, in which the combination of vegetation cover and site and previous land use history are such as to favor its development.

Two areas are known, however, in which podzolization (to the degree just indicated) is rather general. These are: (a) the Pachaug State Forest and surrounding forested land in the towns of Voluntown, Griswold and North Stonington, located in the southeastern part of the State, and (b) certain portions of the Natchaug State Forest in the towns of Eastford and Pomfret, located in the northeastern section. Here, the development of the A_2 horizon is probably due to the low native fertility of the soil, and to stands containing a high proportion of scarlet oak (*Q. coccinea*) and black oak (*Q. velutina*) which produce a strongly acid litter that is slow to decompose (Figures 5 and 6).

Associated with the Brown Podzolic soils is the intrazonal group known as Hydromorphic soils. This group may be subdivided into the poorly drained Gray Hydromorphic (GH), the very poorly drained Half Bog (HB) and the Ground Water Podzols (GWP).[1]

In Gray Hydromorphic soils as found in Connecticut the surface soil is dark grayish-brown, over a grayish-yellow to yellowish-brown subsoil in which mottling begins at 8 to 12 inches and continues into the underlying substratum which is usually somewhat compact.

Half Bog soils have a very dark brown to grayish-black mucky or peaty surface soil, underlain by a gray mineral soil which may or may not contain mottling.

Ground Water Podzols vary considerably in profile characteristics. A small area in the Cockaponset State Forest, classified as Ridgebury stony fine sandy loam, has GWP characteristics in places. The 1 to 2-inch black, compact greasy H layer is underlain by a 1 to 2-inch dark grayish-brown A_1 on a 1½ to 2½-inch gray A_2, on yellow-brown strongly mottled[2] B which is compact at a depth of 28 inches. Only one soil series, Saugatuck, has been recognized in this State as a GWP (see line 42 in the catena key in the Appendix). This soil is described as one having a reddish-brown ortstein or hardpan layer at about 12 inches.

The total area of Hydromorphic soils in forests constitutes a relatively small proportion of the entire State. Timber stands on these soils contain a larger percentage of red maple (*Acer rubrum*), ash, basswood, tulip-tree, alder (*Alnus* spp.), and other moisture-tolerant species than do those on the better drained sites.

Organic or Bog soils (swamps), exclusive of tidal marshes, comprise about 3 per cent of the land area of the State (43), not all of which is forested. They consist of peaty or mucky material ranging from about six inches to many feet in thickness, underlain by gray mineral soil. Forest cover may consist of red maple, alder, southern white cedar (*Chamaecyparis thyoides*) and, in some cases, black spruce (*Picea mariana*).

Alluvial or bottomland soils are excellent for timber production but, because of their suitability for agriculture, only a very small proportion are left in forest.

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[1] Progress Report by the Committee on Great Soil Groups. U.S.D.A. Bur. Plant Ind., Soils, and Agric. Eng., Div. of Soil Survey, Beltsville, Md., August 13, 1947. Mimeographed.

[2] The mottled portion of a poorly drained profile is often referred to as the *glei* (or *gley*) horizon (10, 48, 54). When drainage is impeded by basin-like rock formations (as on the top of Meshomasic Mountain in the town of Portland), or by highly impervious substratum, the glei layer is the result of ground water action and may be designated as the "GG" horizon. On the other hand where surface water is the causative factor, e.g., seepage from higher ground, the glei is sometimes referred to as the "GT" horizon (10).

No areas in this State are known where soil development has been allowed to continue under natural vegetation without disturbance by man. All land has been cut over and, in many cases, burned over numerous times.

As previously indicated, climatic conditions are relatively uniform, and soil differences are due largely to geologic formation, topography and vegetation. The primary soil separations, based on origin of parent material, are as follows:

I. Upland soils derived from glacial till
II. Soils of the glaciofluvial deposits (glacial outwash plains and terraces)
III. Soils of the stream terrace deposits
IV. Soils of the glaciolacustrine deposits
V. Soils of the recent flood plain deposits
VI. Soils developed from windblown materials
VII. Organic soils
VIII. Miscellaneous soils

Differentiation into series within each of the above separations is based in part on the kind of rock or parent material, and in part on drainage class. A catena key for the entire State is given in the Appendix. It differs from the key given by Morgan (43) in Bulletin 423 in the following respects: first, a new drainage class, moderately well drained (formerly called imperfect), has been added; second, it contains a number of soil series not previously recognized in this State but which have been mapped elsewhere; third, a number of new series have been identified and added, and fourth, the key gives the most recent soil series names in those cases where the name has been changed to conform with those of the Soil Survey Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering of the U. S. Department of Agriculture.

Detailed descriptions of many of the soil series listed in the key are found in Bulletin 423 (43). Obviously, some of the descriptions must be altered to fit the revised catena key. As an example of a change in series name, the soil described in Bulletin 423 as Hollis is now known as Ansonia. The name Hollis is now applied to shallow Charlton and closely related schistose soils. The importance of soil depth over bedrock fully justifies its recognition by the use of separate series names for the shallow phases. This means that some areas previously identified as Brookfield, for example, should now be called Brimfield; shallow Gloucester should be called Shapleigh; shallow Cheshire is now Sunderland, and so on. This situation applies particularly to forested areas where the bedrock is frequently close to the surface. The limit for separation of shallow soils in this area has been set at 30 inches to bedrock.

Recent field observations have indicated that the proportion of Paxton in relation to Charlton is greater than formerly believed. This is true also of some of the other series having compact substrata.

Soil Texture

In general, Connecticut soils are relatively light textured, with fine sandy loams and loams predominating. Silty clay loams and clays are very limited in extent and are rarely forested. Textural differences between the A, B, and C horizons are generally small, as shown in the profile descriptions given in this bulletin.

The relative proportions of sand, silt, and clay which make up the various soil classes are given in Table 2. These differ somewhat from the proportions shown in Bulletin 423 (43), and except for minor variations, are in conformity with the designations of the Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering.[1]

TABLE 2. TEXTURAL CLASSIFICATION OF SOILS

(Percentages modified slightly from Committee Report of October 1947)

<table>
<tr><th rowspan="3">Texture Designations</th><th></th><th>V. coarse sand</th><th>Coarse sand</th><th>Medium sand</th><th>Fine sand</th><th>Very fine sand</th><th>Silt</th><th>Clay</th></tr>
<tr><th></th><th colspan="7">Size class diameter limits, mm.</th></tr>
<tr><th></th><th>2.0—1.0</th><th>1.0-.5</th><th>0.5—.25</th><th>0.25-.10</th><th>0.10—.05</th><th>0.05-.002</th><th><0.002</th></tr>
<tr><td>I. Sands</td><td></td><td colspan="7"></td></tr>
<tr><td>Coarse sand</td><td></td><td colspan="2">30+</td><td><25</td><td colspan="2"><50</td><td colspan="2"><10</td></tr>
<tr><td>Sand</td><td></td><td colspan="2">15-25</td><td>25+</td><td colspan="2"><50</td><td colspan="2"><10</td></tr>
<tr><td>Fine sand</td><td></td><td colspan="3"><30</td><td>50+</td><td><50</td><td colspan="2"><10</td></tr>
<tr><td>Very fine sand</td><td></td><td colspan="4"><50</td><td>50+</td><td colspan="2"><10</td></tr>
<tr><td>II. Loamy sands</td><td></td><td colspan="7"></td></tr>
<tr><td>Loamy coarse sand</td><td></td><td colspan="2">30+</td><td><25</td><td colspan="2"><50</td><td colspan="2">10-20</td></tr>
<tr><td>Loamy sand</td><td></td><td colspan="2">15-25</td><td>25+</td><td colspan="2"><50</td><td colspan="2">10-20</td></tr>
<tr><td>Loamy fine sand</td><td></td><td colspan="3"><30</td><td>50+</td><td><50</td><td colspan="2">10-20</td></tr>
<tr><td>Loamy v.f. sand</td><td></td><td colspan="3"><30</td><td></td><td>50+</td><td colspan="2">10-20</td></tr>
<tr><td>III. Sandy loams[1]</td><td></td><td colspan="5"></td><td colspan="2">20+</td></tr>
<tr><td rowspan="2">Coarse s. l.</td><td>(a)</td><td colspan="2">25+</td><td><25</td><td><50</td><td><50</td><td></td><td><20</td></tr>
<tr><td>(b)</td><td colspan="2">25+</td><td><25</td><td><50</td><td><50</td><td><50</td><td><10</td></tr>
<tr><td rowspan="2">Sandy loam</td><td>(a)</td><td colspan="2">15-25</td><td>25+</td><td colspan="2"><50</td><td></td><td><20</td></tr>
<tr><td>(b)</td><td colspan="2">15-25</td><td>25+</td><td colspan="2"><50</td><td><50</td><td><10</td></tr>
<tr><td rowspan="2">Fine s. l.</td><td>(a)</td><td colspan="3"><30</td><td>30+</td><td><30</td><td></td><td><20</td></tr>
<tr><td>(b)</td><td colspan="3"><30</td><td>30+</td><td><30</td><td><50</td><td><10</td></tr>
<tr><td rowspan="2">V. fine s. l.</td><td>(a)</td><td colspan="3">2+</td><td colspan="2">50 + (c)</td><td></td><td><20</td></tr>
<tr><td>(b)</td><td colspan="3"><2</td><td colspan="2">50-52 (c)</td><td><50</td><td><10</td></tr>
<tr><td>IV. Loam</td><td></td><td colspan="5"><52</td><td>28-50</td><td>10-27</td></tr>
<tr><td>V. Silt loam</td><td></td><td colspan="2"></td><td colspan="3"><25</td><td>50+</td><td>0-27</td></tr>
<tr><td>VI. Sandy clay loam</td><td></td><td colspan="5">45+</td><td><28</td><td>20-35</td></tr>
<tr><td>VII. Clay loam</td><td></td><td colspan="5">20-45</td><td></td><td>27-40</td></tr>
<tr><td>VIII. Silty clay loam</td><td></td><td colspan="5"><20</td><td></td><td>27-40</td></tr>
<tr><td>IX. Sandy clay</td><td></td><td colspan="5">45+</td><td></td><td>35+</td></tr>
<tr><td>X. Silty clay</td><td></td><td colspan="5"><20</td><td>40+</td><td>40+</td></tr>
<tr><td>XI. Clay</td><td></td><td colspan="5"><45</td><td><40</td><td>40+</td></tr>
</table>

[1] All sandy loams contain 20% or more silt and clay.

(a) Total sands 52-80%.
(b) Total sands < 52%.
(c) Very fine sand 30+%.

Note: The + sign is used instead of the usual > to avoid confusion with the "less than" symbol <.

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[1] Report of the Committee on Soil Texture, Division of Soil Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md. October 13, 1947. Mimeographed.

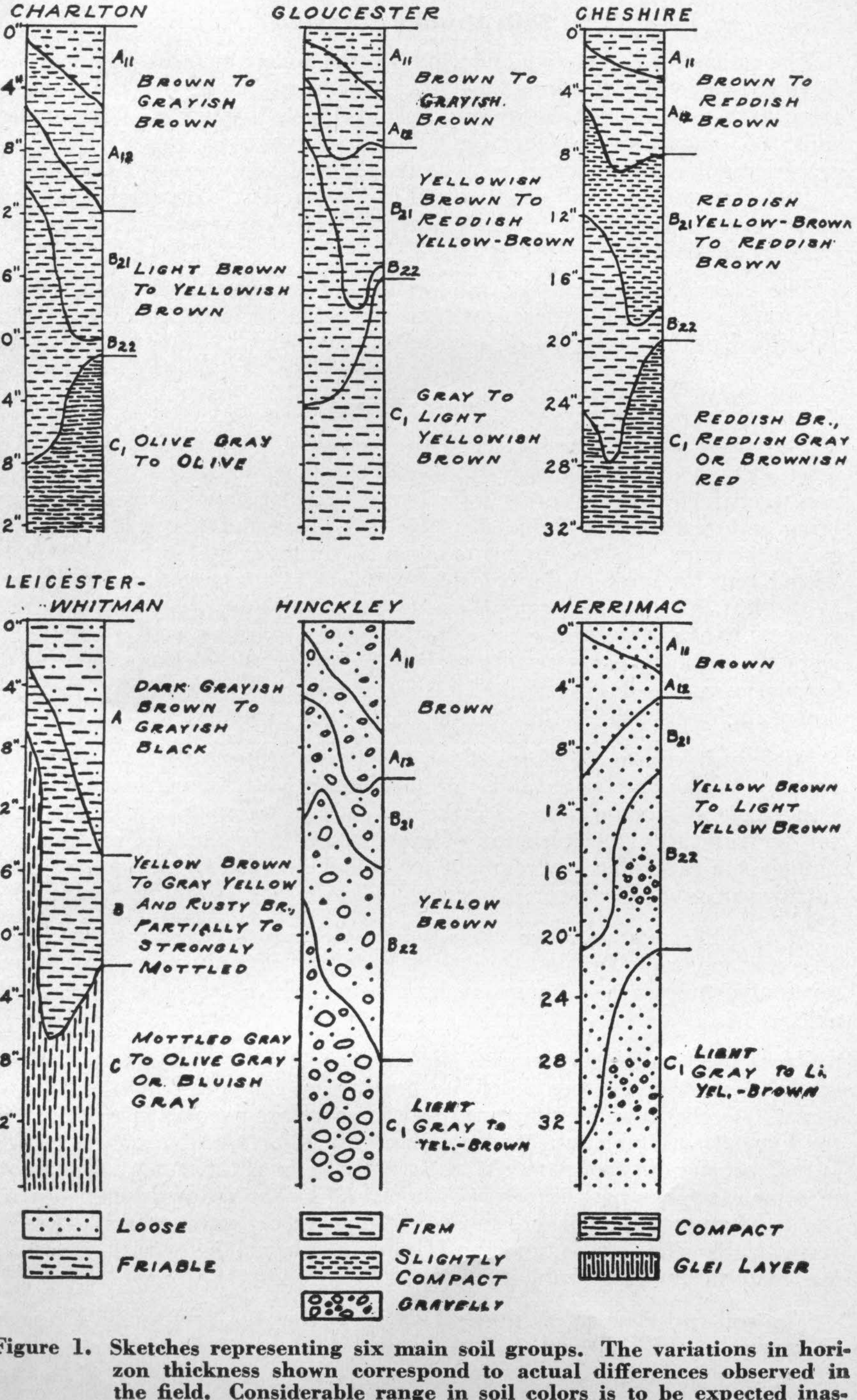

Figure 1. Sketches representing six main soil groups. The variations in horizon thickness shown correspond to actual differences observed in the field. Considerable range in soil colors is to be expected inasmuch as each profile represents more than one soil series.

Soils Usually Forested

The catena key (Appendix) includes some soils which ordinarily are not forested. Generally speaking, the soils most likely to be found in forested areas are: (a) the non-calcareous uplands, including most of the shallow soils; (b) those outwash terraces which are excessively sandy or gravelly, or of irregular topography; (c) the poorly and very poorly drained areas of both (a) and (b) and of other soil groups, and (d) organic soils (peats and mucks). Nearly all of the calcareous soils are used for agricultural crop production.

The characteristics of six soil series, shown graphically in Figure 1, illustrate some of the differences between series. A detailed description of individual profiles is given on pages 21-26.

Humus Types

The presence on the surface of an organic layer consisting of forest litter (leaves or needles, twigs and bark) in various stages of decomposition is characteristic of forest soils in northern latitudes. This humus covering or forest floor is an indispensible link in the nutrient cycle, inasmuch as a large portion of the nutrients taken up by the roots, estimated at 65 to 85 per cent for some of the principal species (11), are returned to the soil in the leaf fall. As this organic matter decays, the nutrients are gradually released in available form for use by the roots. Anything that retards or arrests the decay process results in a tying up of these materials, and the humus is said to be inactivated. Contrawise, the more rapidly it breaks down, the more quickly the nutrients are made available.

As is well known, the forest floor effectively protects the soil from compaction by beating rains and, by facilitating absorption, lessens runoff. Other benefits accrue from its presence, such as its modifying influence on soil temperatures, the lessening of evaporation from the soil, and the providing of a favorable environment for soil fauna which includes, not only earthworms and the larger insects, but also countless minute organisms.

Thus, while retarded decay results in an accumulation of inactive humus, an extremely rapid breakdown would leave the soil unprotected for a large portion of the year. A happy medium between the two extremes is desirable.

From the foregoing comments, it is obvious that the amount and quality of this humus cover has a definite bearing on growing conditions in the forest. Its character is influenced by the species composition of the stand, the kind of soil, moisture conditions and other factors of the environment. It may consist of three parts: L, the freshly fallen litter which is transitory, in some cases having completely disappeared by the following midsummer; the F (fermentation) layer, consisting of partially decomposed litter still recognizable as to origin, and the H (humus) layer, being dark, structureless material unrecognizable as to origin.

The soil surveyor refers to the L layer as the A_{00}, and to the F and/or H layers as the A_{01} and A_{02} respectively. These separations are shown graphically in Figure 2.

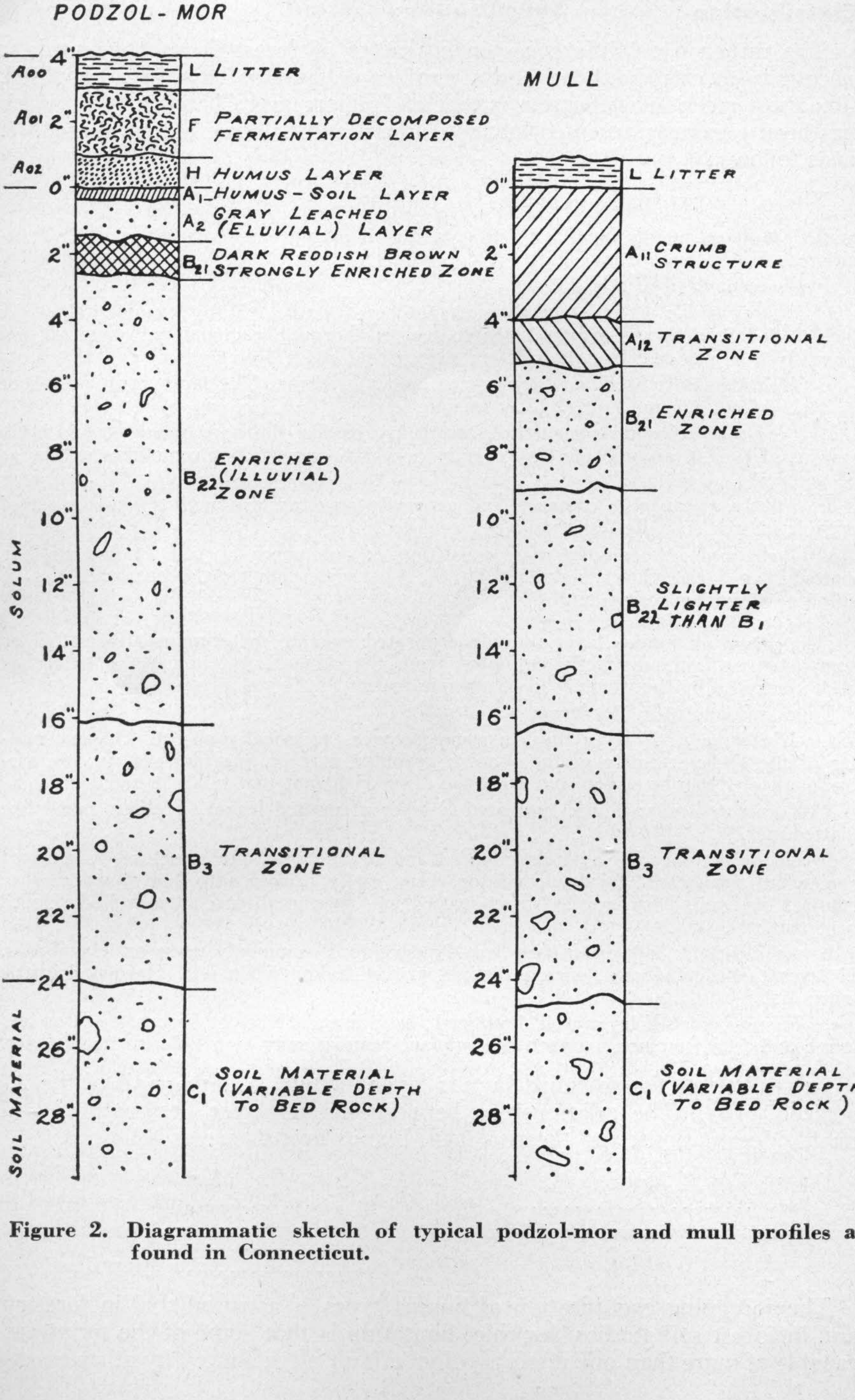

Figure 2. Diagrammatic sketch of typical podzol-mor and mull profiles as found in Connecticut.

Classification

The rather wide differences in character of forest floors have made it necessary to classify them, and a number of systems have been proposed. The most recent classification is that of Heiberg and Chandler (16) which has been generally accepted in this country and to some extent abroad. It is as follows:

There are two main groups: I—Mull, and II—Mor.

(I) **Mull:** A humus layer consisting of mixed organic and mineral matter. Transition to lower horizon not sharp.

Types recognized in this group:

a. *Coarse mull*: Coarse crumb or granular structure. Many granules about $\frac{1}{8}$ inch (2.0-3.0 mm.) or larger. Organic matter thoroughly mixed with mineral soil (usually 5-20 per cent organic matter; exceptional cases even higher).

b. *Medium mull*: Medium crumb or granular structure. The larger granules about $\frac{1}{16}$ inch (about 2.0 mm.) or slightly smaller.

c. *Fine mull*: Granular structure, frequently having the appearance of fine black sawdust. Rich in organic matter (usually over 50 per cent, but sometimes as low as 30 per cent).

d. *Firm mull*: Dense, compact, and generally structureless, with a low content of organic matter (usually less than 5 per cent).

e. *Twin mull*: A complex type consisting of one upper horizon of fine mull or matted mor (see below) underlain by an A_1 horizon having the characteristics of either medium or coarse mull.

(II) **Mor:** A humus layer of unincorporated organic material usually matted or compacted or both, distinctly delimited from the mineral soil unless the latter has been blackened by the washing in of organic matter.

Types recognized in this group:

a. *Matted mor*: F layer thin, in some instances practically absent. Organic matter of the H layer finely granular as in granular mor or fine mull; when dry, virtually all of it can be shaken out from the dense root mat that holds it together.

b. *Laminated mor*: Thick laminated F layer of matted leaves. H layer much like matted mor.

c. *Granular mor*: H layer pronounced and of fine granular structure, lower part somewhat compacted. In dry condition, very easily broken into fine powder when crushed by hand. Distinguished from matted mor by the absence of a well developed root mat.

d. *Greasy mor*: F layer usually weakly developed, commonly more or less fibrous. H layer thick, compacted, with a distinct greasy feeling when wet. Hard and brittle when dry.

e. *Fibrous mor*: F layer well developed; both F and H layers fibrous, more or less tough and felty, but not compact. Many plant remains may be visible in the H layer.

In mull types the so-called humus layer includes a part or all of the A_1 horizon (16). The relationships between humus layer designations, soil profile designations, and the two main humus groups are as follows:

Mull		*Mor*	
A_{00}	L	A_{00}	L
A_{11}	A_{11}	A_{01}	F
		A_{02}	H
		A_{11}	Mineral soil

The foregoing classification of humus types is a useful tool in forestry and in forest soil studies. Its chief limitation is that some of the terms are capable of more than one interpretation, a fault often shared by other classification schemes. Fibrous mor, for example, does not always mean the same thing to different individuals. The term "granular structure" as applied to the forest floor may connote several different meanings.

Some foresters recognize only three mor types—granular, greasy, and fibrous, the latter including both matted and laminated mors. Not all workers would agree on such a grouping nor would all agree on what constitutes a granular mor and what is meant by fibrous. Obviously, there is still room for improvement in this branch of forest soil science.

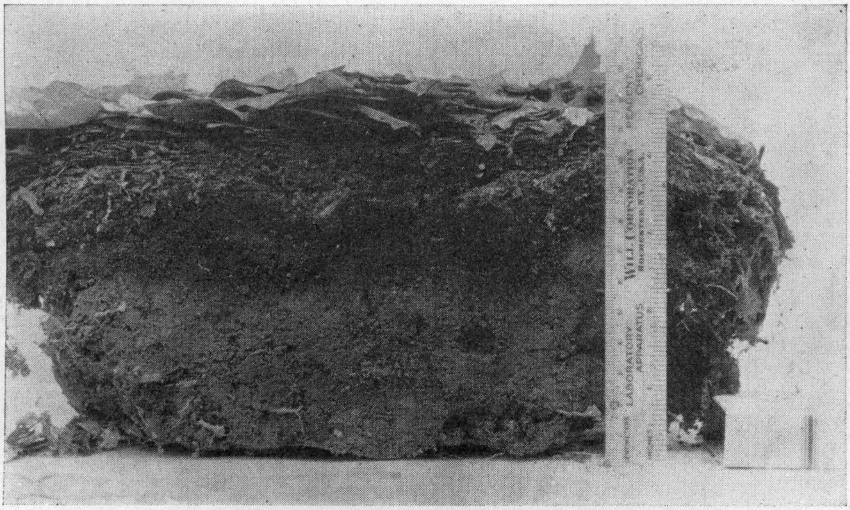

Figure 3. The top five inches of a laminated mor profile under a slow-growing stand of scarlet and chestnut oak. Gloucester stony fine sandy loam.

The types found in Connecticut occur in approximately the following decreasing order of prevalence: granular mor, laminated mor, matted mor, coarse and medium mull, firm mull, fibrous mor, fine mull and twin mull. A form of greasy mor may be found occasionally under old hemlock stands.

Where a definite leached gray layer occurs, it may be associated with any of the mors but most often with fibrous mor. Characteristic mor and mull humus types are illustrated in Figures 2, 3 and 4.

Detailed Descriptions of Representative Forest Soil Profiles

By far the larger proportion of the profiles sampled in this investigation were in the upland group, and consisted chiefly of the following series: Gloucester, Killingworth, Brookfield, Cheshire, Wethersfield, Charlton, Haddam, and Woodbridge, and their shallow counterparts, in approximately that order, Gloucester being in greatest number. Since most of the field observations were made prior to the introduction into Connecticut of new

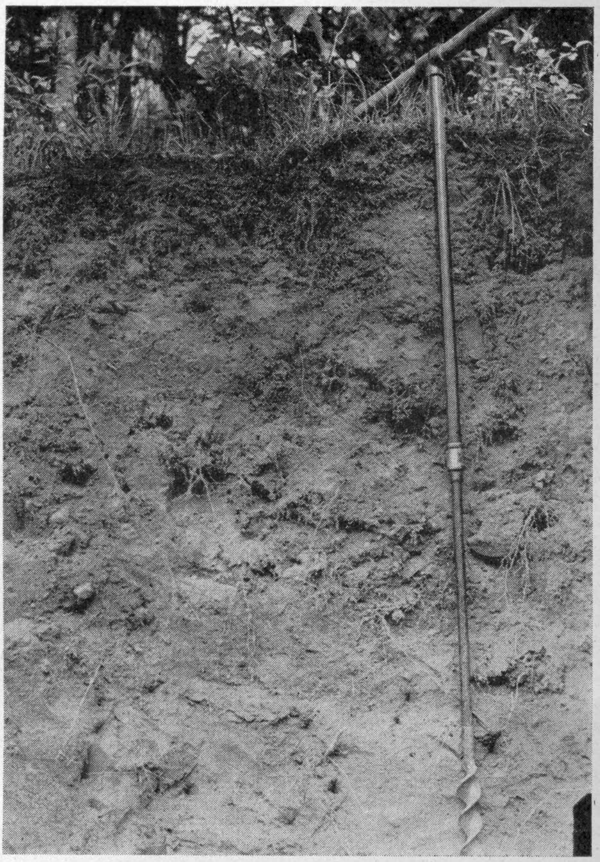

Figure 4. An excellent mull profile with practically no horizonal differentiation. Merrimac fine sandy loam, Simsbury.

series names for shallow soils, it is not possible to separate the soils on that basis except where shallowness is specifically indicated.

Previous experience (18, 28), confirmed by more recent observations, indicates that any attempt to evaluate forest sites on the basis of *individual soil series* is likely to fail. For example, differences between Gloucester, Killingworth, and Brookfield fine sandy loams are not sufficiently great ordinarily to affect the character and growth of forest stands. This is particularly true where other factors, such as topography, density of the stand, previous silvicultural practices and fire, exert proportionately greater influence than do the differences between these three soils.

On the other hand, the more pronounced differences between soils, whether in texture, or in other profile characteristics, or in native fertility, are likely to be reflected in the character of the stand. Variations in moisture (drainage) are particularly significant. The original compilation of the analytical data obtained in this work, therefore, was made on the basis of soil series groups.[1] A portion of these findings are presented in a later section.

Another method is to group by character of the humus layer. It was observed that the two main types, mor and mull, were well represented among the profiles examined, and in addition there were mor types in which the profile contained a well-defined podzol A_2 layer. In view of the rather limited number of profiles in certain soil series for which data had been obtained, it seemed preferable in the present instance to use these main humus types as the primary basis of grouping. Detailed descriptions are presented, therefore, of 12 profiles of the following humus types, all of which are Brown Podzolic soils:

Podzol-mor—Mor humus types with an underlying A_2 horizon (3 profiles)
Mor—Mor humus types without the A_2 horizon (6 profiles)
Mull—(3 profiles)

No pretense is made that these profiles are statistically average or representative of the types illustrated, but observations in the field, and study of the analytical data indicate that they represent reasonably well the field conditions. All are well-drained to moderately well-drained upland till soils. Although the freshly fallen litter was sampled in most cases, no reference to it is given in the detailed descriptions which follow.

Podzol-mor Profiles

51. Pachaug State Forest, Voluntown, Stone Hill Block No. 1.

Lab. Nos. F593-8. Sampled Oct. 10, 1938.

Forest Cover: Black oak, scarlet oak and white oak (*Q. alba*), with a small proportion of other hardwoods.

Lesser Vegetation: Blueberry (*Vaccinium* spp.), huckleberry (*Gaylussacia baccata*), and black cherry (*Prunus serotina*).

Soil: Gloucester stony[2] fine sandy loam. Well drained. Gently undulating. Granular to fibrous mor humus type.

F:	¼ in.	Loose.
H-A_1:	¾ in.	Dark brown; granular to fibrous.
A_2:	0-1 in.	Gray to brownish-gray, granular, friable, f.s.l.[3]
B_{21}:	1-11 in.	Yellowish-brown, granular, firm, f.s.l.
B_{22}:	11-23 in.	Light yellowish-brown, granular, firm, f.s.l.
C_1:	23 in.+	Gray to grayish-yellowish-brown, fragmental, firm, f.s.l.

52. Pachaug State Forest, Voluntown, Little Buck Road.

Lab. Nos. F598a-604. Sampled Oct. 10, 1938.

Forest and Lesser Vegetation: Similar to profile 51.

Soil: Gloucester stony fine sandy loam. Well drained. Gently undulating. Granular to fibrous mor.

F:	½ in.	Rather loose.
H:	1 in.	Dark brown, granular to fibrous.
A_2:	0-1½ in.	Gray to brownish-gray, granular, friable, f.s.l.

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[1] The soil series groups so recognized are: (a) well-drained upland till soils with a friable substratum (represented by Gloucester series); (b) well-drained upland till soils with a firm to compact substratum (Charlton-Paxton); (c) reddish, well-drained upland till soils derived from Triassic red sandstone and shale till with a firm to compact substratum (Cheshire-Wethersfield); (d) poorly-drained upland soils (Leicester); (e) excessively drained glaciofluvial deposits—gravelly knolls and ridges (Hinckley); (f) well-drained glaciofluvial deposits—sandy terraces (Merrimac); (g) well-drained soils derived from diabase (traprock) parent material (Holyoke), and (h) well-drained soils derived from limestone (Dover).

[2] Includes both stony and very stony types. In some instances boulders are present also. At the time these descriptions were recorded, the more recent separations into stony, very stony, bouldery and very bouldery types had not been set up.

[3] Fine sandy loam.

B_{21}: 1½-7 in. Yellowish-brown, but slightly reddish just below the A_2; granular, firm, f.s.l.
B_{22}: 7-21 in. Light yellowish-brown, granular, firm, f.s.l.
C_1: 21 in.+ Grayish-brown to yellowish-brown, granular, firm, f.s.l.

87. Pachaug Forest, Voluntown, Plainfield Compartment 10.

Lab. Nos. F895-901. Sampled Nov. 27, 1941.

Forest and Lesser Vegetation: Similar to profile 51.

Soil: Gloucester stony fine sandy loam. Well drained. Gently undulating. Fibrous to matted mor humus type.

F: ½ in.± Matted, moderately decomposed.
H: 1½ in. Dark brown to black fibrous to slightly granular.
A_2-B_1: 0-4 in. Upper portion brownish-gray, lower portion dark yellowish-brown, granular, friable, loam.
B_{21}: 4-12 in. Medium yellowish-brown, granular, firm, loam.
B_{22}: 12-28 in. Light yellowish-brown, granular, firm, loam.
C_1: 28 in.+ Brownish-gray to gray, fragmental, firm to slightly compact, loamy fine sand.

In this profile separate sampling of the B_1 was not practicable. There was some evidence of a plow layer still present.

The profile shown in Figure 5 is similar to the three soils just described. Figure 6 shows a typical stand in the Pachaug State Forest.

Mor Profiles

50. Maltby Lakes, West Haven (former site of lysimeters under hardwoods) (31).

Lab. Nos. F547-553. Sampled March 29, 1938.

Forest Cover: Black birch (*Betula lenta*) and red oak (*Q. borealis*) up to 15 inches DBH, 55-60 years old; sugar maple, dogwood (*Cornus* spp.), red maple, white oak.

Figure 5. Podzolized profile of Gloucester fine sandy loam. Pachaug State Forest, Voluntown, Connecticut.

Figure 6. An unprofitable stand of scarlet, white and black oaks with a heavy ground cover of vaccinium, hazelnut, and shadbush. Gloucester fine sandy loam, Voluntown.

Lesser Vegetation: Arrow-wood (*Viburnam acerifolium*), chestnut sprouts, pinxter flower (*Rhododendron nudiflorum*), blueberry, wild sarsaparilla (*Aralia nudicaulis*).

Soil: Grafton stony loam. Well drained, nearly level to gentle slope to west. Fibrous mor humus type.

F: ½ in. Rather loose, normal decomposition.
H: ½ in. Black, felty, fibrous.
A_{11}: 0-1½ in. Very dark brown, finely granular, friable, loam.
A_{12}: 1½-4 in. Brown, finely granular, friable, loam.
B_{21}: 4-13 in. Yellowish-brown, somewhat granular, firm, f.s.l.
B_{22}: 13-31 in. Reddish-yellow-brown, somewhat granular, firm, f.s.l.
C_1: 31 in.+ Reddish-to-yellowish-brown, moderately compact, f.s.l.

In the C_1 there were occasional zones of iron accumulation in root channels and cracks.

53. Meshomasic State Forest, Portland. Cabin Lot.

Lab. Nos. F605-612. Sampled Oct. 28, 1938.

Forest Cover: Black birch, white oak, red oak, black oak, up to 10 inches DBH; hickory (*Carya* spp.), sugar maple, red maple, beech, chestnut oak (*Q. montana*), yellow birch (*Betula lutea*).

Lesser Vegetation: Blueberry, huckleberry, wild sarsparilla, Canada May flower (*Maianthemum canadense*), dewberry (*Rubus hispidus*), witch-hazel (*Hamamelis virginiana*).

Soil: Haddam stony fine sandy loam. Well drained, gentle slope. N. to N.W. Granular mor humus type.

F: ½ in. Slightly matted, moderate decomposition.
H-A_1: ¾ in. Very dark brown to black, granular to slightly fibrous.

A_{12}:	0-¾ in.	Dark grayish-brown, slightly granular, firm, f.s.l.
B_{21}:	¾-2 in.	Reddish to yellowish-brown, slightly granular, firm, f.s.l.
B_{22}:	2-12 in.	Yellowish-brown, slightly granular, firm, f.s.l.
B_3:	12-21 in.	Yellowish-brown with slight pinkish cast, slightly granular, dense, f.s.l.
C_1:	21 in.+	Pinkish to brownish-gray to gray, somewhat granular, compact, sandy loam.

64. Natchaug State Forest, Eastford, Compartment 19. (Growth Study Plots 516-517).

Lab Nos. F738-746. Sampled Oct. 30, 1941.

Forest Cover: Mixed hardwoods, principally the common oaks.

Lesser Vegetation: Practically none. Some grass in the more open areas.

Soil: Acton stony fine sandy loam. Moderately well drained, practically level. Granular mor humus type.

F:	½ in.	Slightly matted.
H:	¾ in.	Nearly black, well decomposed, granular with some tendency toward a root mor.
A_{11}:	0-½ in.	Very dark brown to black, crumb, mellow, f.s.l.
A_{12}:	½-2 in.	Dark brown, crumb, mellow, f.s.l.
B_{21}:	2-8 in.	Dark yellowish-brown to reddish-brown, slightly granular, firm, f.s.l.
B_{22}:	8-26 in.	Yellowish-brown, mottled in places, slightly granular, firm, loamy sand.
C_1:	26 in.+	Grayish-brown to yellowish-gray, somewhat mottled, slightly compact l.s.

The soil on these plots was quite variable. A thin grayish black A_2 was found in places. In others the A_{12} was 5 to 6 in. thick.

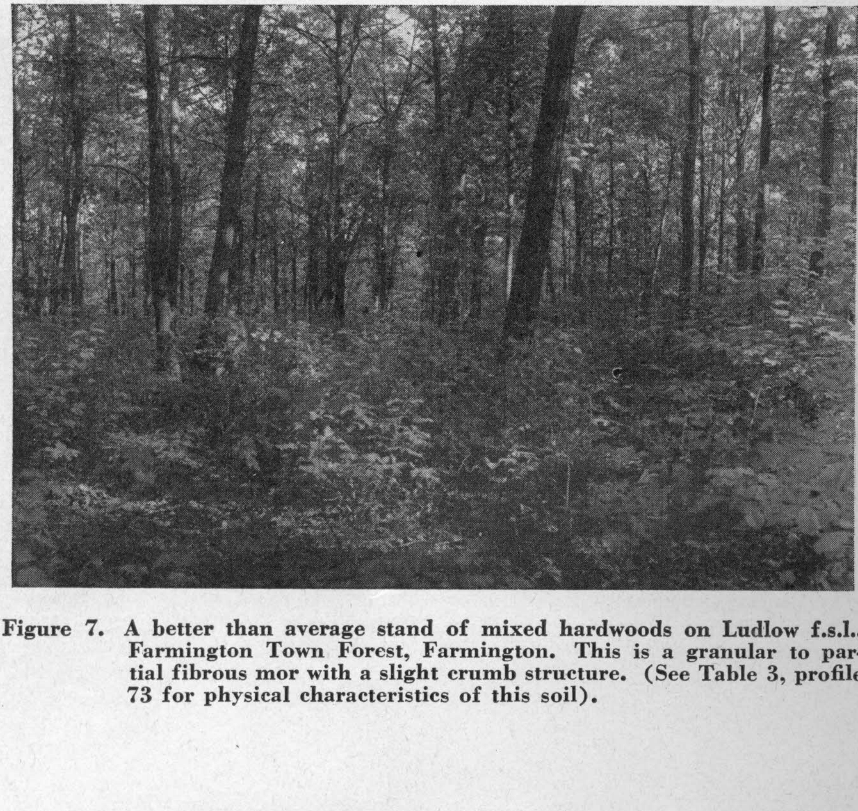

Figure 7. A better than average stand of mixed hardwoods on Ludlow f.s.l., Farmington Town Forest, Farmington. This is a granular to partial fibrous mor with a slight crumb structure. (See Table 3, profile 73 for physical characteristics of this soil).

73. Farmington Town Forest, Farmington. (Figure 7)

Lab. Nos. F806-812. Sampled Nov. 19, 1941.

Forest Cover: Mixed hardwoods, principally black, white and red oaks, with occasional beech.

Lesser Vegetation: Oak and maple reproduction, some clumps of mountain laurel (*Kalmia latifolia*), bracken fern (*Pteridium latiusculum*).

Soil: Ludlow fine sandy loam. Moderately well drained; level upland. Granular to slightly fibrous mor humus type.

F:	¼ in.	Normal, matted.
H:	½ in.	Granular to slightly fibrous mor.
A:	0-4 in.	Brown, crumby, mellow loam.
B_{21}:	4-13 in.	Yellowish-brown with a slight reddish cast, granular, firm loam.
B_{22}:	13-22 in.	Lighter yellowish-brown, fragmental, firm, loam.
C_1:	22 in.+	Brownish-red, somewhat mottled, fragmental, compact, loamy sand.

81. Cockaponset State Forest, Haddam. (Growth Study Plot 123).

Lab. Nos. F860-866. Sampled Nov. 24, 1941.

Forest Cover: Mixed hardwoods.

Lesser Vegetation: Not recorded.

Soil: Killingworth stony loam. Well drained. Level to moderate slope. (Only the level portion was sampled). Fibrous mor humus type.

F:	½ in.±	Slightly matted.
H:	1 in.±	Firm, gray, felty.
A:	0-3 in.	Dark reddish-yellow-brown, granular, friable loam.
B_{21}:	3-12 in.	Reddish-yellow-brown, granular, friable "gritty" f.s.l. to loam.
B_{22}:	12-30 in.	Yellowish-brown, granular, firm "gritty" f.s.l.
C_1:	30 in.+	Yellowish-gray to gray, granular, slightly compact f.s.l.

86. Tunxis State Forest, Hartland. (Hardwood Weeding Plot 1723).

Lab. Nos. F888-894. Sampled Nov. 26, 1941.

Forest Cover: Black birch, white birch (*Betula papyrifera*), red maple, hemlock and white ash, with some beech (*Fagus grandifolia*), fire cherry (*Prunus pennsylvanica*), basswood (*Tilia americana*), yellow birch (*Betula lutea*) and occasional other species.

Lesser Vegetation: Very light. Species not listed.

Soil: Paxton stony loam. Well drained; fairly steep, uniform slope W. to N. W. Matted mor humus type.

F:	¼ in.	Slightly matted.
H:	½ in.	Somewhat granular.
A:	0-3 in.	Dark brown to black, granular, mellow, loam.
B_{21}:	3-8 in.	Reddish-yellow-brown, granular, firm, loam.
B_{22}:	8-18 in.	Yellowish-brown, weakly granular, firm to slightly compact, loam.
C_1:	18 in.+	Olive yellow-brown, slightly platy, very compact, loamy sand.

This soil exhibited considerable variation in the consistence of the B and C_1 horizons.

Mull Profiles

54. Mt. Higby Reservoir, Middlefield.

Lab. Nos. F613-619. Sampled Nov. 8, 1938.

Forest Cover: Red oak (a 5 x 5 plantation planted in 1913).

Lesser Vegetation: Occasional black cherry

Soil: Cheshire loam. Well drained; slight slope west. Mull humus type.

F:	¼ in.	Loose, rather rapid decomposition.
A_{11}:	0-¾ in.	Dark brown, crumb, mellow, loam.
A_{12}:	¾-6 in.	Light yellowish-brown with slight reddish cast, finely granular, mellow to friable, loam.
B_{21}:	6-12 in.	Light reddish-brown, coarsely granular, firm, loam.
B_{22}:	12-19 in.	Reddish-yellow-brown, coarsely granular, firm, loam.
C_1:	19 in.+	Light reddish-brown to reddish-gray, slightly compact, loam.

63. Housatonic State Forest, Sharon. Sharon Mt. Block. (Growth Study Plot 210).

Lab. Nos. F730-737. Sampled Oct. 27, 1941.

Forest Cover: Aspen (*Populus* spp.), red maple, white oak and chestnut oak, with some red oak, scarlet oak and hickory (*Carya* spp.), and occasional white ash, white birch, tulip tree and black oak.

Lesser Vegetation: Very light. Species not listed.

Soil: Gloucester stony fine sandy loam. Well drained; moderate east slope. Twin mull humus type.

F: ½ in. Normal.
H: ½ in.± Slightly matted mor, with rather high admixture of mineral soil.
A_{11}: 0-2 in. Dark reddish-brown, crumb, mellow, f.s.l.
A_{12}: 2-7 in. Reddish-yellow-brown, crumb, mellow, f.s.l.
B_{21}: 7-15 in. Yellowish-brown, granular, firm, sandy loam.
B_{22}: 15-24 in. Lighter yellowish-brown, granular, firm, sandy loam.
C_1: 24 in.+ Grayish-yellow-brown, granular, slightly compact, sandy loam.

75. Meshomasic State Forest, Portland. (Stevens Plot 1804).

Lab. Nos. F818-824. Sampled Nov. 19, 1941.

Forest Cover: Red pine and white pine (plantation), with scattered hardwoods in the openings.

Lesser Vegetation: Practically none.

Soil: Killingworth very stony fine sandy loam. Well drained, but subject to seepage from higher ground, especially in the center. At foot of long gentle east slope. Twin mull humus type.

F: 1 in. Moderately rapid decomposition.
A_{11}: 0-4 in. Brown to grayish-black, firm to crumb mull (variable), mellow, f.s.l. In the lower wetter portions of the plot the A_{11} is 6 inches thick and consists of a very mellow, crumb mull.
A_{12}: 4-8 in. Light brown, crumb, friable, f.s.l.
B_{21}: 8-17 in. Yellowish-brown, granular, firm, gravelly f.s.l.
B_{22}: 17-23 in. Yellowish-brown, slightly granular, firm, sandy loam.
C_1: 23 in.+ Light pinkish-brown, structureless, firm, fine sand.

Summary of Profiles Described

Podzol-Mor
51 Gloucester stony, fine, sandy loam. Pachaug State Forest, Voluntown.
52 Gloucester stony, fine, sandy loam. Pachaug State Forest, Voluntown.
87 Gloucester stony, fine, sandy loam. Pachaug State Forest, Voluntown.

Mor
50 Grafton stony loam. West Haven.
53 Haddam stony, fine, sandy loam. Meshomasic State Forest, Portland.
64 Acton stony, fine, sandy loam. Natchaug State Forest, Eastford.
73 Ludlow fine, sandy loam. Farmington Town Forest, Farmington.
81 Killingworth stony loam. Cockaponset State Forest, Haddam.
86 Paxton stony loam. Tunxis State Forest, Hartland.

Mull
54 Cheshire loam. Mt. Higby Reservoir, Middlefield.
63 Gloucester stony, fine, sandy loam. Housatonic State Forest, Sharon.
75 Killingworth very stony, fine, sandy loam. Meshomasic State Forest, Portland.

The soil character in relation to geologic formation and topography, and the accompanying forest cover are shown in the diagrammatic sketch, Figure 8, which portrays an idealized cross-section of the State, north of Hartford and extending about 12 miles on each side of the Connecticut River. The vertical scale, of course, is greatly exaggerated relative to the horizontal scale.

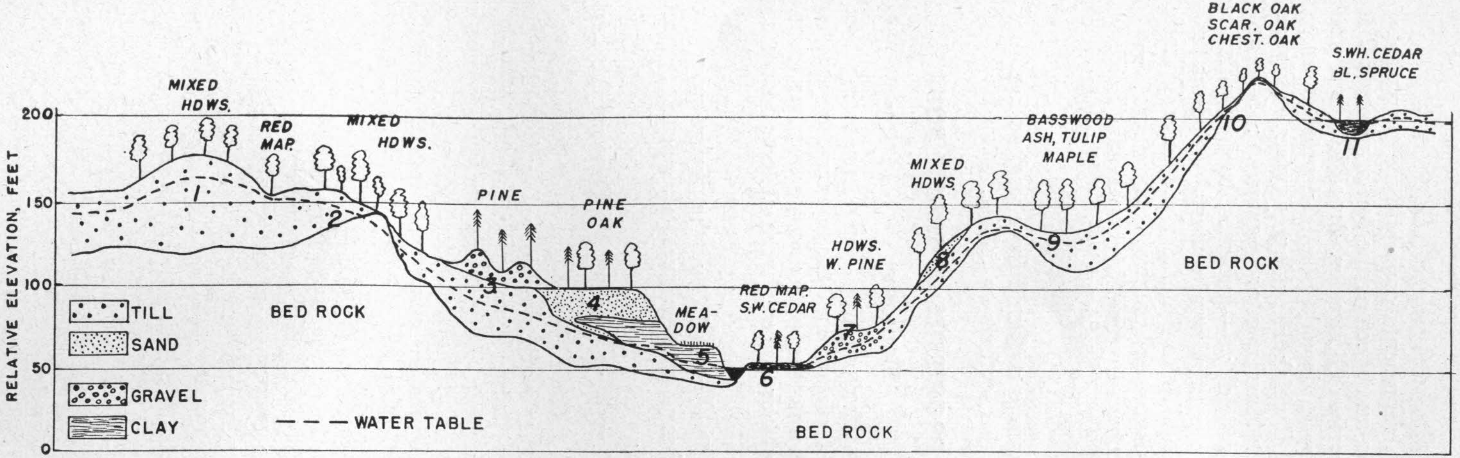

Figure 8. Idealized cross-section to show the association of forest composition and tree size with topography, soil character and depth, and water table. The horizontal distance should be considered at about 25 miles.

Soil series represented are as follows:

1. Charlton; 2. Brookfield or Gloucester; 3. Hinckley; 4. Merrimac; 5. Suffield (lacustrine deposits of silt and clay); 6. Podunk (a rather poorly drained bottomland soil developed from recent alluvial material); 7. Manchester; 8. Enfield (wind deposited); 9. Leicester; 10. Shapleigh; 11. Peat or Muck, and Whitman (very poorly drained upland soil).

Position 1 on the sketch represents drumlin-type topography on which occur such soils as Charlton and Paxton; the soil at position 2 is shallower and more friable, and comprises Gloucester, Brookfield and similar upland till soils; at 3 are the loose, droughty soils developed on glaciofluvial ice-contact drift deposits, of which Hinckley is typical (Figure 18); 4—level terrace sandy soils (Merrimac or Agawam); 5—level lacustrine deposits of silt and clay (Suffield); 6—imperfect to poorly drained bottomland soils developed from recent alluvial material (Podunk); 7—gravelly knoll type of topography, similar to 3 but derived from Triassic materials (Manchester); 8—wind deposited material (Enfield); 9—a depression kept moist by seepage from adjoining higher land (Leicester); 10—a shallow Gloucester type of soil (Shapleigh), and 11—swamp or Bog and Half Bog soils.

Laboratory studies of samples collected from various localities constitute the material presented in the sections to follow.

PHYSICAL PROPERTIES OF FOREST SOILS

Methods

Weight of forest floor. A hollow, iron square measuring 12 x 12 inches was held firmly on the soil surface and the square foot area cut through with a knife. The material was then placed in a paper bag, oven dried and weighed. Usually three or four squares were collected from each plot or area.

Mechanical analyses. Determined by the hydrometer method of Bouyoucos[1]. Separation of sand particle sizes, where such separations were made, was done by sieving.

Moisture equivalent. Centrifuge method, following the technique of Veihmeyer et al.[2]

Volume weight. The earlier work was carried on by either the cylinder method as recommended by Burger[3], or by the paraffin-immersion method described by Shaw[4]. The data in Table 6 and all other recent determinations were made by means of 250-ml brass cylinders (2⅛ inches long by 3 inches in diameter) held in a sampling tool similar, except in size, to the one described by Coile[5]. A numbered series of 24 cylinders with individual lids was available for this work.

Porosity, water-holding capacity, and field air capacity. All three were determined on the same 250-ml sample used in volume weight measurements. Porosity $= \frac{\text{Specific gravity} - \text{Volume weight}}{\text{Specific gravity}}$. Field air capacity $=$ porosity – field moisture content.

Specific gravity. Pycnometer method (34, p. 236).

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[1] J. Am. Soc. Agron. 22:746-750, 1930.
[2] Proc. First Internatl. Cong. Soil Sci. Washington 1:512-534, 1927.
[3] Physikalische Eigenschaften der Wald-und Freilanböden, Zürich, 1923.
[4] J. Am. Soc. Agron. 9:38-42, 1917.
[5] Soil Science 42:139-142, 1936.

Aggregate analysis. The wet sieve method was used in which water rises and falls in a nest of stationary sieves. The apparatus[1] consists of a nest of five brass sieves with round holes whose diameters are 5, 3, 2, 1 and 0.5 mm., respectively, from top to bottom. The base of the nest was equipped with a ¼-inch inlet tube and a 1-inch outlet, the latter connected by pipe and rubber tubing to a siphon made of ¾-inch glass tubing. Wide rubber bands cut from an old inner tube of an automobile tire served to prevent leakage at the junctions between sieves. With proper adjustment of the rate of inflow, the water rises almost to the top of the top sieve and then automatically runs out very rapidly through the siphon. This process is repeated about three times a minute.

A sample of fresh soil equivalent to 50 grams air-dry weight is placed in a beaker of water and allowed to slack about two hours. With the apparatus in operation and properly adjusted, the sample is transferred to the top sieve and subjected to the action of the water until the outflowing water is free of suspended matter,—usually a period of four to eight minutes. A gentle stream of water is played on the top sieve to prevent material from remaining on the solid part of the sieve between holes.

When the sieving operation is finished, the sieves are taken off one at a time and the material on each is oven dried and weighed, and then passed through the 0.5 mm. sieve using the fingers or a rubber pestle to crush all aggregates. Any stones or coarse sand present is then subtracted from the gross weight of the aggregates of each size class.

Total Weight of Forest Floor

Numerous measurements in various forests and woodlots of the State show a range in thickness of the forest floor of from ¼-inch or less for the F layer alone to about two inches for the F and H layers together, depending on the tree species, the age of the trees and the rate of decomposition. Occasionally, one can find a 3- or 4-inch layer under hemlock, particularly on a moist site. Under hardwoods, the F layer averages about 0.4 inch, and the amount on an acre weighs, roughly, 7,400 pounds, or 17,580 pounds per acre-inch, with a range from 10,000 to 32,000 pounds per acre-inch. The H layer, when present, averages probably 0.8 inch in thickness and weighs 32,000 pounds per acre, or approximately 40,000 pounds per acre-inch.

Data on the forest floor of pine plantations (mostly red pine) (*Pinus resinosa*) have shown a range from 7,000 to 33,000 pounds per acre, and an average density of around 16,000 pounds per acre-inch. A limited amount of data from a white pine plot in the Rainbow Plantation in Windsor indicated somewhat less total material on the ground than under red pine of the same age in a nearby plot. Subsequent measurements of annual needle fall, however, showed a somewhat larger amount per acre under white pine and a very much larger amount per tree,—193 pounds

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[1] The apparatus herein described is a modification of one used by G. Torstensson at the Ultuna Agr. Expt. Station, Sweden. A somewhat similar apparatus is described and illustrated by Heinrich Dittrich in Bodenkunde und Pflanzenernährung, 16 (1-2):36-37, 1939.

per white pine tree compared with 103 pounds for red pine. The white pine trees were larger than the reds, with fewer trees per plot.

The annual needle fall under red pines (planted in 1902) and measured each year from 1931 to 1946 inclusive (excepting 1945) ranged from 1,600 to 5,700 pounds per acre, and averaged 3,620 pounds for the 15 years. There was a tendency for the amount to increase with increasing age of the trees. Thus, the average for the first five years was 3,093 pounds, for the 2nd five, 3,761, and for the 3rd, 4,009 pounds.

For the purpose of approximating the weight of the forest floor, the values 17,000 pounds per acre-inch for the F layer and 40,000 for the H may be considered reasonably satisfactory for Connecticut conditions.

Texture and Mechanical Analysis of the Mineral Soil

As might be expected from the geology and climate of this area, the soils of the forested lands are predominately fine sandy loams, with some loams, sandy loams and sands. The mechanical analysis and moisture equivalent data on 8 of the 12 profiles previously described are given in Table 3.

These values, together with those presented in an earlier bulletin (24), show in most cases a slightly heavier texture in the B horizon as indicated by the clay and total colloids content. Corresponding increases in the moisture equivalent values do not always occur, indicating that so far as moisture-holding capacity is concerned, the effect of the higher clay content of the B horizon in some instances is more than offset by the lower organic colloid content of that horizon. One profile, No. 63 (Gloucester f.s.l), shows no evidence of eluviation and illuviation, but rather a steady decrease in fine material and an increase in sand with depth. Chemical tests of this profile, discussed later, show a decrease in pH with depth which is contrary to the usual relationship. Furthermore, exchangeable calcium of the A_{11} and A_{12} horizons, exchangeable potassium of the A_{11} and the available phosphorus content of the whole profile are higher than in the corresponding portions of the other profiles. This profile is located in the extreme northwestern part of the State and may be influenced by limestone although there is no evidence of the fact in the field. Possibly the field had been tilled at one time.

The heavier Charlton and Paxton soils averaged higher in colloids throughout the profile than did the more open, lighter Gloucester and similar series; and the upper portion of Cheshire soils showed still higher colloid values. Highest of all were the Holyoke and Towaco soils (till soils strongly influenced by trap rock) (Figure 9), although in this case the number tested was too few to permit definite conclusions. The sandy terrace soils were poorest in colloids as would be expected.

Volume Weight, Specific Gravity and Related Properties

The horizons of forest soil profiles differ greatly in thickness and in density, hence the commonly accepted values for arable soils of 2,000,000 pounds for the weight of the top 6 2/3 to 7 inches, and 4,000,000 pounds for the 7 to 20-inch depth on an acre, are wholly inappropriate for forest

TABLE 3. MECHANICAL ANALYSIS AND MOISTURE EQUIVALENT DATA OF SOME TYPICAL PROFILES IN CONNECTICUT

In Per Cent

Profile No.	Soil Type	Horizon	Depth In.	Total Sands	Silt	Clay[1]	Total Colloids[1]	Moisture Equivalent
52	Gloucester st. f.s.l. (Podzol-mor)	A_2	0–1½	58.4	33.3	8.3	13.6	14.1
		B_{21}	1½–7	60.6	28.4	11.0	17.9	13.7
		B_{22}	7–21	60.4	31.3	8.3	14.2	9.9
		C_1	21 +	61.4	34.3	4.3	6.9	7.6
87	Gloucester st. f.s.l. (Podzol-mor)	A_2–B_1	0–4	50.3	42.7	7.0	12.3	23.5
		B_{21}	4–12	50.3	37.2	12.5	20.1	16.1
		B_{22}	12–28	51.0	41.0	8.0	14.8	11.7
		C_1	28 +	54.3	41.2	4.5	11.1	8.5
50	Grafton st. l. (Mor)	A_{11}	0–1½	58.0	34.3	7.7	15.4	....
		A_{12}	1½–4	57.8	30.2	12.0	21.4	19.6
		B_{21}	4–13	54.0	31.8	14.2	21.2	13.9
		B_{22}	13–31	53.6	33.2	13.2	20.9	12.7
		C_1	31 +	53.6	36.4	10.0	15.1	11.6
53	Haddam st. f.s.l. (Mor)	A_{12}	0–¾	70.8	22.0	7.2	12.5	13.7
		B_{21}	¾–2	70.8	22.7	6.4	11.6	13.0
		B_{22}	2–12	69.0	22.5	8.5	12.8	9.5
		B_3	12–21	76.4	17.0	6.6	9.6	7.3
		C_1	21 +	74.0	24.5	1.5	3.1	6.1
73	Ludlow f.s.l. (Mor)	A	0–4	48.7	43.2	8.1	17.2	24.8
		B_{21}	4–13	50.3	41.1	8.6	14.9	18.4
		B_{22}	13–22	55.9	36.1	8.0	13.9	12.3
		C_1	22 +	71.1	24.6	4.3	8.2	6.5
81	Killingworth st. l. (Mor)	A	0–3	57.0	34.1	8.9	14.8	18.9
		B_{21}	3–12	60.1	27.5	12.4	16.2	14.0
		B_{22}	12–30	67.3	31.5	1.2	3.9	9.8
		C_1	30 +	65.3	33.5	1.2	1.5	8.5
54	Cheshire loam (Mull)	A_{11}	0–¾	44.8	43.0	12.2	19.9	25.8
		A_{12}	¾–6	52.0	31.5	16.5	24.6	....
		B_{21}	6–12	37.2	39.2	23.6	32.0	22.5
		B_{22}	12–19	41.2	40.2	18.6	25.4	16.8
		C_1	19 +	45.2	41.4	13.4	20.1	15.1
63	Gloucester st. f.s.l. (Mull)	A_{11}	0–2	54.6	36.4	9.0	16.3	23.3
		A_{12}	2–7	57.3	34.3	8.4	15.2	16.9
		B_{21}	7–15	63.8	28.4	7.8	13.1	11.0
		B_{22}	15–24	67.2	26.4	6.4	9.8	9.7
		C_1	24 +	67.9	26.0	6.1	8.9	8.0

[1] Clay—$<$ .005 mm.; total colloids—$<$ .05 mm.

soils. Measurements based on arbitrary depths are of little value. Only those estimates founded on actual measurements of thickness and density of each horizon are reliable. Rough approximations can be made, however, by use of the data in Table 4. So far as the A and B horizons are concerned, their density is influenced more by the type of humus and the degree of podzolization than by any other factor or factors. The Podzol is representative of the Podzol great soil group as found in the spruce and spruce-hardwoods forest types in New Hampshire.

The data in Table 5 show the results of tests on the various physical

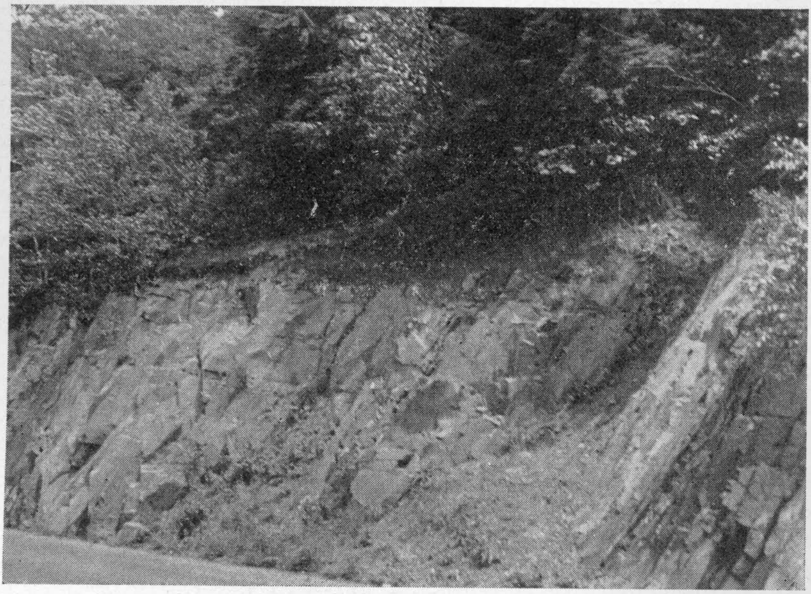

Figure 9. Showing a thin layer of soil (Towaco) overlying traprock. The parent material consists of a mixture of till and weathered diabase.

properties of profiles 51 to 54 inclusive. Porosity, water-holding capacity, and field air capacity decreased, generally speaking, with increase in volume weight from top to bottom of the profile. Previous work (19) has shown that organic carbon and moisture equivalent are rather closely correlated with volume weight. In the studies cited, correlation coefficient "r" equalled — .800 ± .033 and — .511 ± .068, respectively. Neither clay nor silt-plus-clay content was correlated to any definite degree. The low volume weight and high water-holding capacity of the A_2 horizons are not typical of leached layers but must be due to the inclusion of considerable organic matter in the sample. Similar studies on strongly developed podzols in New Hampshire (24) showed a volume weight of 1.1 to 1.3 for the A_2 and about 0.9 for the B_{21}.

The results of the aggregate analyses are perplexing, especially with respect to the relatively high aggregate percentage in the C_1 of profile 53. Possibly these were lightly cemented particles which crumbled readily when rubbed after the water treatment, rather than true aggregates. Also the values for the B_{21} in the first profile were considerably lower than those on the corresponding horizon of the other profiles,—without known reason. The excellent crumb condition of the mull profile, so readily observed in the field, was characterized in the tests chiefly by a relatively high percentage of 1.0-.5 mm. aggregates in the A_{12} and B_{21} horizons, as well as by the lower volume weight and higher porosity of the A.

TABLE 4. AVERAGE VOLUME WEIGHT AND POUNDS PER ACRE-INCH IN FOUR KINDS OF PROFILES[1]

(Water = 1.0)

Horizon	Podzol		Brown Podzolic					
	Greasy mor		Podzol-mor		Mull		Sandy Profiles (Merrimac sand)	
	Vol. wt.	lbs/A-inch[2]	Vol. wt.	lbs/A-inch	Vol. wt.	lbs/A-inch	Vol. wt.	lbs/A-inch
F	0.088	20,000	0.066	15,000	0.066	15,000	....	....
H	0.177	40,000	0.177	40,000	....	....	....	....
A_{11}	....	....	....	....	0.87	197,055	1.28	289,920
A_{12}	....	....	....	....	1.10	249,150	1.40	317,100
A_2	1.25	283,125	1.10	243,150	....	....	....	....
B_{21}	0.90	203,850	1.00	226,500	1.30	294,450	1.45	328,425
B_{22}	1.10	249,150	1.20	271,800	1.40	317,100	1.45	328,425
B_3	1.30	294,450	1.35	305,775	1.45	328,425	1.45	328,425
C_1	1.50	339,750	1.50	339,750	1.50	339,750	1.45	328,425
Ortstein	1.65	373,725						

[1] The values presented in this table are approximately average for the type of profile indicated and do not refer to any particular profile.

[2] Volume weight × 226,500 = Pounds per acre inch.

CHEMICAL PROPERTIES

Analytical Methods

Inasmuch as the analyses reported in this work were made over a period of years, some variation in methods was inevitable. New techniques and improved equipment were adopted as they became known and available. Except where specifically mentioned as being otherwise, the results obtained where more than one method was used are reasonably comparable and satisfactory for the purposes intended.

Soil reaction was determined in 1 : 1 soil-water suspensions or in thin pastes by means of a glass electrode pH meter. On a few profiles pH readings were made also on soil-KCl(N/1) suspensions. *Total nitrogen* was determined by the Kjeldahl method or by the modification of Stubblefield and DeTurk[1]; *organic carbon* in part by the Parr method[2, 3] and in part by that of Schollenberger[4], and *total calcium* and *magnesium* by the usual analytical methods.

Acid-soluble calcium, iron, and R_2O_3 (oxides of Fe, Al, P, Mn) were obtained by digestion of the soil in HCl, sp. gr. 1.115, on a steam bath for 10 hours. Separation was made by a modification of several published methods[5, 6, 7]. The iron in an aliquot portion was reduced to the ferrous condition by stannous chloride and then oxidized by a standard solution of potassium dichromate. The R_2O_3 constituents were precipitated and weighed as the hydroxide by the usual methods.

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[1] Ind. and Eng. Chem. Anal. Ed. 12:396-399, 1940.

[2] A.O.A.C. Methods of analysis pp. 25-26, 1925.

[3] Ind. and Eng. Chem. Anal. Ed. 1:145-148, 1929.

[4] Soil Sci. 40:311-320, 1935.

[5] Emerson, P. Soil characteristics, McGraw Hill, New York, 1925.

[6] Scott, W. W. Standard methods of chemical analysis Vol. 1, 4th Ed. Van Nostrand, N. Y. 1927.

[7] Sutton, F. A. Systematic handbook of volumetric analysis, 11th Ed. P. Blakiston's Son & Co. Phila. 1924.

TABLE 5. SPECIFIC GRAVITY AND OTHER PHYSICAL PROPERTIES OF FOUR FOREST SOIL PROFILES

Profile Number and Location	Profile type	Horizon	Depth in.	Sp. Gr.	Vol. Wt.	Porosity %	Water hold. cap. g.[1]	Field moist. in 100 ml. of soil g.	Field air cap. %	Aggregates per cent Size limits, mm.			
										5-3	3-1	1-.5	Total
51 Pachaug Forest	Podzol-Mor (Gloucester st.f.s.l.)	A_2	0–1	2.35	0.97	58.8	111.9	23.5	35.3	15.0	12.4	12.1	39.5
		B_{21}	1–11	2.46	1.07	56.6	99.9	21.5	35.1	4.6	4.9	6.7	16.2
		B_{22}	11–23	2.57	1.20	53.2	90.5	19.3	33.9	7.2	11.5	11.7	30.4
		C_1	23+	2.60	1.35	48.2	73.2	18.0	30.2	5.0	12.8	16.1	33.9
52 Pachaug Forest	Podzol-Mor (Gloucester st.f.s.l.)	A_2	0–1½	2.38	0.94	60.3	115.6	23.5	36.8	17.8	17.9	12.7	48.4
		B_{21}	1½–7	2.48	1.15	53.6	88.9	18.3	35.3	15.6	13.5	11.3	40.4
		B_{22}	7–21	2.57	1.25	51.4	87.9	17.5	33.9	2.9	7.4	9.0	19.3
		C_1	21+	2.62	1.36	48.2	73.0	18.0	30.2	3.7	12.1	10.2	26.0
53 Meshomasic Forest	Mor (Haddam st.f.s.l.)	A_{12} B_{21}	0–3/4 3/4–2	2.35	1.04	55.7	112.9	28.2	27.5	10.0	11.0	14.9	35.9
		B_{22}	2–12	2.58	1.21	53.2	86.9	21.1	32.1	6.6	6.6	11.3	24.5
		B_3	12–21	2.76	1.33	48.3	76.7	19.7	28.6	3.7	5.7	8.7	18.1
		C_1	21+	2.61	1.49	43.0	69.6	21.3	21.7	23.2	18.1	9.6	50.9
54 Mt. Higby Reservoir Middlefield	Mull (Cheshire loam)	A_{11}	0–3/4	2.09	0.77	63.4	96.7	31.3	32.1	9.5	20.8	13.8	44.1
		A_{12}	3/4–6	2.31	0.89	61.5	95.7	29.5	31.9	7.8	12.9	15.1	35.8
		B_{21}	6–12	2.34	0.92	60.6	93.7	33.5	27.1	3.8	11.2	23.1	38.1
		B_{22}	12–19	2.40	1.27	47.3	84.7	32.8	14.5	1.5	7.2	22.5	31.2
		C_1	19+	2.52	1.29	48.9	85.1	32.5	16.4	0.9	5.6	9.6	16.1

[1] Grams per 250 ml. soil (volume basis)

Exchangeable calcium and *exchangeable potassium* were determined by leaching the soil with N/2 acetic acid, although in some cases N/1 ammonium acetate was the extracting agent for calcium. *Total bases, base capacity,* and *exchangeable hydrogen* were determined by a procedure[1] based on the one proposed by Chandler[2]. In all cases equal volumes of soil were used, with the final values calculated on the basis of air-dry weight. For *total phosphorus,* the magnesium nitrate method[3] was used on the few samples reported. Available phosphorus was determined by Truog's method[4], and also by the citric acid method[5, 6], in which the soil is shaken in one per cent citric acid for an hour in the late afternoon and again for an hour the next morning. In some instances citric acid-soluble potassium was also determined using the same extraction procedure as for phosphorus. Inasmuch as the citric acid method is used by many laboratories abroad, it seemed advisable to make some analyses by that method for comparative purposes.

Available P, K, Ca and Mg were also determined on some samples by a modification of the Wolf method[7]. For *total* P, K, Ca and Mg in the litter, the perchloric nitric acid digestion procedure[8] was followed.

Soil Reaction

The forest soils of Connecticut are strongly acid in the upper portions of the profile, especially the H layer, with a slight but gradual increase in pH with depth. The pH values of the several humus types are shown in Table 6 and Figure 10. Data on the soil series groups are given in Table 20 in the Appendix.

The pH of the horizons from the A_2 upward was definitely lower in the podzol-mors than in the other humus types. The mull profiles showed a higher pH from the A_{11} downward, although the differences are not large. Among other types of profiles, the poorly drained soils, such as Leicester and Wilbraham, were somewhat less acid (Figure 10 and Table 20), as were also soils developed from traprock. Limestone-derived soils in this State range from moderately acid to alkaline.

These data indicate that our soils are more acid than the great majority of forest soils in this country which, according to Wilde (55), range from pH 5 to 6.5. Wilde, of course, takes into account the extensive areas of forested land in the Middlewest and other parts of the country outside of the Northeast.

Because of the presence of iron pyrites, FeS_2, in the parent material of Brookfield soils, it is generally considered that such soils are inclined to be more acid than are soils derived from other schists. However, the following data from Brookfield profiles, when compared with that in Table 6, fails to reveal any such tendency in Connecticut soils.

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[1] Soil Sci. Soc. Amer. Proc. 5:344-349, 1941.
[2] J. Agr. Res. 59:491-506, 1939.
[3] A.O.A.C. Methods of analysis pp. 9-10, 1940.
[4] J. Amer. Soc. Agron. 22:874-882, 1930.
[5] Wright, C. H. Soil analysis, pp. 172-173, Thomas Murby & Co. London, 1934.
[6] Ztschr. Pflanz. Dung. u. Bodenk. 18:315-323, 1930.
[7] Ind. and Eng. Chem. Anal. Ed. 15:248-51, 1943.
[8] Ibid. 7:185-186, 1935.

Horizon	No. of Samples	Average pH
A_{11}	3	4.6
A_{12}	41	4.7
B_{21}	30	5.0
B_{22}	3	5.1
C_1	3	5.3

A neutral salt suspension of acid soils generally gives a lower pH than is obtained in a water suspension, due to the replacement of hydrogen ions in the soil colloids by the cations of the salt. The difference between the two pH values is used by some European investigators as a measure of the exchangeable acidity, neutrality or alkalinity of a soil. According to Teräsvuori, as reported by Aaltonen (1), the difference is dependent upon the electrolyte content of the soil. Soils low in electrolytes exhibit a greater difference than do those with a high electrolyte content. According to Mattson and Lönnemark (38), where the pH in salt suspension is lower than the pH in water it indicates that the soil possesses a strong

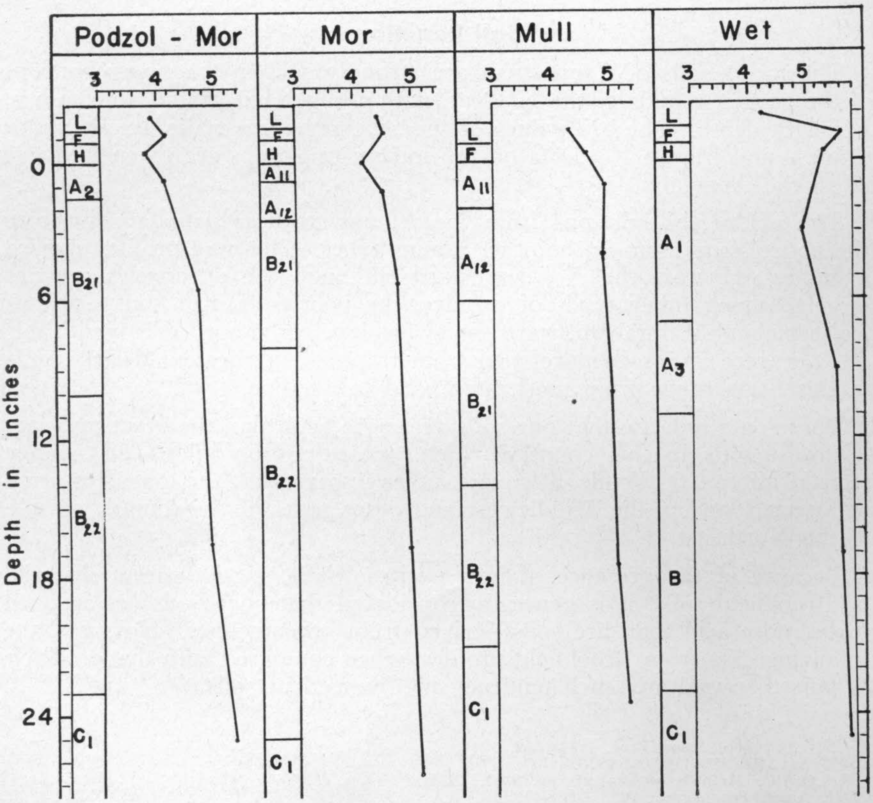

Figure 10. Average pH values for the several types of Connecticut soil profiles. Data for the three well-drained profiles were taken from Table 6. The wet soil (poorly to very poorly drained upland) from Table 21.

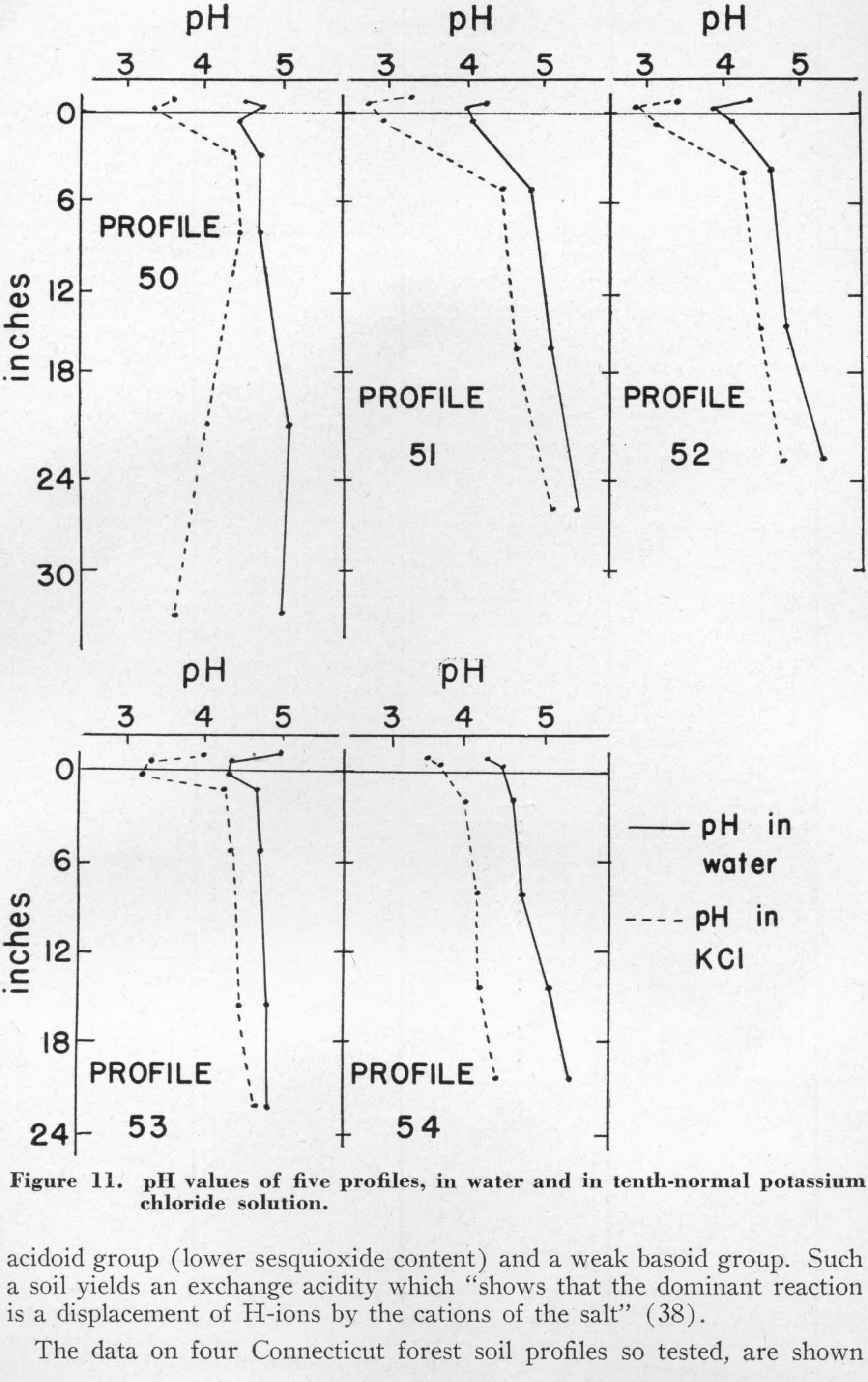

Figure 11. pH values of five profiles, in water and in tenth-normal potassium chloride solution.

acidoid group (lower sesquioxide content) and a weak basoid group. Such a soil yields an exchange acidity which "shows that the dominant reaction is a displacement of H-ions by the cations of the salt" (38).

The data on four Connecticut forest soil profiles so tested, are shown

TABLE 6. SOIL REACTION, TOTAL NITROGEN, ORGANIC CARBON, AND CARBON-NITROGEN RATIO OF REPRESENTATIVE UPLAND PROFILES

	Horizon	Podzol-Mor				Mor							Mull			
		51	52	87	Av.	50	53	64	73	81	86	Av.	54	63	75	Av.
pH	L	....	3.89	3.86	3.87	....	5.10	3.99	4.11	4.04	4.80	4.41	4.03	4.78	4.11	4.31
	F	4.21	4.38	3.86	4.15	4.56	4.99	4.45	4.30	3.63	5.13	4.51	4.27	5.24	4.27	4.59
	H	4.02	3.91	3.49	3.81	4.79	4.34	3.65	3.60	4.32	4.45	4.19	....	....	....	....
	A_{11}	....	....	....	....	4.73	4.29	4.40	4.28	4.69	4.39	4.46	4.50	5.55	4.62	4.89
	A_{12}	....	....	....	....								4.60	5.29	4.70	4.86
	A_2	4.06	4.16	4.13	4.12	....	....	....	....	....	....	....	....	....	....	....
	B_{21}	4.80	4.66	4.66	4.71	4.67	4.69	4.70	4.62	4.85	5.00	4.75	4.71	5.35	4.96	5.01
	B_{22}	5.01	4.89	4.82	4.91	5.05	4.74	5.08	4.68	4.94	5.06	4.93	5.07	5.12	5.09	5.08
	C_1	5.40	5.28	5.16	5.28	4.98	4.86	5.37	5.02	5.01	5.11	5.06	5.33	5.13	5.28	5.25
N%	L	....	1.077	0.912	0.995	....	1.108	0.805	0.675	0.695	0.800	0.817	1.260	0.607	0.685	0.851
	F	1.430	1.550	1.282	1.421	1.346	1.548	1.302	1.574	1.242	1.588	1.433	1.102	1.227	1.020	1.116
	H	1.095	0.938	1.324	1.119	1.022	0.877	1.190	1.109	1.312	1.268	1.129	....	....	....	....
	A_{11}	....	....	....	....	0.136	0.125	0.343	0.171	0.113	0.274	0.194	0.356	0.132	0.227	0.238
	A_{12}	....	....	....	....								0.203	0.063	0.106	0.124
	A_2	0.093	0.111	0.189	0.131	....	....	....	....	....	....	....	....	....	....	....
	B_{21}	0.051	0.056	0.075	0.061	0.040	0.095	0.295	0.071	0.063	0.117	0.113	0.146	0.023	0.073	0.081
	B_{22}	0.014	0.026	0.028	0.023	0.017	0.037	0.047	0.033	0.020	0.055	0.035	0.038	0.024	0.056	0.039
	C_1	0.014	0.008	0.010	0.011	0.014	0.016	0.023	0.005	0.022	0.015	0.016	0.019	0.023	0.025	0.022
C %	L	....	49.00	51.00	50.00	....	50.02	50.80	51.10	51.30	49.50	50.54	45.50	49.50	50.10	48.37
	F	47.60	50.50	51.60	49.90	44.40	41.60	51.50	49.60	51.60	49.30	48.00	45.40	49.70	49.60	47.90
	H	29.70	27.95	40.80	32.80	27.20	23.20	37.20	32.10	41.50	31.30	32.08	....	....	....	....
	A_{11}	....	....	....	....	3.22	3.86	7.20	5.10	3.58	6.05	4.83	5.62	3.60	5.16	4.79
	A_{12}	....	....	....	....								2.48	1.53	2.61	2.21
	A_2	2.95	3.85	6.37	4.39	....	....	....	....	....	....	....	....	....	....	....
	B_{21}	1.13	1.63	1.33	1.36	0.64	2.12	3.84	1.32	1.22	2.12	1.88	1.86	0.55	1.14	1.18
	B_{22}	0.38	0.36	0.49	0.41	0.30	0.74	1.12	0.41	0.51	0.71	0.63	0.44	0.39	0.83	0.55
	C_1	0.22	0.11	0.30	0.21	0.25	0.18	0.48	0.30	0.31	0.20	0.29	0.27	0.40	0.37	0.35
C : N	L	....	45.5	55.8	50.6	....	45.1	63.1	75.7	73.8	61.9	63.9	36.1	81.5	73.2	63.6
	F	33.3	32.6	40.2	35.4	33.0	26.9	39.5	31.5	41.5	31.1	33.9	41.2	40.6	48.7	43.5
	H	27.1	29.8	30.8	29.2	26.6	26.5	31.3	28.9	31.6	24.5	28.2	....	....	....	....
	A_{11}	...	...	...	...	23.7	30.9	21.0	29.4	31.7	22.1	26.5	15.8	27.3	22.7	21.9
	A_{12}	...	...	...	...								12.2	24.3	24.7	20.4
	A_2	31.7	34.6	33.7	33.3	....	....	....	....	....	....	....	....	....	....	....
	B_{21}	21.9	29.1	17.7	22.8	15.9	22.3	13.0	18.7	19.4	18.0	17.9	12.7	23.8	15.6	17.4
	B_{22}	26.9	13.7	17.6	19.4	18.0	19.9	23.9	12.1	25.8	12.9	18.6	11.5	16.1	14.7	14.1
	C_1	15.6	13.7	30.0	19.8	18.2	11.2	21.0	60.9[1]	14.1	13.2	15.5	14.2	17.3	14.9	15.5

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[1] Omitted from average.

in Figure 11. It appears that all four profiles are of the acidoid type. In every case the pH differences are greatest in the H and A_2 horizons which means that the exchange acidity is highest in those horizons. In mor profile 50 the A_{12} (1½-4 in.) and B_{21} (4-13 in.) horizons approach exchange neutrality in contrast to the rest of the profile. Since the amount of illuviated material is usually greatest in the B_{21}, that fact accounts largely for the low degree of exchange acidity in that horizon.

The C_1 of profiles 50 and 54 show a higher degree of exchange acidity than do the corresponding horizons of the other two profiles. Comparison with other data on the same profiles shows that the subsoils of these two profiles are characterized by a higher exchangeable hydrogen concentration, base capacity, moisture equivalent, total colloids, and clay content.

Nitrogen and Organic Matter

Analyses show a total nitrogen content of the forest floor of 1 per cent or more, with the F layer practically always higher than the litter, due to the relatively higher proportion of carbon to nitrogen in the litter (Table 6). In well developed Podzol profiles the A_2 is frequently the poorest part of the profile as a result of leaching. However, the podzol-mor type in the Brown Podzolic soil group do not show such clear-cut differences. Previous work (24) revealed a tendency for the F and H layers of Podzols to have a higher N content and a narrower C-N ratio than the same horizons of mor and mull soils. Where the tree cover is largely coniferous as it is in the strongly podzolized soils in New Hampshire, the higher N content can be explained by the fact that more nitrogen is returned to the soil under conifers than under hardwoods (34). In the present work, this relationship is not in evidence for the cover was chiefly hardwoods. In the A horizons, on the other hand, the mulls have a higher nitrogen content than either the mors or the podzol-mors.

Figure 12 is a graphic representation of the distribution of nitrogen to a depth of 30 inches in forest soils, as found in four profiles (Nos. 50, 51, 53 and 54). Mor types contain a larger percentage of their nitrogen above ground than do mulls, although in mature Podzols in the White Mountains of New Hampshire, the B_{21} and B_{22} layers contain a large amount inasmuch as the humus concentration is high in those horizons. Profile 54 (Cheshire loam—a mull) is a good soil with a site index of 76 compared with an average SI of 60 and a range of 30 to 83 obtained in a study of 76 plots (28). In this work, 56 of the 76 plots had a site index between 50 and 70.

In a comparison of the total nitrogen content of soil series groups (p. 21), the data in Part II of the Appendix show relatively little difference between the three upland groups of well-drained soils, although those derived from Triassic materials tended to be somewhat lower in N. The poorly drained group and the Holyoke soils contain more nitrogen in their A and upper B horizons due to their higher content of organic matter. Sandy soils, of course, ran low.

Forest soils have characteristically wide C-N ratios due to the less rapid breakdown of the organic matter and the low proportion of N in

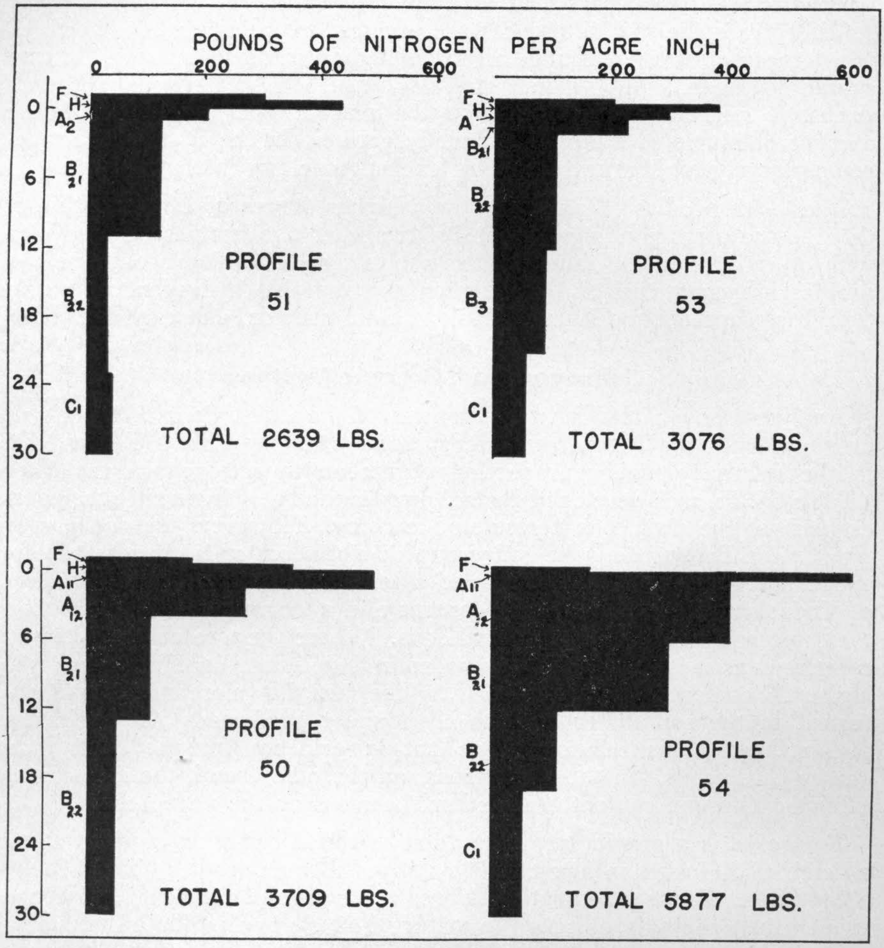


Figure 12. Vertical distribution of nitrogen, in pounds per acre-inch and the total amount per acre to a depth of 30 inches, in four Connecticut soil profiles.

the litter. There is a tendency for the B horizons of podzol-mors to have a wider ratio than the corresponding portions of mull profiles.

Cations and Cation Exchange

Total and Acid Soluble Calcium

Previous studies (24) showed that, percentagewise, total calcium in Podzol and Brown Podzolic profiles in New England is highest in the L or F layers and lowest in the H, A_1 and A_2 horizons. As a rule, calcium increases from the A_2 downward. The total amount per acre, however, is highest in the lower mineral horizons due to their greater volume weight. The following data, based on information from several sources, illustrate these relationships in three kinds of profiles—all calculated to a depth of 30 inches of mineral soil.

	Podzol			Brown Podzolic					
				Podzol-mor			Mull		
	Thickness in.	Ca %	Ca lbs/A	Thickness in.	Ca %	Ca lbs/A	Thickness in.	Ca %	Ca lbs/A
F	1	0.81	162	½	0.95	95	..	..	..
H	4	.37	590	1	.39	156	..	..	..
A	4	.32	3,225	4	.44	4,280	8	0.65	12,367
B_{21}	2	.42	1,712	6	.64	8,700	7	.54	11,130
B_{22}	12	.47	15,330	12	.78	26,500	9	.78	22,260
C_1	12	.73	29,760	8	.83	22,560	6	.81	16,572

In Podzol profiles, calcium distribution does not coincide with that of iron (see p. 49) or of organic matter, since the calcium is removed before the latter two materials are displaced. In this displacement process, the calcium is not concentrated in the upper B layer but is apparently diffused through the entire B and into the C.

In the earlier investigations (24), analyses included calcium soluble in hot HCl (sp. gr. 1.115). The data showed that acid-soluble Ca comprised from 15 to 50 per cent of the total Ca content, depending on the kind of profile and the horizon. In Podzols the B_{21} horizon had the lowest proportion of acid-soluble to total Ca, with a general increase with depth to 30-40 per cent in the C_1. The mull soils were conspicuous in having some 30 to 50 per cent soluble in the A horizon, with the same or slightly lower percentage in the B and C layers.

Total Magnesium

Incomplete data indicate that magnesium, like calcium, increases with depth below the A_1 horizon. Mean values ranged from about 0.2 to 0.9 per cent Mg. No cases were found in which the forest floor ran more than 0.38 per cent. The ratio of Mg to Ca varied in the organic horizons from 0.1 to 0.6, with an average of 0.18, and in the mineral horizons from 0.3 to 5.72, with an average of 1.25.

Exchangeable Cations and Related Properties

The data discussed in this section are presented in Table 7. It is seen that the seat of exchange reaction resides largely in the organic matter, hence the A_0 and the horizon of illuviation (B_{21}) in podzols show high values (14).

Exchangeable calcium is highest in the F layers, followed by the L and then the H, although other data have shown the L to contain the highest concentration in many instances. Exchangeable Ca tended to be higher in mull soils than in the other two soil groups. It had previously been found (24) that in the F and H layers exchangeable Ca comprised some 30 to 75 per cent of the total calcium in those layers, in the A horizon 2 to 20 per cent, and in the B and C horizons less than 5 per cent. These values for the mineral horizons of forest soils are considerably less than is usually found in fertile agricultural soils where a higher Ca concentration and pH is required.

Exchangeable potassium varied between horizons similarly to calcium, and was highest in the L layers and lowest in the H (of the three organic horizons).

Contrary to what might be expected, exchangeable hydrogen did not differ very widely between the three humus types.

Theoretically, the sum of the exchangeable cations (Ca, Mg, K, and Na) should equal the value for total exchangeable cations obtained by difference between cation capacity and exchangeable cation content. Although neither magnesium nor sodium was determined on these samples, previous analyses have shown that the values for Mg approximate only about one-tenth those for Ca, and Na runs very low. Thus, Ca and K comprise the bulk of the exchangeable cation content. The fact that the sum of these two cations does not approximate the total cation values, except in a relatively few cases, may be due in part to errors in analysis. There is evidence (29) that the usual cation exchange procedures when applied to organic materials may be subject to error. The result is that in some cases the total milligram equivalents of Ca and K are considerably below and in some cases considerably above the total cation figure. Obviously, the per cent saturation will vary widely in those instances of disagreement, depending upon which values are used in the calculation.

The process of podzolization consists of the displacement of bases by hydrogen, and is controlled to a large extent by the degree to which the soil is saturated with bases. The lower the base content, the more completely this displacement takes place and the more thoroughly a soil is podzolized; the higher its base content, the more it resists podzolization. The data in Part II of the Appendix show that exchangeable calcium in the L and F layers and in the subsoils was considerably higher in both the red Triassic soils and the poorly drained group than it was in the corresponding horizons of the other soil groups. The B horizons of the traprock soils were even higher, while the one limestone soil was highest of all. There were no consistent differences in exchangeable calcium between the lighter Gloucester type soils and the somewhat heavier Charlton type. Cation capacity comparisons were similar to those for exchangeable calcium except that the Triassic soils were essentially no different than either of the other two upland types.

There is a suggestion that high Ca in the B horizon is reflected in the calcium content of the F and H layers. Data in support of this belief will be presented in the discussion of forest humus (p. 52).

Citric Acid-Soluble Potassium

In conjunction with the determination of available phosphorus in soils by the citric acid method, analyses of a few samples for available potassium were made at the same time on identical citric acid extracts. The data on four profiles, given in Table 8, compare citric acid-soluble K with exchangeable K.

It is evident that, in general, the values obtained are of the same order of magnitude by the two methods. As is usual when different methods

TABLE 7. EXCHANGEABLE BASES, BASE CAPACITY AND PER CENT SATURATION OF REPRESENTATIVE UPLAND PROFILES
Milligram Equivalents per 100 Grams of Soil

Horizon	Podzol-Mor				Mor							Mull			
	51	52	87	Av.	50	53	64	73	81	86	Av.	54	63	75	Av.
Exchangeable Calcium															
L	....	11.40	....	....	....	17.76	18.82	....	....	....	18.29	12.66	41.10	....	26.88
F	14.69	17.11	....	15.90	20.60	25.96	19.08	....	....	....	21.88	20.75	45.60	....	33.18
H	2.29	3.96	....	3.12	7.45	6.15	4.60	....	....	....	6.07	....	....	....	....
A_{11}	....	....	....	....	0.13	0.31	0.31	0.29	0.23	3.41	0.78	1.52	3.05	1.64	2.07
A_{12}	....	....	....	....								0.43	1.33	0.24	0.66
A_2	0.17	0.21	0.00	0.13	....	....	....	....	....	....	....	....	....	....	....
B_1	0.08	0.22	0.10	0.13	0.10	0.13	0.20	0.05	0.24	0.37	0.18	0.38	0.01	0.05	0.15
B_2	0.23	0.24	0.08	0.14	0.35	0.09	0.26	0.04	0.05	0.38	0.19	0.55	0.19	0.22	0.32
C_1	0.05	0.11	0.22	0.17	0.23	0.07	0.37	0.13	0.32	0.28	0.23	0.45	0.46	0.11	0.34
Exchangeable Potassium															
L	....	4.58	....	....	....	4.26	....	....	....	....	....	3.46	....	....	....
F	2.13	2.54	....	2.14	3.66	3.79	2.65	1.53	2.15	3.14	2.82	2.62	3.63	8.87	5.04
H	1.21	1.34	....	1.45	1.28	1.33	1.22	1.75	1.66	1.66	1.48	....	....	....	....
A_{11}	....	....	....	....	0.09	0.11	0.08	0.14	0.10	0.20	0.12	0.23	0.30	0.17	0.23
A_{12}	....	....	....	....								0.11	0.10	0.08	0.10
A_2	0.06	0.10	0.17	0.11	....	....	....	....	....	....	....	....	....	....	....
B_1	0.01	0.03	0.10	0.05	0.07	0.02	0.00	0.08	0.06	0.12	0.06	0.02	0.09	0.12	0.08
B_2	0.00	0.03	0.09	0.04	0.05	0.02	0.03	0.00	0.09	0.13	0.05	0.04	0.12	0.00	0.05
C_1	0.01	0.03	0.09	0.04	0.09	0.03	0.06	0.06	0.11	0.13	0.08	0.05	0.08	0.00	0.05
Exchangeable Hydrogen															
L	....	38.70	....	....	....	31.20	37.00	....	....	....	34.10	46.33	27.00	....	36.67
F	40.40	43.40	....	41.90	41.00	37.00	36.00	....	....	....	38.00	45.70	22.80	....	34.25
H	48.00	39.33	....	43.66	31.70	34.30	56.00	....	....	....	40.67	....	....	....	....
A_{11}	....	....	....	....	7.10	6.90	15.45	10.00	6.76	12.94	9.86	14.70	5.75	10.29	10.31
A_{12}	....	....	....	....								10.70	2.63	4.42	5.92
A_2	6.00	8.00	15.31	9.77	....	....	....	....	....	....	....	....	....	....	....
B_1	2.54	3.87	4.70	3.70	3.20	5.00	9.78	3.25	2.64	5.68	4.93	5.50	0.96	2.96	3.14
B_2	1.41	1.41	2.09	1.64	2.80	2.40	2.35	1.75	1.92	3.48	2.45	3.10	0.83	2.38	2.10
C_1	0.65	0.60	1.27	0.84	2.20	0.80	1.00	0.59	0.69	1.31	1.10	2.10	0.76	0.43	1.10

TABLE 7 (Continued)

Horizon	Podzol-Mor				Mor							Mull			
	51	52	87	Av.	50	53	64	73	81	86	Av.	54	63	75	Av.
							Total Bases								
L	....	5.50	....	....	....	18.80	30.00	....	....	....	24.91	4.67	20.00	....	12.33
F	13.20	8.60	....	10.90	23.50	20.50	25.20	....	....	....	23.07	11.60	37.80	....	24.70
H	4.30	3.97	....	4.07	21.70	6.50	11.00	....	....	....	13.07	....	....	....	....
A_{11}	....	....	....	....	2.50	0.80	4.65	4.95	4.64	4.99	3.75	3.10	3.21	4.01	3.44
A_{12}	....	....	....	....								1.70	1.90	2.45	2.02
A_2	1.15	0.74	2.59	1.49	....	....	....	....	....	....	....	....	....	....	....
B_{21}	0.79	0.78	1.15	0.91	0.40	0.48	3.42	2.62	1.79	3.55	2.04	3.50	0.52	0.86	1.63
B_{22}	0.70	0.48	0.82	0.66	0.80	0.10	1.21	1.83	0.00	1.35	0.88	1.60	0.36	0.83	0.93
C_1	0.32	0.70	0.65	0.56	1.30	0.30	1.33	1.39	0.06	0.41	0.80	1.40	0.12	0.50	0.67
							Base Capacity								
L	....	44.20	....	....	....	50.00	67.00	....	....	....	58.50	51.00	47.00	....	49.00
F	53.60	52.00	....	52.80	64.50	57.50	61.20	....	....	....	61.07	57.30	60.60	....	58.95
H	52.30	43.30	....	47.80	43.40	40.80	67.00	....	....	....	50.40	....	....	....	....
A_{11}	....	....	....	....	9.60	7.70	20.10	14.95	11.40	17.93	13.61	18.00	8.96	14.30	13.75
A_{12}	....	....	....	....								12.40	4.53	6.87	7.93
A_2	7.15	8.74	17.90	11.26	....	....	....	....	....	....	....	....	....	....	....
B_{21}	3.33	4.65	5.85	4.61	3.60	5.48	13.20	5.87	4.43	9.23	6.97	9.00	1.48	3.82	4.77
B_{22}	2.11	1.89	2.91	2.30	3.60	2.50	3.56	3.58	0.92	4.83	3.16	4.70	1.19	3.21	3.03
C_1	0.97	1.30	1.92	1.40	3.50	1.10	2.33	1.98	0.75	1.72	1.90	3.50	2.00	0.93	2.14
							Per cent Saturation								
L	....	12.5	....	....	....	37.6	44.8	....	....	....	41.2	9.2	42.6	....	25.9
F	24.6	16.5	....	20.5	36.4	35.7	41.2	....	....	....	37.8	20.2	62.4	....	41.3
H	8.2	9.2	....	8.7	50.0	15.9	16.4	....	....	....	27.4	....	....	....	....
A_{11}	...	...	...	...	26.0	10.4	23.1	33.1	40.7	27.8	26.9	17.2	35.8	28.0	27.0
A_{12}	...	...	...	...								13.7	41.9	35.7	30.4
A_2	16.1	8.5	14.5	13.0	....	....	....	....	....	....	....	....	....	....	....
B_{21}	23.7	16.8	19.7	20.1	11.1	8.8	25.9	44.6	40.0	38.5	28.1	38.9	35.1	22.5	32.2
B_{22}	33.2	25.4	28.2	28.9	22.2	4.0	34.0	51.1	0.0	28.0	23.2	34.0	30.3	25.9	30.1
C_1	33.0	53.8	33.9	40.2	37.1	27.3	57.1	70.2	8.0	23.8	37.3	40.0	62.0	53.8	51.9

are compared, agreement was unobtainable in some cases. Such instances were not sufficiently common, however, to invalidate the findings.

TABLE 8. COMPARISON OF CITRIC ACID-SOLUBLE POTASSIUM WITH EXCHANGEABLE POTASSIUM
Parts per million of K

	Profile No.							
	51		52		53		54	
Horizon	Exch.	C.A.S.[1]	Exch.	C.A.S.	Exch.	C.A.S.	Exch.	C.A.S.
L	....	....	1791	1568	1666	1855	1351	1332
F	833	772	994	905	1480	970	1022	565
H	475	382	525	531	513	338	....	....
A_{11}	....	....	....	....	....	....	88	35
A_{12}	....	....	....	....	....	....	42	12
A_2	24	27	46	43	45	54	....	....
B_{21}	5.9	7.2	10.3	29	7.0	9.7	8.0	17
B_{22}	0	4.0	9.8	28	7.0	8.8	16	5.0
C_1	6.0	15	9.9	54	9.9	15	22	8.0

[1] Citric acid soluble

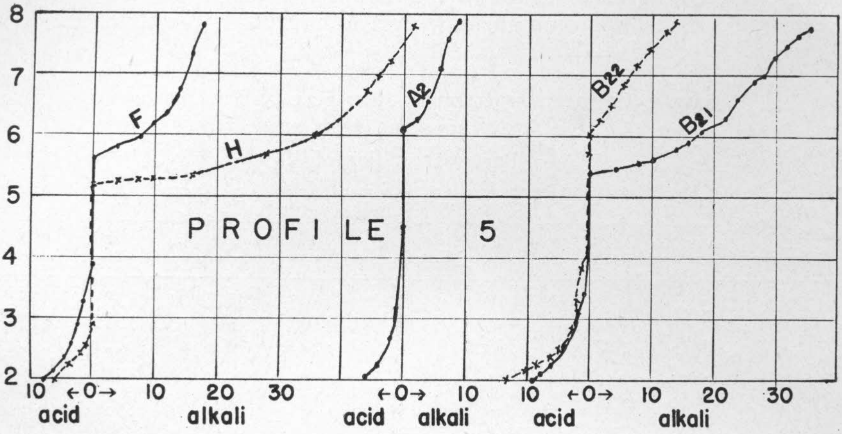
Buffer Capacity

When a soil suspension is titrated with an acid or a base, as the case may be, to bring the suspension to a definite pH, the amount of solution required, when plotted, gives a very good picture of the buffer capacity of the sample. This was done on five profiles, two of which came from New Hampshire and three from Connecticut. To 15 g. of air dry soil were added 20 ml of distilled water, and the mixture treated with increasing amounts of tenth-normal H_2SO_4 to pH 2.0. Similar samples were likewise treated with tenth-normal NaOH to pH 7.8. The findings are reported in Figures 13 and 14.

In podzol profile 5 (Figure 13), the buffering effect against alkali was highest in the H and lowest in the leached A_2 horizon. The B_{21}, being the layer of greatest accumulation, showed good buffering also. Against acid, there was relatively little difference among the several horizons.

In the New Hampshire mull profile No. 21, which proved to be an unusual soil with an exceptionally large amount of calcium in the whole profile, the buffering capacity against acid was very high, particularly in the A horizon. On the alkaline side, the A was less resistant to change than was the B_1 of the podzol. In Figure 14 it is seen that the Connecticut profiles, 52, 53 and 54, were much less extreme than the two from New Hampshire, 5 and 21, with several rather interesting differences. The B_{21} showed greater acid buffering, and the B_{22} less akaline buffering than did the New Hampshire counterpart.

The higher buffer capacity of the B_2 in profile 5 as compared with that of the corresponding horizons in profiles 52, 53 and 54, can be ascribed to higher organic carbon content of the former (7.9% cf. 0.4 to 2.1%).



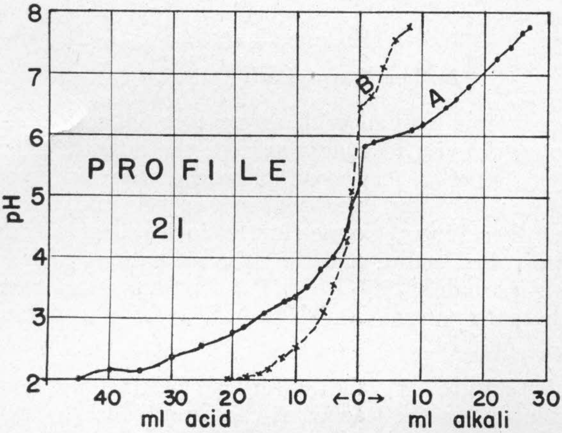


Figure 13. **Buffer curves of two profiles from New Hampshire. Number 5 is a strongly developed podzol under a mature virgin red spruce stand near Waterville. Number 21 is an excellent crumb mull under a beech-yellow birch-sugar maple stand near Bethlehem. The values are milliliters of N/10 acid or alkali.**

Phosphorus

Although the phosphorus content of Connecticut forest soils is low, it is not ordinarily considered to be a limiting element. At least, response to phosphorus treatment usually fails to approach that resulting from nitrogen fertilization. There is evidence, however, as shown by Mitchell (40, 41) and Lunt (30), that phosphorus may be a controlling factor in some situations.

The data in Table 9 are indicative of the total phosphorus content of

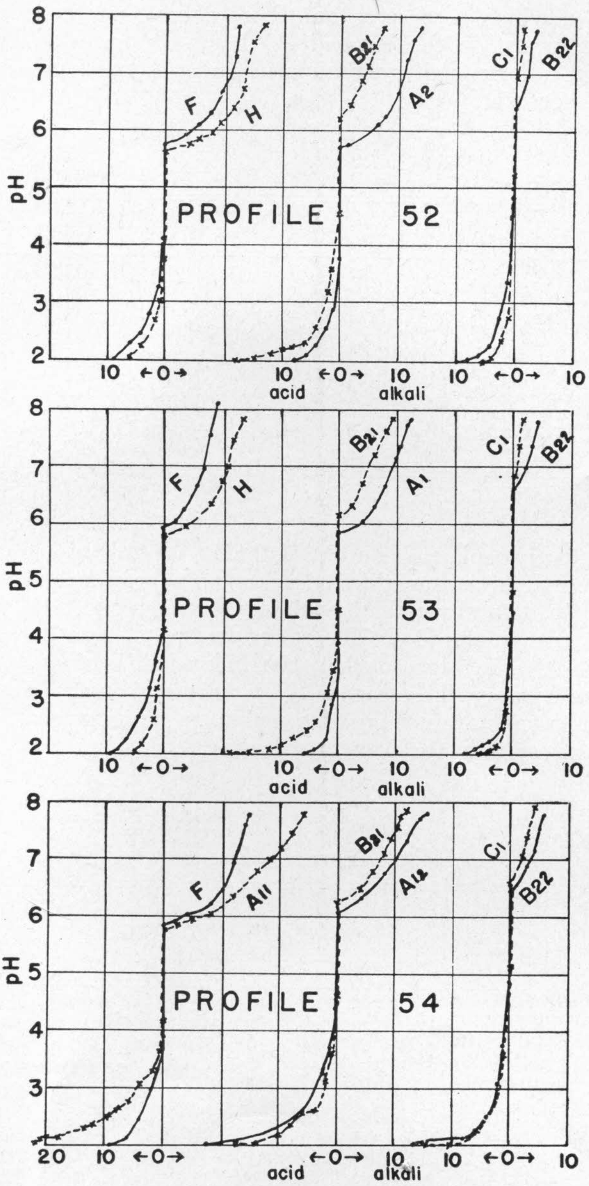


Figure 14. Buffer curves of three Connecticut profiles previously described (pp. 00). Number 52 is a podzol-mor weakly developed podzol; No. 53, a mor humus type; and No. 54, a mull. The values are milliliters of N/10 acid or alkali.

forest soils, in which it is seen that P is highest, on the average, in the F layer and lowest in the leached A_2 layer. Morgan (42) reported a range in the A horizon of general farm and pasture land of from about 0.05 to 0.11 per cent.

TABLE 9. TOTAL PHOSPHOROUS CONTENT OF FOREST SOILS

Horizon	No.[1]	Total per cent Av.	Total per cent Range
L	41	.07	.03-.18
F	7	.13	.09-.17
H	4	.10	.07-.13
A_{11}	4	.08	.03-.10
A_{12}	3	.07	.04-.09
A_2	3	.03	.01-.05
B_{21}	8	.05	.03-.09
B_{22}	3	.05	.04-.06
C_1	7	.05	.02-.11

[1] Number of samples

The *available* phosphorus content of the 12 profiles previously described and also the general averages for a larger number of profiles are given in Table 10. The data show that available P was highest in the litter and seemingly lowest in the B_{21}. The range in the C_1 was somewhat higher than in the B_{22}. The variation between individual profiles is greater than the difference between the means of each profile group. Reliable comparisons between groups are not possible without a much larger representation of each than there is in the present material.

TABLE 10. AVAILABLE PHOSPHORUS (TRUOG METHOD) IN TWELVE TYPICAL PROFILES—ppm.

Horizon	Podzol-Mor			Mor						Mull			General Av. of 10 or more upland profiles
	51	52	87	50	53	64	73	81	86	54	63	75	
L	...	218	...	...	257	...	...	...	...	209	...	...	273
F	170	180	291	270	220	243	228	212	171	168	347	150	213
H ...	64	77	150	112	87	100	91	69	94	...	...	...	102
A_{11} ...	...	...	...	2	16	7	14	10	6	18	55	10	18
A_{12} ...	...	...	...							8	39	5	119
A_2 ...	8	13	11	...	...	...	...	...	...	...	...	...	...
B_1 ...	2	4	8	3	3	1	...	10	3	3	26	3	7
B_2 ...	2	6	6	1	1	2	2	9	5	8	26	2	8
C_1 ...	13	10	8	3	3	6	8	11	8	13	32	3	9

While the Truog method is more or less standard in this country, there are many laboratories abroad in which preference is shown to other extractants, particularly citric acid. The following data serve to indicate the values to be expected by that procedure, and make direct comparison with the Truog method. Usually citric acid gives much higher results.

	Profile 51		Profile 53		Profile 54	
	Truog ppm	Citric Acid ppm	Truog ppm	Citric Acid ppm	Truog ppm	Citric Acid ppm
L	..	..	257	443	209	203
F	170	213	220	244	168	115
H	64	84	87	113	..	..
A_{11}	..	..	..	..	18	68
A_{12}	..	..	16	46	8	44
A_2	8	14	..	..	..	..
B_{21}	2	13	3	23	3	33
B_{22}	2	11	1	7	8	18
C_1	13	63	3	22	13	45

Evaluation of the merits of the two methods is beyond the scope of this bulletin. The need for standard procedures, if results by different investigators are to be compared, is obvious.

Sesquioxides and Insoluble Matter

The unequal distribution of iron and aluminum in forest soils of podzolic regions is characteristic. Studies of a number of Connecticut profiles together with some Podzols from New Hampshire were reported in an earlier publication (24). A summary of these data is given in Table 11. The concentration of sesquioxides in the B horizon is indicative of the podzolization process. In strongly developed Podzols, iron is concentrated mostly in the B_{21} and aluminum and other oxides in the B_{22}. The high percentage of insoluble matter in the A_2 of the Podzols is in marked contrast to the figures for the underlying B horizons, and for the A horizons of the mor and mull profiles.

When compared with similar data reported elsewhere, it appears that the strongly podzolized soils of New England would be classified as iron-humus profiles, for both iron and organic matter are low in the A_2 and high in the B.

The silica-sesquioxide ratio of soil colloids is of value in determining the degree of podzolization (22) of a soil, the ratio decreasing as one progresses from north to south (in the eastern United States), or in going from a strongly developed Podzol under a greasy mor to a Brown Podzolic mull soil. Although in this work the colloids were not studied, the relationship between insoluble matter of the soil, which consisted principally of silica, and Fe_2O_3 plus Al_2O_3 (together with other oxides) was determined on samples whose analyses were reported previously (24). These relationships for the A horizon are summarized at the bottom of Table 11. The differences between Podzol and Brown Podzolic mors or mulls are striking, and serve to emphasize the effect of the podzolization process on the A horizon. In the B horizon differences between profiles determined by the above means are relatively slight.

BIOLOGICAL PROPERTIES

Organic Matter Decomposition

The humus and litter cover, together with the uppermost layer of mineral soil, is the center of biological activity in forest soils. The freshly fallen litter possesses a very wide C-N ratio, usually between 50 and 90.

TABLE 11. SESQUIOXIDES AND INSOLUBLE MATTER
Averages of Three or Four Profiles

Horizon	Podzol (New Hampshire)	Brown Podzolic (Conn.)		
		Podzol-Mor	Mor	Mull
		Fe_2O_3, per cent		
A_{11}	...	...	3.57	4.47
A_{12}	...	...	3.49	4.43
A_2	1.58	1.71	...	...
B_{21}	5.40	4.50	4.05	4.70
B_{22}	4.82	4.00	3.47	4.61
C_1	2.68	3.28	2.35	3.66
		Al_2O_3 and other oxides exclusive of Fe_2O_3, per cent		
A_{11}	...	...	3.29	4.88
A_{12}	...	...	4.13	4.49
A_2	1.09	1.25	...	...
B_{21}	2.64	3.64	4.63	5.13
B_{22}	5.35	4.51	3.88	5.41
C_1	2.55	4.03	2.77	5.36
		Insoluble Matter, per cent		
A_{11}	...	...	80.8	75.6
A_{12}	...	...	85.6	80.0
A_2	93.2	90.8	...	...
B_{21}	74.5	81.6	87.4	83.8
B_{22}	73.9	83.4	89.6	85.5
C_1	90.6	88.3	93.1	85.5
		Ratio of insoluble matter to $Fe_2O_3 + Al_2O_3$ (+ other oxides)		
A_2 or A_{12}	34.9	30.7	11.2	9.0

As this material lays on the ground, soluble constituents, notably potash, are leached out by rain in appreciable amounts within the first month or two (25). In the decomposition process, carbon is lost, with a gradual narrowing of the C-N ratio to about 40 in the F material and 30 in the H. When the process was studied by incubating soils in the laboratory and measuring the amount of CO_2 evolved (24), it was found that the rate was highest about the second day with a gradual dropping off over a period of three months, the maximum period studied. In some samples, the decrease was very slight.

Of the several horizons, the rate was highest from the L and least from the mineral soil, as would be expected. The tendency in all soils is a narrowing of the C-N ratio, ultimately to about 10:1 in cultivated soils. In forest soils, however, the ratio seldom drops lower than 15.

Correlations between rate of decomposition and humus type were not in evidence, nor were there correlations between decomposition and chemical properties of the material (aside from C-N ratio). We know from observation in the field that the litter on mull types disappears as a surface covering more quickly and completely than does that on other humus types. Melin (39) found a parallelism between ratio of decomposition and total nitrogen content *within* a given species but not when different species are involved.

Nitrogen Transformation

The investigations of Hesselman (17), Němec and Kvapil (45), Melin (39) and others stress the importance of nitrogen transformation in forest soils. If the humus becomes inactivated for any reason, stagnation of growth results (49).

The first studies at this Station on nitrification (18) were carried on in samples from young red pine plantations. Samples from the A_0 (principally F layer) and the upper four or five inches of mineral soil ($A_{11}+A_{12}$) were incubated at room temperature for three months. The primary objective was to determine if a correlation could be found between the amount of nitrogen transformed and the site index. Except for the sandy soils in which both site index and nitrogen transformation were low, no correlation was apparent. Possibly the relative youthfulness of the stands, the low requirements of the specie, and the generally favorable growing conditions were the factors responsible for these negative results.

Other studies (24) were made on samples from different types of profiles in Connecticut and a few from New Hampshire. The results may be summarized briefly as follows:

> Ammonification occurred in practically all samples, but nitrification was generally very poor. The addition of lime caused the formation of nitrates at the expense of ammonia. Nitrogen transformation, as a rule, was greater in the F layer than in either the H or the A_1. Inoculation of L layer samples which developed very little ammonia with a water extract of an F or H layer sample which showed high ammonifying capacity, had very little influence on the original samples with respect to the amount of ammonia formed.
>
> Treatments consisting of bloodmeal and potassium phosphate resulted in some increase in nitrogen transformation, due mostly to the bloodmeal, but in no case did all of the nitrogen in the bloodmeal nitrify. Samples possessing a very wide C-N ratio required a large amount of nitrogen to supply the needs of cellulose-decomposing organisms. Otherwise all available soil nitrogen is used by these organisms and no accumulation of ammonia or nitrates will take place.
>
> A positive correlation existed between nitrogen transformation and the pH values, the Ca content and, in some cases, total nitrogen content of the soil. With C-N ratio the correlation was inverse. These relationships were more in evidence with the H layers than with the F.

Later studies were carried on with a modified procedure (26) in which the samples consisted of cores of the upper six or eight inches of soil removed with a sampling cylinder and transferred intact to quart glass jars or cardboard containers. These were incubated out of doors (protected from sun and rain) for three months starting early in May. At the end of the period the organic and mineral portions of each sample were tested separately for ammonia and nitrates. The samples represented a rather wide range of Connecticut forest conditions. The results in brief are as follows:

> 1. The mull types found in fast-growing hardwood stands nitrified to a considerable degree with the formation of only a relatively small amount of ammonia.
>
> 2. The greatest ammonia accumulation occurred in the thick duff found in mature hemlock-hardwood and mature white pine stands.

3. Lime stimulated nitrification in the soil from a white pine plantation but had little effect in a red pine plantation.

4. Soil from a black locust (*Robinia Pseudo-Acacia*) stand nitrified to a marked degree and was in extreme contrast in this respect to a young red pine plantation adjoining. Growth of the red pine trees was directly correlated with the nitrifying capacity of the soil.

5. In general, there was an inverse relation between ammonia accumulation and initial acidity. The change in reaction during the incubation period was toward a lesser acidity where nitrification was greatest.

6. There was no correlation between nitrogen transformation and the amount of other soil constituents as determined by the spot plate method.[1]

The amounts of available nitrogen formed in the soil when incubated under these conditions were much less than in the previous conventional procedure. Maximum concentrations after three months incubation were of the following order of magnitude:

Conventional method (24) : 2500-3000 ppm NH_3N; 1500-3000 ppm NO_3N
Modified method (26) : 700-900 ppm NH_3N; 50-75 ppm NO_3N

It is believed that these lower values are much more nearly representative of natural field conditions. Actually, of course, utilization by the existing vegetation ordinarily prevents the accumulation of even these smaller amounts.

ADDITIONAL CHARACTERISTICS AND RELATIONSHIPS

Composition of the Litter in Relation to Characteristics of the Mineral Soil

In an analysis of the leaves of 23 species, collected in September, McHargue and Roy (35) found variations as follows: nitrogen, 1.08 to 3.12 per cent; total ash, 4.8 to 27.0; phosphorus, 0.07 to 0.56; potassium, 0.60 to 2.27, and calcium, 0.97 to 7.81 per cent. Previous studies have indicated that rate and type of decomposition and the kind of humus resulting, are rather closely identified with the nitrogen and calcium content of the litter, particularly the latter. Because of the importance of calcium, it seems advisable to reproduce in Table 12 data taken in their entirety from Chandler (7). Some of Chandler's analyses were made on samples collected in Connecticut.

The writer analyzed litter samples, collected in the fall, from 37 plots, all of which were hardwoods except two.

These data are summarized in Table 13. The rather wide range in chemical composition is due in part to the variations in specie composition of the mixed hardwoods from which most of the samples were taken and in part to soil differences.

When certain properties of the soil—namely, pH, total bases, per cent saturation, and exchangeable calcium—were plotted against calcium content of the litter in the 37 plots mentioned above, it was found (Figure 15) that best correlation was with the exchangeable calcium content of the A horizon, followed by that of the B, and least by C_1. Correlation with pH, total bases, and per cent saturation was generally good. In practically

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[1] Conn. Agric. Expt. Sta. Bul. 372, 1935, later superseded by Bul. 450 (1941).

Table 12. Percentage Calcium Content of Mature Foliage of Twenty-Seven Forest Tree Species [From Chandler (7)]

Species	Number of trees in sample	Calcium content, expressed as percentage of dry material	
		Range	Average
Tulip poplar (*Liriodendron tulipifera* L.)	14	2.98-3.69	3.24
Red cedar (*Juniperus virginiana* L.)	10	2.63-3.15	2.93
Basswood (*Tilia americana* L.)	26	2.00-3.90	2.81
Black locust (*Robinia Pseudo-Acacia* L.)	11	1.94-3.62	2.65
Mockernut hickory (*Carya alba* [L.] K. Koch)	10	1.68-3.84	2.62
Bitternut hickory (*Carya cordiformis* [Wang.] K. Koch)	10	1.90-3.36	2.50
White cedar (*Thuja occidentalis* L.)	13	2.06-3.10	2.48
Hop hornbeam (*Ostrya virginiana* [Mill.] K. Koch)	16	1.68-3.10	2.27
Trembling aspen (*Populus tremuloides* Michx.)	18	1.62-2.76	2.21
White ash (*Fraxinus americana* L.)	10	1.50-3.56	2.19
Black cherry (*Prunus serotina* Ehrh.)	4	1.88-2.40	2.14
Shagbark hickory (*Carya ovata* [Mill.] K. Koch)	10	1.34-2.46	1.94
American elm (*Ulmus americana* L.)	10	1.40-2.23	1.81
Sugar maple (*Acer saccharum* Marsh.)	85	1.06-2.91	1.75
Norway spruce (*Picea excelsa* Link)	6	1.52-1.71	1.60
White oak (*Quercus alba* L.)	15	1.22-1.46	1.36
Red oak (*Quercus borealis* Michx. f. var. *Maxima* Ashe)	11	0.99-1.76	1.21
Yellow birch (*Betula lutea* Michx. f.)	34	0.96-1.52	1.21
Chestnut oak (*Quercus montana* Willd.)	6	0.80-1.55	1.20
White pine (*Pinus strobus* L.)	15	0.70-1.55	1.20
Balsam fir (*Abies balsamea* [L.] Mill.)	10	0.75-1.35	1.15
Red maple (*Acer rubrum* L.)	40	0.68-1.90	0.91
Red pine (*Pinus resinosa* Ait.)	13	0.50-1.05	0.80
Hemlock (*Tsuga canadensis* [L.] Carr.)	12	0.50-0.90	0.80
Beech (*Fagus grandifolia* Ehrh.)	65	0.50-1.50	0.75
Scotch pine (*Pinus sylvestris* L.)	10	0.50-0.80	0.69
Red spruce (*Picea rubra* [DuRoi] Dietr.)	10	0.44-0.73	0.62

TABLE 13. COMPOSITION OF FOREST LITTER FROM 37 PLOTS

	Average	Range	
pH	4.37	3.50 -	5.10
Per cent Nitrogen	0.797	0.576 -	1.260
" Carbon	50.2	45.5 -	51.6
" Loss-on-ignition	95.4	88.5 -	98.0
" Phosphorus	0.073	0.026 -	0.180
" Potassium	0.273	0.137 -	0.530
" Calcium	1.085	0.462 -	1.890
" Magnesium	0.197	0.096 -	0.376

all cases it was poorest with the C_1 layer. It would seem that the B_{22} horizon would influence the composition of the litter more, perhaps, than any other portion of the profile. However, statistical analysis showed a

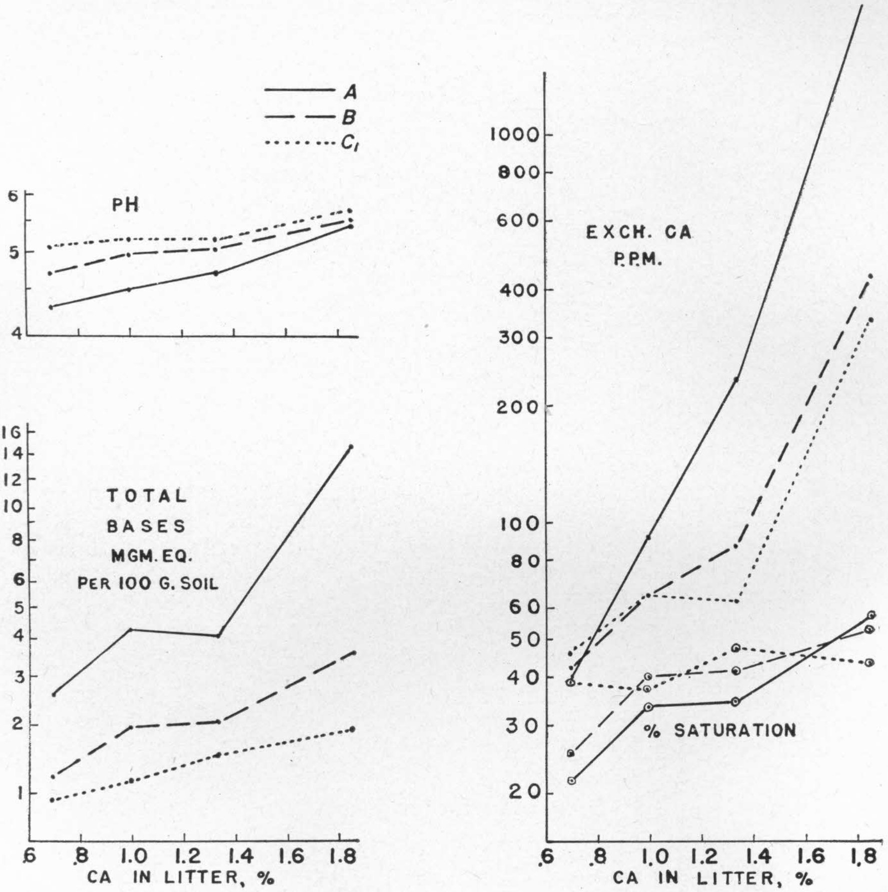

Figure 15. Relation between the calcium content of the litter (A_{00}) and the following soil properties: pH, total bases, exchangeable calcium and per cent saturation.

correlation of only 0.551 ± .081 between the exchangeable calcium content of the B_{22} horizon and that of the litter. As a further check on these relationships, the K, Ca and Mg contents of the litter were compared with the per cent saturation of the A horizon. Neither K nor Mg showed any correlation whatever. Calcium was definitely and positively correlated, as was total bases (sum of the three) but, in the latter case, it was the calcium that governed the relationship, inasmuch as calcium was present in much larger quantities than either of the other two bases.

Further information on calcium relationships in the forest floor was obtained by Garstka (13), who studied the calcium content of the F layer of 12 forest types in Connecticut and found distinct differences between some of the types. The total calcium content, in per cent, averaged as follows:

Oak—hickory hardwoods	1.74	1.56 Average
Seedling hardwoods (after gray birch)	1.52	
Bottom land hardwoods (immature)	1.51	
Bottom land hardwoods (mature)	1.46	
Mixed oaks	1.13	1.12 Average
Scarlet oak—mixed oaks (mature)	1.12	
Hemlock—hardwoods	1.12	
Gray birch (old field)	.99	.89 Average
Scarlet oak—mixed oaks (immature)	.95	
White pine (old field, immature)	.73	
White pine (old field, mature)	.45	.40 Average
Pitch pine (*Pinus rigida*) (old field, mature)	.35	

These differences are highly significant. A similar relationship was found in the exchangeable calcium data. Garstka's study showed ". . . a remarkable degree of uniformity in the total and replaceable calcium contents of samples widely separated geographically and from different soil types, but from the same forest type".

Wilde (55) compared the nutrient content of different types of organic remains from upland forests and found that hardwood-hemlock duff[1] contained the largest amount of available phosphorus and potassium, hardwood duff the most calcium, and the following four duffs approximately equally high amounts of total nitrogen: hemlock, hardwood-hemlock, hardwood-spruce-fir, and hardwood. Alway et al. (2) found that both the freshly fallen litter and the underlying humus in maple-basswood forests contained considerably more lime, phosphorus, potash, sulfur and nitrogen than did the litter and humus in jack pine (*Pinus Banksiana*) and Norway (red) pine forest, with white pine intermediate. All of these occurred on the same soil type, Cass Lake Fine Sand.

Forest Lysimeter Studies

Another method of ascertaining the properties of forest soil is through the use of lysimeters. Such a study was conducted a few years ago in a red pine plantation and later in a mixed hardwood stand (27, 31) in which

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[1] The total mass of organic debris on the ground, also referred to as *forest floor*.

the object was to study the movement of nutrients out of (a) the forest floor, and (b) the upper four inches of mineral soil. Two types of lysimeters were used: the tank or filled type, four inches deep, in which the soil was free of root competition; and the pan type where the roots were largely undisturbed. In the latter instance the "pan" was inserted either on the surface of the mineral soil just beneath the forest floor, or in the mineral soil four inches below the surface. Complete data and full discussion of the results were given in previous publications (27, 31). Only a brief summarization will be made here.

The average yearly removals of nitrogen and other nutrients from the A_1 and A_0, separately and together as a unit, are given in Table 14. The effect of live roots in the soil greatly lessened the losses, particularly in the $A_0 + A_1$. This, of course, is the true condition existing in the forest. The soils free of roots (in tanks) were in a decidedly unnatural condition and the data obtained from them are of value primarily in showing the possible maximum losses, that is, losses from these particular portions of the profile. The experiment did not provide information on whether these materials were entirely lost or were merely washed down into some of the lower layers, to be brought back up again later. In the case of the pan lysimeters where roots were present, the amounts obtained were extremely low and it is obvious that no permanent losses took place. In contrast, Morgan et al. (44) reported the following losses from 30-inch tanks containing Merrimac sandy loam:

Average Yearly Drainage Water Losses from Tanks Receiving
No Nitrogen, in Pounds per Acre

	N	Ca	K	Mg	S
No Crop	53	83	95	18	65
Tobacco	27	58	75	15	58
Grass Sod	3	48	63	13	59

Direct comparisons are risky, of course, because of the differences in conditions under which the two experiments were conducted, but it is obvious that losses are markedly lower in the forest.

Of the nitrogen contained in the leachate from the forest soils ($A_0 + A_1$), some 80 per cent was in the form of nitrates where the soil was root-free, and 9 to 38 per cent as nitrates in the undisturbed soil, showing that nitrates tend to accumulate in the absence of roots and where moisture conditions are more favorable. The tank soils were almost always higher in moisture than the pan soils. Nitrogen transformation continued into early winter, and the concentration of nitrogen and other constituents was frequently as high in winter as at any other time of the year. This is in contrast to the situation found in eight-inch deep lysimeter tanks containing agricultural soils (20) at Windsor, in which winter production of available nitrogen was only a minute fraction of that produced during the growing season.

Pot Culture Studies with Undisturbed Soil

A still different approach toward the understanding of conditions existing in the upper portion of the profile and the effect of certain treatments

TABLE 14. AVERAGE YEARLY AMOUNTS OF THE SEVERAL ELEMENTS LEACHED FROM FOREST SOIL

Pounds per Acre

Element		Red Pine on Hartford gravelly f.s.l.			Mixed Hardwoods on Grafton fine sandy loam		
		A_0[1]	A_1[2]	$A_0 + A_1$	A_0[3]	A_1[2]	$A_0 + A_1$
Total Nitrogen.	Tanks[4] ..	24.3	34.6	43.7	43.1	45.0	83.2
	Pans[5] ...	16.7	3.4	1.1	10.4	1.6	1.4
Calcium	Tanks ..	49.6	41.7	48.1	24.7	13.8	24.7
	Pans	30.0	9.6	3.0	16.2	2.1	2.2
Potassium	Tanks ..	24.5	16.1	23.6	35.2	41.0	44.0
	Pans	14.7	3.3	1.0	19.5	3.2	3.7
Sulfur	Tanks ..	31.9	16.7	33.0	29.6	22.4	37.7
	Pans	18.1	8.7	2.0	15.7	6.1	5.5
Magnesium ...	Tanks ..	...	...	...	4.52	3.80	7.08
	Pans	...	...	...	3.08	0.75	1.42
Phosphorus ...	Tanks ..	...	...	...	0.655	0.126	0.239
	Pans	...	...	...	0.514	0.052	0.073

[1] Pine needle F layer about 1 inch thick, underlain by a crumb mull condition.

[2] The top 4 inches of mineral soil.

[3] F ½ inch; H ½ inch, — *fibrous mor type.*

[4] Soil in tanks was free of root competition.

[5] Soil over pans was subject to natural root competition.

on these conditions was taken in a pot culture experiment (30). Small blocks of the top six or seven inches of soil (Gloucester stony fine sandy loam), together with the overlying A_0 layer, were excavated from a slow growing, low quality oak stand in the Pachaug State Forest. The characteristics of the soil and humus layer, and of the stand, were similar to those described in profiles 51, 52 and 87. These soil blocks were transferred with a minimum of disturbance to two-gallon pots and to wooden squares (12 x 12 x 6 inches). Treatments consisted of several combinations of fertilizer and lime in one series, and burning, raking and mixing of the A_0 in the other. Norway spruce (*Picea Abies*) was seeded and, at intervals, the pots (but not the squares) were flooded with water which, after standing about three hours, was removed by suction and analyzed.

Briefly the findings were as follows: (a) The seedlings suffered high losses where the normal humus cover was present, but relatively low mortality where the humus was removed, burned or turned under. Obviously, damping off was much more prevalent in the presence of organic matter on the surface. (b) Phosphorus treatments, alone or with nitrogen, had a generally favorable effect upon growth. (c) Fertilizer treatments resulted in an increase in available nutrients and in total nitrogen and organic matter in the soil. (d) There was a tendency toward a narrowing of the organic matter—nitrogen (OM/N) ratio of the A_2 as the result of burning, raking or mixing of the A_0.

Pot Culture Studies with Soil-Sand Mixtures

Using a technique similar to that frequently employed in soil fertility investigations of agricultural soils, a greenhouse study[1] was made of the crop-producing power of two forest soils. One was a Shapleigh (shallow Gloucester) stony fine sandy loam in Bethany, on which there was a slow growing stand of scarlet and chestnut oak. The matted F layer was one inch thick, and the black, felty, fibrous H layer 1.5 inches (Figure 3). The other soil was Wethersfield loam, located on the property of the Beseck Fish and Game Club, Middlefield, supporting a vigorously growing high forest of mixed hardwoods (Figure 16). This was an excellent mull

Figure 16. Excellent, fast-growing hardwood stand on a good mull soil (Cheshire loam). Middlefield.

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[1] Carried on by M. F. Morgan and H. G. M. Jacobson of this Station in 1931; not previously published.

with no duff on the ground except the current leaf fall. The following mixtures of soil and quartz sand, by volume, were potted:

Gloucester st. f.s.l.

Horizon	Humus or Soil	Sand
F	1/3	2/3
H	1/3	2/3
A	1/2	1/2
Composite	1/3	2/3

Wethersfield Loam

Horizon	Humus or Soil	Sand
L	1/3	2/3
..	...	...
A	1/2	1/2
Composite	1/3	2/3

The composite was a mixture of top soil and the overlying forest floor, such as would be included in the plowing of a forest soil. After applying fertilizer treatments, two crops of tobacco and one of oats were grown. Table 15 gives the characteristics of the soils used in this study, prior to mixing with sand.

TABLE 15. CHARACTERISTICS OF SOILS USED IN POT CULTURE STUDY

(Data refers to the original material prior to mixing with sand)

	Gloucester f.s.l. (fibrous mor)				Wethersfield l. (granular mull)		
Soil No. →	358	359	360	361	362	363	364
Horizon →	F	H	A	Comp.[1]	L	A	Comp.[1]
pH	4.60	4.11	4.35	4.43	4.79	5.08	5.18
Total nitrogen[2] ......%	1.65	1.23	0.22	0.32	0.97	0.14	0.19
Total phosphorus[2] ...%	0.11	0.11	0.09	0.09	0.13	0.06	0.08
Total potassium[2] .....%	0.41	0.52	0.94	0.83	0.25	1.18	1.22
Total calcium[2] ....%	1.23	0.52	0.45	0.77	1.59	0.31	0.49
Organic carbon ......%	47.50	35.80	5.40	8.03	45.50	3.42	4.50
C:N	28.8	29.16	24.22	25.21	47.15	24.96	23.56
Exch. K mg. eq./100 g soil	1.30	1.11	0.18	0.27	1.27	0.17	0.27
Exch. Ca mg. eq./100 g soil	25.50	8.50	.37	1.05	28.25	2.89	3.38
Exch. Mg mg. eq./100 g soil	2.84	1.79	.56	1.23	3.25	1.87	1.85
Base capacity mg. eq./100 g soil	75	62	11	17	65	12	11
NH_3—N ....ppm	290	245	27	...	380	51	...
NO_3—N ....ppm	0	0	0	0	0	0	0
Available P (Truog) ppm	120	28	55	38	80	13	11
Active aluminum...ppm	0.5	2.5	50	25	0	20	15
Active manganese ..ppm	1680	440	28	82	440	50	55
$CaCO_3$ requirement (Jones) ...... lbs/A.	331[3]	1588[4]	4614[5]	7270[6]	46[7]	2680[8]	3900[6]
Increase in available N during 3 months incubation							
Untreated							
NH_3—N ....ppm	1983	955	100	140	–305	11	–52
NO_3—N ....ppm	0	17	12	12	0	95	154
NPK treatment							
NH_3—N ....ppm	2495	1365	472	..	–290	654	..
NO_3—N ....ppm	0	27	164	..	0	435	..

[1] Composite,—mixture of duff and mineral soil.

[2] Oven-dry basis; all other data on air-dry basis.

[3] Based on 15,000 lbs. soil per acre.

[4] 6,000 lbs./A.

[5] 750,000 lbs./A.

[6] 950,000 lbs./A.

[7] 3,000 lbs./A.

[8] 725,000 lbs./A.

The differences between the Gloucester and Wethersfield soils are quite pronounced in many respects, notably in the C-N ratio in the forest floor, the total and exchangeable Ca content, the lime requirement, and the increase or decrease in ammonia and nitrates during incubation. Evaluation of the comparative fertility of the two soils on the basis of these analyses is difficult because neither soil is superior to the other in all tests. However, the lower acidity and lime requirement, the higher exchangeable Ca and Mg content, and the higher degree of nitrification in the Wethersfield soil would indicate a somewhat superior medium for plant growth as compared with the Gloucester soil.

Treatments and yields are presented in Table 16. Photographs of the first and second tobacco crops grown on the Gloucester F layer-sand mixture and on the A horizon-sand mixture just before harvest are shown in Figure 17.

It should be emphasized that deficiencies are accentuated by the techniques used in this work, first by the diluting effect of the sand which causes deficiencies to appear more quickly than they otherwise would, and second, through the application of incomplete mixtures which tends to exaggerate the deficiency of elements not added. Frequently, a soil receiving an incomplete fertilizer will produce lower yields than the same soil without any fertilizer. The method is probably of most value in indicating which elements are present in abundance. For example, if the yield with NP is as high as with NPK, then it is obvious that the available potassium supply in that particular soil is ample, for the immediate future at least. If the NP yield is less than with NPK, potassium is needed if N and P are in abundance. If the NP yield is no better than the N yield, then either P is in abundant supply or K is deficient.

The main points to be observed in Table 16 are as follows: (a) In the case of the Gloucester soil, the yields of the F and H mixtures tended to exceed those of the A horizon for the two crops of tobacco, but not for the oats crop. (b) In the second tobacco crop on Wethersfield soil, the L mixture averaged higher yields than the A mixture, but otherwise there was little difference. (c) The Wethersfield L mixture produced conspicuously lower tobacco yields than did either the Gloucester F or the Gloucester H mixtures except where N and P were included. The wide C-N ratio of the L layer was undoubtedly an important factor with respect to N response. (d) The Wethersfield A horizon produced, on the whole, larger yields than did the Gloucester A horizon. (e) The oat yields without treatment or with N alone were proportionally much higher than were the previous tobacco yields, indicating either a somewhat lower nutrient requirement, or the presence of residual nutrients from the previous cropping, or both. (f) There was a general lack of response to lime. Although neither tobacco nor oats have a high lime requirement, it would be expected that, in soils as acid as these were, lime would have resulted in some increase in growth. (g) In the first crop the Wethersfield composites consistently outyielded the Gloucester composites, but not in the second or third crops. This was due probably to the higher initial nitrate nitrogen content of the Wethersfield soil, while for the later crops

TABLE 16. YIELDS ON SAND-SOIL MIXTURES IN GREENHOUSE POT CULTURES, 1931

Total Dry Weight, in Grams, from Two Pots

		Treatments[1]												
Soil		O	N	NP	PK	NPK	Av. no lime	L	LNK	LNP	LPK	LNPK	Av. with lime	Over-all Av.
							Tobacco, 1st Crop							
Gloucester f.s.l. (mor)	F	17.5	20.8	20.9	32.2	53.9	29.1	12.6	18.1	23.9	19.7	48.4	24.5	26.8
	H	7.5	21.0	22.0	18.0	58.9	25.3	12.6	20.2	34.2	45.0	44.8	31.4	28.4
	A	1.4	1.6	17.1	25.3	31.9	15.5	6.4	3.7	13.0	19.3	17.8	12.0	13.7
	Comp.[2]	...	...	...	...	42.0	...	...	4.6	20.4	31.8	19.8	19.2	23.7
Wethersfield loam (mull)	L	0.3	3.6	29.4	0.2	51.5	17.0	0.2	1.4	25.2	0.1	31.6	11.7	14.3
	A	4.4	3.2	25.0	33.3	51.8	23.5	3.6	2.0	20.4	37.1	34.8	19.6	21.6
	Comp.	..	...	...	...	49.7	...	...	5.6	25.8	35.0	32.4	24.7	29.7
							Tobacco, 2nd Crop							
Gloucester f.s.l. (mor)	F	13.2	14.2	9.5	12.0	55.0	20.8	4.8	1.7	7.4	14.9	51.6	16.1	18.4
	H	4.7	5.8	3.3	24.8	73.4	22.4	1.4	1.9	2.0	1.4	59.6	13.3	17.8
	A	5.3	0.5	1.7	8.8	42.2	11.7	2.9	2.3	3.0	16.5	53.8	15.7	13.7
	Comp.	...	...	...	...	46.1	...	...	3.5	2.3	11.2	55.3	18.1	23.7
Wethersfield loam (mull)	L	1.5	9.8	13.1	2.4	56.4	16.6	0.6	5.2	15.8	1.8	66.5	18.0	17.3
	A	5.2	3.2	1.6	10.1	37.3	11.5	9.8	11.5	3.6	18.0	42.2	17.0	14.3
	Comp.	...	...	...	...	54.5	...	...	6.0	2.7	9.8	48.3	16.7	24.3
							Oat Crop (Following Tobacco)							
Gloucester f.s.l. (mor)	F	15.3	41.4	11.8	21.7	42.9	26.6	16.6	41.5	16.1	22.1	41.1	27.5	27.1
	H	13.3	38.4	11.5	21.3	49.7	26.8	15.1	33.8	15.9	29.9	47.9	28.5	27.7
	A	14.8	12.9	19.0	19.6	43.2	21.9	20.3	35.0	23.0	28.5	40.3	29.4	25.7
	Comp.	...	...	...	...	49.8	...	...	33.8	24.0	16.6	49.7	31.0	34.8
Wethersfield loam (mull)	L	14.3	15.3	5.1	19.8	41.5	19.2	9.6	25.7	12.5	18.4	47.2	22.9	20.9
	A	19.2	21.5	20.9	24.8	47.2	26.7	19.8	33.1	25.3	34.3	48.2	32.1	29.4
	Comp.	...	...	...	...	58.0	...	...	21.4	23.2	21.9	53.7	30.1	35.6

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[1] The original treatments supplied the following amounts per pot: N 1.2 g, P_2O_5 1.0 g, K_2O 1.0 g. Following harvest, the soils were flooded with water, drained by suction, and fertilized. For the second tobacco crop 1.0 g each of N, P_2O_5, and K_2O respectively; for oats, 1.0, 1.5, and 1.0 g. All soils received also a minor element solution containing Mg, Mn, Fe, S, and Cl ions.

[2] Composite: A mixture of top soil and the overlying duff, such as would be included in the plowing of a forest soil.

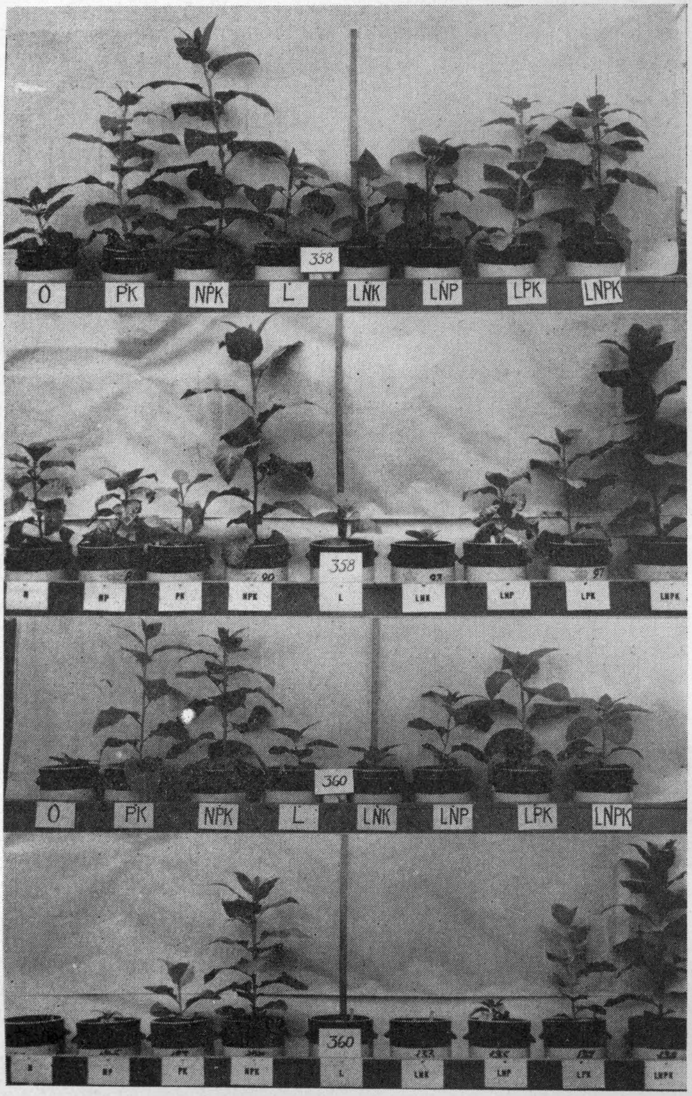

Figure 17. Tobacco plants grown in humus-sand mixture (358) and in soil-sand mixture (360). Gloucester f.s.l., fibrous mor.

In order from top to bottom:

First crop on soil mixture 358 (F layer 1 part, sand 2 parts)
Second crop on soil mixture 358 (F layer 1 part, sand 2 parts)
First crop on soil mixture 360 (mineral soil, A, 1 part, sand 1 part)
Second crop on soil mixture 360 (mineral soil, A, 1 part, sand 1 part)

O—no treatment
P—phosphorus
N—nitrogen
K—potassium
L—lime

the nitrogen in the Gloucester soil may have nitrified sufficiently to provide relatively more available N than in the Wethersfield soil.

In Table 17 will be found comparative yields of the two forest soil composites and those of four agricultural soils, all mixed with sand in the ratio of 1 to 2 by volume, for the NPK and LNPK treatments. No comparable data were available on untreated soils. It is seen that the forest soil yields were equal to or better than those from the agricultural soils. It is believed that the yields on unfertilized forest soils would be initially higher than those of untreated agricultural soils, provided the acidity was not too high, but would decline rather rapidly with succeeding crops to an ultimate level below the agricultural soils. When adequately limed, the yields of fertilized forest soils are likely to remain higher than those of similarly fertilized farm soils for a considerable period of time, due to the reserve supply of humus.

TABLE 17. COMPARISON OF YIELDS OF FOREST SOIL COMPOSITES AND FOUR AGRICULTURAL SOILS IN SOIL-SAND MIXTURES

Total Dry Weight, in Grams, from 2 Pots

	Forest Soils		Agricultural Soils			
Crop	Soil No. 361 Gloucester f.s.l.	Soil No. 364 Wethersfield loam	Pasture Charlton loam	Expt. Field Merrimac loam	Tobacco Merrimac s.l.	Grass Hay Dutchess si.l.
			NPK[1]			
Tobacco 1st crop	42	50	30	21	41	41
" 2nd "	46	55	25	22	26	41
Oats	50	58	46	13	38	45
			LNPK[2]			
Tobacco 1st crop	20	32	23	18	33	19
" 2nd "	55	48	30	28	27	32
Oats	50	54	43	..	45	43

[1] 1.2 g N, 1 g P_2O_5, and 1 g K_2O per two-gallon pot. Between crops the soils were flooded, then drained and refertilized at the same rate.

[2] Same as NPK but limed, using variable amounts of precipitated chalk, depending on the original pH.

Comparison of Forest, Pasture and Cultivated Soils

In an erosion study[1] conducted in south-central Connecticut, nine locations were selected where adjacent or nearby fields of practically identical slope and of apparently the same inherent characteristics were represented by the following conditions: (a) ungrazed woodland with no evidence of former clearing or cultivation; (b) land in permanent pasture or old orchard sod for at least 40 years, and (c) land frequently cultivated during the past 40 years or more. Seven of the locations were on Cheshire fine sandy loam and two on Wethersfield fine sandy loam. The humus types in the woodlands varied from a weakly developed granular mor (consisting of only an F layer ½ inch or less in thickness) to a crumb mull. Samples

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[1] Erosion as related to land use and land capability in south-central Connecticut, by M. F. Morgan, et al. (Unpublished)

of all horizons were collected for analysis and larger quantities of the A horizon were brought to the greenhouse for pot culture studies.

Table 18 contains the results of the physical and chemical analysis as averages for the nine locations. The right half indicates whether or not the differences between the three types are significant as determined by analysis of variance.

In the A horizon the woodland soils were characterized by significantly lower volume weight and pH, and higher moisture equivalent, water-holding capacity, total nitrogen, exchangeable hydrogen and base exchange capacity. The cultivated soils were definitely highest in available phosphorus and exchangeable calcium as the result of fertilization and liming and lowest in water-holding capacity.

The only significant difference observed in the B horizon was the lower pH of the wooded soils. Additional analyses, such as permeability and air capacity of the whole soil mass, would very likely reveal further differences but the differences would be much more difficult to find.

These results serve to demonstrate that mineral soil conditions in the forest are, for the most part, superior to those in meadow and in cultivated soils. It does not take into account the nutrients in the overlying forest floor which are important in tree nutrition but which do not exist outside of the forest. Comparison of the full forest soil profile with that of farm soils would show even more striking differences.

There are three principal factors accounting for these differences: (a) The presence of the mulch of forest leaves and other debris; (b) the presence of deeply penetrating tree roots which serve to admit air and moisture to the subsoil, and (c) the fact that little or nothing is removed from the forest, while on the other hand, farm crops are harvested regularly and much of the nutritive material removed permanently from the farm.

Root Development in Relation to Soil Properties

In a study of the root distribution of two seven-year old plantations of white pine, red pine, Norway spruce, white ash and red oak planted in pure and mixed rows in northern Connecticut, Garin (12) found that the soil in the zones of greater root concentration had a significantly higher moisture equivalent, loss-on-ignition, total nitrogen and total exchange capacity than did the soil where roots were few or absent. It was further found that the roots in Merrimac loamy sand contained more mycorrhizae, and penetrated deeper and showed greater lateral spread than did those in Charlton fine sandy loam. Also, there were significantly fewer small roots in the Merrimac soil. Red pine roots often go down 10 to 15 feet or more in gravelly soil (Figure 18).

With respect to species, white pine had the greatest number of roots of all sizes, and a short stubby tap root, with small roots forming a heavy mass around the root crown. Red pine showed a strong tendency to form a tap root, and the smaller roots were more equally distributed between the A and B horizons than in the case of white pine. Norway spruce had

TABLE 18. COMPARATIVE PROPERTIES OF SOILS IN WOODLOTS, UNDER SOD, AND CULTIVATED
Cheshire and Wethersfield fine sandy loam

	Mean values			Significance of differences							
	Woods	Sod	Cultivated	Between stations	Between types	Woods vs. sod+cult.	Sod vs. cultivated	Woods vs. cult.	Woods+cult. vs. sod	Woods+sod vs. cult	Woods vs. sod
A Horizon											
Volume Weight	0.99	1.22	1.26	XX	XX	XX	o	....	....	....	....
Moisture Equivalent %	24.0	18.0	17.3	X	XX	XX	o	....	....	....	....
Water-holding capacity	64.7	50.6	46.3	o	XX	XX	o	....	....	....	....
pH	4.88	5.24	5.43	X	XX	XX	o	....	....	....	....
Total nitrogen %	0.215	0.146	0.145	o	XX	XX	o	....	....	....	....
Organic carbon %	3.98	1.99	1.94	X	o	....	....	....	....	....	....
Total phosphorus %	0.083	0.072	0.075	X	o	....	....	....	....	....	....
Total potassium %	1.297	1.386	1.319	o	X	o	XX	....	....	XX	o
Available phosphorus ppm	34.8	23.1	67.7	o	X	o	X	o	XX	....	....
Exchangeable potassium ME[1]	0.236	0.138	0.226	o	XX	....	....	....	....	XX	o
Exchangeable calcium ME	0.931	1.333	2.646	o	o	....	....	....	....	....	....
Exchangeable magnesium ME	0.484	0.451	0.799	o	XX	XX	o	....	....	....	....
Exchangeable hydrogen ME	8.9	5.3	4.5	o	XX	XX	o	....	....	....	....
Base exchange capacity ME	12.4	8.4	8.2	o	XX	XX	o	....	....	....	....
B Horizon											
Moisture Equivalent %	15.1	13.0	13.8	X	o	....	....	....	....	....	....
Colloids %	16.7	12.7	16.9	XX	o	....	....	....	....	....	....
pH	5.00	5.59	5.39	o	XX	XX	o	....	....	....	....

[1] Milligram equivalents per 100 grams soil.
XX Highly significant.
X Significant.
o Not significant.
.... Not determined.

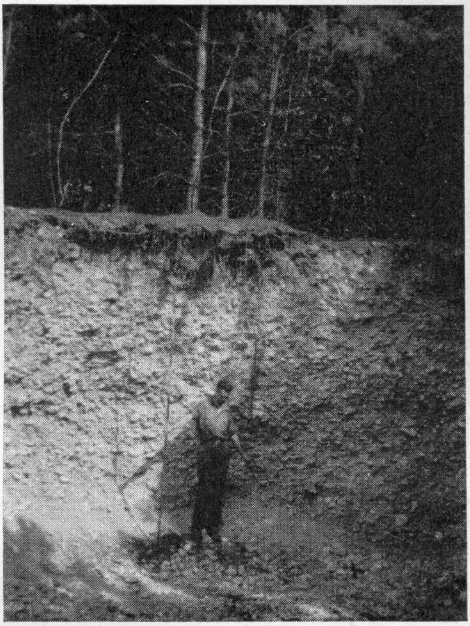

Figure 18. Red pine growing on a gravelly kame (Hinckley sandy loam, gravelly phase), showing depth of root penetration.

next to the lowest number of roots, with a higher proportion of the total in the A horizon. It had no true tap root, and the lateral roots remained near the surface. White ash generally had a tap root which branched into several heavy roots with a conspicuous downward trend. Lateral branches did not come out in a mass as they did in conifers, and the proportion of small roots was considerably greater than in the other species. Red oak had a definite tap root which, in some cases, turned horizontally and continued its development on that plane, a situation common on the heavier soil which had a relatively high water table. Lateral branching of red oak roots was quite extensive but the total number of roots of all sizes was least of the five species.

According to Coile (8) every forest soil, under given forest and climatic conditions, has its "root capacity". Hence, true root competition presumably does not begin until the root capacity is reached. Garin's observations tend to support that view. His investigations led him to suggest (12) that "in devising a proper mixture of tree species, consideration be given to a combination of those with shallow and deep root systems, of those forming compact and spreading root masses and of those having a tendency to either build up or lower the acidity of the soil. The use of some tree species on shallow or rich soils and others on poor or deep soils is suggested. The information can also be utilized in diagnosing poor or good growth . . . . on certain sites . . . ."

Effect of Fire on the Soil

No extensive studies on the effect of fire on the soil have been made by this Station. A few samples collected in 1937 in adjacent burned and unburned areas (the fire occurring in 1930 in one case and in 1934 in the other), on upland till soils, showed the following results:

- (a) Original field samples
  1. pH of A_0 and A_{11} were slightly higher in the burn.
  2. Ammonia nitrogen, available phosphorus and exchangeable potassium of the A_0 were conspicuously lower in the burn.
- (b) After three months incubation in the laboratory
  1. pH and ammonia nitrogen of A_0 and A_{11} were slightly lower in the burn.
  2. Exchangeable potassium of the A_0 was lower in the burn.
  3. Exchangeable calcium of the A_0 and A_{11} was conspicuously higher in the burn.

It would seem that, as a result of fire, phosphorus and potassium were lost, the former probably converted to insoluble iron and aluminum phosphate, the latter leached out of the soil in soluble form. On the other hand, calcium tended to increase in concentration and thereby affected the pH and ammonifying power of the soil. Nitrates were very low in all cases and showed no differences at the time of sampling.

At the Rainbow Plantation in Windsor the litter on certain red pine and white pine plots was burned off annually, starting in 1929. Soil studies at the end of 15 years showed no positive effect of burning on the available nitrogen, either in the field soil or after incubation in the laboratory. The use of lime had a much stronger influence, reducing ammonia formation and increasing nitrification. Other tests on the soils, however, showed that burning resulted in a higher pH, and an increase in total nitrogen, organic carbon and available phosphorus in the A. Exchangeable calcium was increased in the A_{11}; exchangeable hydrogen was slightly lower in A_{11}, A_{12} and B_{21}.

In the pot culture experiment (30) with undisturbed blocks of soil, described on p. 56, burning the A_0 resulted in an increase in pH and in exchangeable calcium, total nitrogen and organic matter content of the A_2 horizon. Analysis of the drainage water showed that the water from the burned soils had a higher pH, a lower conductivity and a lower ammonia and available potassium content than did the water from the unburned series. Burning resulted in a much better survival but poorer growth than on the unburned soils.

DISCUSSION

Soil Differences

Critical examination of the characteristics of *individual soil series* and appraisal of their relative merits for the production of timber was not an objective in this work. As previously stated, it is believed that differences between individual soil series within any one soil series group (p. 21) are small and not significant from the standpoint of tree growth.

Differences between *soil series groups,* however, are in evidence. There is some indication, for example, that the amount of exchangeable calcium in the subsoils of the Triassic soil group is higher than in non-Triassic but otherwise similar soils. Marked differences in drainage, texture, and composition of the parent material and associated rock are reflected, of course, in differences in soil composition. On the basis of native fertility, soils derived from traprock are unquestionably the most fertile in the State. Practically, however, owing to shallowness or excessive stoniness they do not usually show a high site quality. Deeper soils derived from a mixture of traprock and red sandstone till are superior to those whose parent material contains no traprock.

The soils in the limestone areas of this State have not been sufficiently investigated to permit their evaluation for timber production. The limited data on hand, however, indicate that such soils are well supplied with bases and rank high in crop producing power. Reports from investigators elsewhere show that soils derived from limestone (if not seriously leached) are capable of producing excellent tree growth.

As shown in the catena key, soils influenced by limestone come under three categories, viz. (a) those which are neutral or slightly alkaline in the surface, and strongly calcareous in the C horizon, represented by the Pittsfield and Dover series; (b) those that are quite acid in the surface and practically neutral or very slightly alkaline in the C,—Lenox and Colrain series, and (c) an intermediate group of which Cossayuna and Stockbridge are representative.

These groups, especially the first and second, should show considerable difference in their profile characteristics as measured in the laboratory, and in kind of vegetation which they support, including forest composition and rate of growth. Further work on these soils remains to be done, although the area involved is small compared with the rest of the State.

The importance of the kind of rock in influencing profile development where climatic differences are not a factor is well illustrated in the diagram prepared by Pallmann (47) and reproduced in Figure 19 for the benefit of American soil scientists. The most extreme differences occur in the mature soils designated in the diagram as climax soils, and the wide range from immature to mature soils occurs only where marked differences in climate are found, such as in going from low to high elevations, or from one climatic region to another. In Connecticut only those conditions depicted by the extreme right and left portions of the diagram will be found. The same principles hold here as elsewhere; the difference is only one of degree.

Profile differences based on mode of formation and texture are readily demonstrated. The sandy and gravelly glaciofluvial soils are usually low in fertility due to their low colloid content (both organic and inorganic colloids). Moderately well drained and poorly drained soils contain more than average amounts of nitrogen and organic matter and, in many instances, bases. Their suitability for tree growth depends upon depth to bedrock, the degree of drainage and other factors of site, and the species grown.

Reference has been made (pp. 11, 57) to the soils in the southeastern part of the State which are podzolized and on which fibrous mor tends

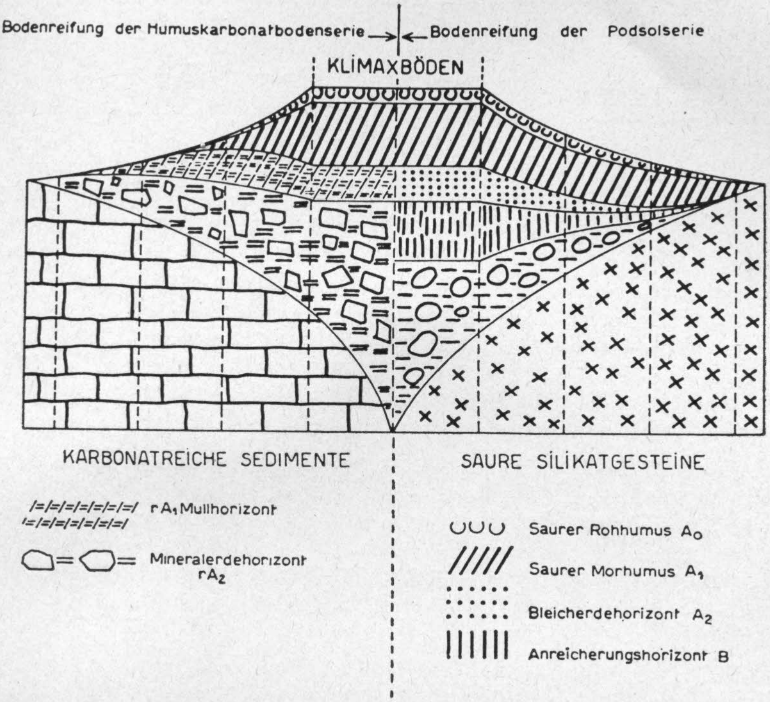

Figure 19. The relation between degree of soil maturity, character of parent rock, and morphological characteristics of the profile (from Pallmann [47]). Limestone rock on the left half of the diagram, acidic rock on the right.

to accumulate. The stands on these soils are rather open, slow-growing, and unthrifty (site index about 52 compared with a State average of 59.7) (28). That these soils are lower than average in fertility is shown in Table 19. Total nitrogen, total cation content and cation exchange capacity of soils from the Pachaug State Forest area in Voluntown, and the Cockaponset State Forest in Haddam, Chester and Killingworth are compared with soils from part of the Natchaug State Forest in Eastford (northeastern section of the State), and with soils from other sections of Connecticut. Sandy and gravelly terrace soils (Merrimac and Hinckley series) are obviously low in fertility and were excluded. Separation of the soils in the Natchaug State Forest was made because of the definitely higher values found in these soils. In this case, however, the high average was due in part to the fact that two of the six soils were in the lower drainage classes.

Differences in nitrogen are greatest in evidence in the A horizon, but they are also present in the B_{22} and C_1 layers. All horizons show marked differences in cation content and cation exchange capacity.

The relation between soil fertility and humus type has been mentioned. According to Bornebush [reported by Mar: Möller (37)], "The causes of

TABLE 19. NATIVE FERTILITY OF SOILS IN SEVERAL DIFFERENT SECTIONS OF THE STATE

Averages and Standard Deviations

	Horizon	Pachaug and Cockaponset Forests (11-15 profiles)	Natchaug Forest (6 profiles)	Other parts of the State (12-21 profiles)
Total Nitrogen, %	F	1.285 ± .235	1.350 ± .096	1.295 ± .195
	H	1.177 ± .316	1.293 ± .223	1.047 ± .133
	A	0.120 ± .040	0.267 ± .072	0.209 ± .090
	B_{21}	0.081 ± .043	0.131 ± .081	0.081 ± .047
	B_{22}	0.031 ± .014	0.049 ± .009	0.041 ± .016
	C_1	0.011 ± .005	0.025 ± .011	0.019 ± .009
Total Pounds N per Acre (to 30 inch depth)		4196[1] ± 1031	7349 ± 1598	5591[2] ± 1880
Total Bases, mgm. equiv. per 100 g. soil	A	2.02 ± 1.39	6.24 ± 1.95	3.75 ± 1.56
	B_{21}	1.01 ± 0.48	3.15 ± 0.67	2.39 ± 1.62
	B_{22}	0.69 ± 0.51	1.88 ± 1.19	1.93 ± 1.67
	C_1	0.45 ± 0.49	1.00 ± 0.85	1.73 ± 1.40
Cation Exchange Capacity, mgm. equiv. per 100 g. soil	A	10.14 ± 3.14	17.92 ± 4.57	12.69 ± 3.97
	B_{21}	4.92 ± 1.54	7.69 ± 2.80	5.56 ± 2.04
	B_{22}	2.87 ± 1.03	3.79 ± 1.12	4.00 ± 1.74
	C_1	1.66 ± 1.40	2.13 ± 1.24	2.93 ± 1.23
Soil Series Represented and Number of Profiles of Each		Acton 1	Acton 1	Brookfield 1
		Brookfield 1	Brookfield 2	Charlton 1
		Essex 1	Killingworth 1	Cheshire 6
		Gloucester 8	Leicester 1	Gloucester 4
		Haddam 1	Sutton 1	Grafton 1
		Killingworth 3		Haddam 1
				Killingworth 1
				Lenox 1
				Wethersfield 3
				Woodbridge 1

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[1] 12 profiles.

[2] 21 profiles

the accumulation of humus with consequent formation of mor in forests are in general mainly to be found in the fact that poor soils do not provide favorable living conditions for earthworms, whose work of mixing the remains of foliage with the mineral earth therefore does not take place, and for bacteria, whose rapid decomposing activity, comprising about three-quarters of the litter, is also absent."

Expanding upon Bornebush's statement about the causes of humus accumulation, Mar: Möller (37) projects the view that soil conditions which cause a rapid, vigorous growth of the forest are likewise those which bring about a rapid decomposition of the litter. These soil conditions are: suitable moisture and temperature, adequate supply of oxygen, and an abundance of mineral nutrients.

Soil Properties and Tree Growth

One of the principal goals in forest soils work is to determine what relation, if any, exists between characteristics of the soil and tree growth or site index. Because of the relatively slow growth of most forest trees and because of the influence of uncontrolled factors other than soil, definite correlations are more difficult to establish than in the case of farm crops.

The earlier work with red pine (18) showed a low degree of correlation between those soil characteristics usually considered important in soil-plant relations, except in those cases where rather marked differences in texture and/or moisture were the controlling factors. In a later study with oak stands (28), there was a low but significant positive correlation between site index and total nitrogen of the A horizon, but only after eliminating 11 plots that exhibited obvious external influences.

In a third study in which basal area[1] was used as the criteria of specie composition and growth (32), there was no significant difference between forest tracts or between site conditions on the basis of the 10 species with the highest total basal areas. Some significant correlations were found; for example, chestnut oak and black oak had higher basal areas on the drier soils, and red maple, yellow birch, aspen (*Populus* spp.), and blue beech (*Carpinus caroliniana*) excelled on the moister sites.

Explanation for this failure to find significant differences in basal area between site conditions may be found in the recent paper of Mar: Möller (37) in which he states that "increment of basal area per hectare is astonishingly independent of site-class". He found under Danish conditions that site quality differences were reflected much more in height than in basal area, and best of all in volume increment.

Another reason for the rather low correlations found in all three studies mentioned above is the influence of unknown practices and events which may have occurred in the past. Differences in cuttings, in weedings, and in frequency and severity of fires can affect growing conditions, including specie composition, sufficiently to counteract or mask the effect of soil and other site factors.

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[1] Sum of the cross sectional area of all stems at breast height on a given area of land.

When, on the other hand, the soil is the primary variable, and particularly when dealing with stands at the lower end of the site index scale, differences in growth are to be expected. Data recently obtained on the growth of white pine and Norway spruce plantings reveal striking differences, due largely to differences in soil texture. Transplants of these two species were planted on two blocks in the Rainbow Plantation in Windsor, Connecticut, in the spring of 1942. The soil on Block 64 is Merrimac loamy sand. Block 59 is on slightly higher ground and the soil is Manchester sandy loam. Previous borings had shown that the substratum in the vicinity of Block 59 was considerably more moist than average for the tract with some mottling at a depth of seven feet. Tree roots were observed at the six and eight-foot depths, a condition not common on other portions of the plantation.

The presence of a locust stand adjoining on the east may have had some influence on tree growth but the prevailing westerly winds would not be favorable to spreading locust leaves on the block in question. Blocks 59 and 64 are only 100 yards apart, so that other environmental conditions were practically identical.

Measurements taken in 1944 and again in 1947, together with physical tests of the soils are given in Table 20. In 1944 the soil differences had had no effect on white pine but exerted a very marked influence on Norway spruce. By 1947 the pine showed response to the slightly heavier soil, and total height differences of the spruce were 20 per cent greater than in 1944.

TABLE 20. GROWTH OF WHITE PINE AND NORWAY SPRUCE TREES

Planted in April 1942; measured in the fall of the year indicated

Block No.	Soil		1944		1947	
			Total Height	Growth in '44	Total Height	Growth '45-'47
	White Pine					
64	Merrimac loamy sand	cm	40.9	13.8	108.8	67.9
59	Manchester sandy loam	cm	40.9	13.3	127.3	86.4
	Difference	cm	0	–.5	18.5	18.5
	"	%	0	–3.6	17.1	27.4
	Norway Spruce					
64	Merrimac loamy sand	cm	25.7	5.7	52.9	27.2
59	Manchester sandy loam	cm	38.4	13.9	89.7	51.6
	Difference	cm	12.7	8.2	36.8	24.4
	"	%	49.4	144.0	69.5	89.7

CHARACTERISTICS OF THE SOILS (A HORIZON)

Block No.	Soil	Total Sands	Silt	Clay	Total Colloids[1]	Moisture equivalent
64	Merrimac loamy sand	83.5%	11.5%	5.9%	8.5%	6.3%
59	Manchester sandy loam	76.3	17.2	7.3	10.2	1.8

[1] Bouyoucos hydrometer method.

How long these differences in rate of growth would be maintained cannot be determined inasmuch as the property is no longer available for experimental purposes. However, data on the total volume per acre obtained on the 37-year-old white pine stand that was destroyed by the 1938 hurricane, when compared with stands elsewhere in the tract, indicate that Block 59 was a somewhat better site than most of the other blocks.

The role of the parent material in influencing the character of the resulting soil and of the vegetation growing thereon has been mentioned. Generally speaking, soils of the granitic tills are the poorest of the upland till soils, and this difference in most instances is reflected in the yield classes of the stands growing thereon. Going outside the State, a practical example is to be found in the composition and growth of stands in the Green Mountains of Vermont as compared with those in the White Mountains of New Hampshire. The soils in the Green Mountains, derived largely from schist parent material, are somewhat heavier textured, and a higher proportion of the area exhibits a mull humus condition than is the case in the granitic soils of the White Mountains. Largely because of these differences in soils, the timber stands of the Green Mountains contain a higher percentage of hardwoods and the site quality is higher than in the White Mountains.

In considering the fertility status of forest soils, one must not overlook the significance of the findings of the pot culture experiments, viz., (a) that phosphorus, with or without nitrogen, had a favorable effect upon growth of spruce seedlings; (b) that the forest floor had a deleterious effect upon the survival of the seedlings, and that mixing such material into the mineral soil was as effective as its removal; (c) that, when two crops of tobacco and one of oats were grown on soil-sand mixtures, response to N and/or NP was generally larger in the first crop than in the second or third crops; (d) that nitrogen was the most seriously limiting factor in the L of the Wethersfield soils; (e) that highest yields in all cases occurred with the NPK treatment; (f) that Wethersfield composites consistently outyielded the Gloucester composites for the first crop but not in the subsequent crops, and (g) that yields on the forest soil composites were equal to or better than those on the agricultural soil mixtures.

Timber versus Farm Crops

The statement made on page .. that man, through his tillage practices, has brought about a deterioration in the physical conditions of the soil is borne out by the data presented in Table 18. By means of liming and fertilizing, the nutrient level of farm soils can be readily kept up (although the maintenance of the organic matter content presents a serious problem in many cases), but the favorable physical conditions characteristic of forest soils can hardly be maintained by any practical means where the land is cropped regularly. The protection afforded by litter and other parts of the forest floor against compaction of the surface soil by rain, the benefits of shade in keeping the soil from baking and becoming hard, the absence of compacting agencies such as heavy farm machinery and tramping by animals (provided the land is not grazed), and the beneficial effect of tree roots and forest floor fauna in maintaining channels into the subsoil through which air, moisture and organic matter may pass,—all these are factors making for good physical conditions under forest, and most of which are absent or opposite when the land is cultivated. There is no known practical means of maintaining the exemplary qualities of forest soil while at the same time producing farm crops.

Pastures and meadows may not suffer to the same degree as tilled soils from the effects of compaction by implements or by rain; nevertheless, the soil is compacted by animals, and it does not have the benefit of deep penetrating roots or forest soil fauna activity.

SUMMARY

This bulletin is in the nature of a report on various phases of forest soil investigations made at the Connecticut Station up to the present time. Brief descriptions of the geologic, topographic and climatic factors are given, followed by a condensed history of land use in Connecticut. At the present time, about 60 per cent of the land area is in forest and brush. With the exception of a few small areas such as the North Haven-Wallingford sand plain and certain sandy, wind-swept portions of the coast, there are no sections of the State which will not support tree growth.

The upland soils belong to the Brown Podzolic great soil group and, with few exceptions, are strongly acidic and light to medium textured (mostly fine sandy loams and loams). Podzol profiles with a definite leached gray layer are uncommon and are generally associated with conditions of low soil fertility and strongly acid humus. A soil catena key is given which includes all of the known soils of the State regardless of their use.

Granular mor, laminated mor and matted mor are the most common types of humus found. Excellent crumb mulls occur in many places.

Twelve soils, three of which are mors with a weakly developed podzol horizon (A_2 less than 1 inch); six, mors without an A_2 layer, and three, mulls, are described in considerable detail.

The F layer under hardwoods averages about 0.4 inch in thickness and weighs around 7,400 pounds per acre, while the H layer, where present, is frequently about 0.8 inch thick, weighing some 32,000 pounds on an acre. For approximating the weight of the forest floor of mor humus types, exclusive of the litter, the values, 17,000 pounds per *acre-inch* for the F layer and 40,000 pounds for the H, are useful.

Mechanical analyses of upland till soils show the B horizon to be slightly heavier than the A in most instances, but the A has a higher water-holding capacity due to its greater organic matter content. Volume weight of the A horizon of mulls is less than 1, being frequently as low as 0.8, while the same horizon of sod land averaged 1.22 and of cultivated fields 1.26. Data are presented on the porosity and related properties and the aggregate analysis of four profiles.

The pH of upland till-derived soils varies from an average of 3.8 in the

H layer of podzol-mor profiles to about 5.2 in the C_1 of the mor and mull humus types. Poorly drained and traprock soils are somewhat less acid, and those in the limestone section range from moderately acid to alkaline. Comparison with the pH determined in a neutral salt-soil suspension indicates that Connecticut soils are of the acidoid type, and the exchange acidity is greatest in the H and A_2 horizons.

Owing to the relatively high nitrogen content of the forest floor, mor humus types contain a larger proportion of their nitrogen above ground than do mulls, and the distribution and total amount in the profile vary considerably with type of profile and native fertility of the soil. Forest soils are characterized by a wide C-N ratio.

Cation exchange studies show considerable variation in the horizons within the profile and also between profiles. The exchange capacity of the A horizons ranged from 4 to 20 milligram equivalents per 100 g of soil; from 1 to 13 in the B, and from 1 to 3.5 in the C. In the forest floor the values are high—50 to 60. In a comparison of soil groups, the soils derived from Triassic till and those of the poorly drained group contained a higher per cent of calcium than the other groups, excepting soils influenced by traprock and limestone. The buffer capacity of five profiles is included in these studies.

Total phosphorus content is low in forest soils, and available P by the Truog method ranges from a low of 1 ppm in the C_1 to 300 ppm or better in the forest floor. There is evidence that P may be a limiting element in some instances. Some data are presented on available P and K as determined by 1 per cent citric acid.

Sesquioxide and insoluble matter data, all from previous studies, place New England Podzols in the iron-humus group. The ratio of insoluble matter (chiefly silica) to sesquioxides in the A horizon varied from 35 in strongly developed Podzols (of New Hampshire) to nine in Brown Podzolic mulls in Connecticut.

In the decomposition of the litter, carbon is lost and the C-N ratio narrows from the 50 to 90 found in the litter, to about 40 in the F and 30 in the H. In the mineral soil the ratio seldom drops lower than 15. Correlations between rate of decomposition and humus type have not been found. Incubation studies have shown that in podzol-mor and mor humus types considerable NH_3-N but very little NO_3-N are found, while in mull types the opposite is true. The addition of lime to the former causes the material to nitrify similar to mulls.

Attempts to correlate the calcium content of the litter with characteristics of the mineral soil were most successful in the case of the exchangeable calcium content of the A horizon. Correlation with pH, total bases, and per cent saturation was generally good. A previous investigator had found a significant difference in the Ca content of the F layer in different forest types in Connecticut.

Lysimeter studies indicated that, under natural conditions, nutrients are taken up by the roots as rapidly as they become available and that normally no permanent losses occur. Nitrogen transformation continues into the winter and the concentration of all nutrients was frequently as high then as at any other time of the year.

From pot culture studies with undisturbed soil, it was found that the presence of the surface organic debris (F and H layers) caused a high mortality of spruce seedlings, which was greatly reduced where this material was removed, burned or turned under. Phosphorus, alone or with nitrogen, favorably affected growth of the seedlings. In pot culture studies with soil-sand mixtures, lowest yields of tobacco were obtained from the litter of a mull soil, except where N and P were included in the treatment, while the mineral soil of the mull produced bigger yields than the mineral soil of the mor profile. Where forest soils were compared with tilled soils (with complete treatment in both cases), the former yielded as much as or more than the latter.

In a comparison with cultivated and pastured soils, woodland soils were characteristically more acid and lower in exchangeable calcium but were in better physical condition, had a higher moisture-holding and base exchange capacity, and contained more nitrogen.

Tree root studies showed that zones of greater root concentration were associated with a soil condition typified by a significantly higher moisture equivalent, loss-on-ignition, total nitrogen and base exchange capacity than in those parts of the profile where the roots were sparse. The importance of favoring stands containing species with diverse types of root systems is emphasized.

Analyses and incubation studies of soils on burns indicate a loss in available P and K, and an increase in Ca and pH as a result of fire. The application of lime had a much greater influence on nitrogen availability than did burning. In pot cultures, burning resulted in better survival but poorer growth of spruce seedlings.

Differences between soil series groups with respect to native fertility and site quality are discussed. Soils derived from till of granitic origin are usually poorest of the upland till soils and, generally speaking, they show it in the type of humus formed and the character of the vegetative cover. The forest soils of the southeastern part of the State appear to be lower in fertility based on total nitrogen, total bases and base capacity, than comparable soils elsewhere in the State.

Because of the generally favorable climatic and soil conditions in Connecticut, and the strong influence of other factors of site, correlations between soil and tree growth are not readily found. However, other conditions being equal, stands on the better soils consist of the better grade hardwoods whose rate of growth appreciably exceeds that on poorer soils. Recognition of differences in soils, in humus types and in rooting habits of trees would seem to be the first step in improving forest production through management practices.

CONCLUSIONS

Evidence has been presented to show that soil is an important factor in determining the character of the forests in Connecticut. Desirable soil qualities include a friable to soft, medium textured (loam) A horizon, a friable

B horizon of fine sandy loam or loam texture, a firm to slightly compact C at a depth of 30 inches or more, and moderate to good fertility.

The presence of good forests on soils lacking in some of the forementioned qualities is usually due to the influence of other site factors, particularly moisture supply, which make for a better site than would be indicated by the soil alone. By the same token, site factors may create a poorer site than indicated by the soil. Differences in previous forest practices and land use, largely unknown, have a bearing on both the soil and the stand.

Improvement in forest production in Connecticut is a matter of better forest management such as selective cutting, the favoring of soil-improving species where necessary, prevention of fire, and proper choice of species when planting.

REFERENCES

1. AALTONEN, V. T. Einige pH = Bestimmungen in Waldböden. Communicationes Instituti Forestalis Fenniae 25(2) :1-52. Helsinki. 1937.
2. ALWAY, F. J., KITTREDGE, JOSEPH AND METHLEY, W. J. Composition of the forest floor layers under different forest types on the same soil type. Soil Science 36(5) :387-398. 1933.
3. ANONYMOUS. The Harvard Forest Models. Tercentenary Celebration of Harvard University, Cambridge, Mass. 1936.
4. BALDWIN, HENRY I. Forestry in New England. Natl. Resources Planning Board, Region One. Publ. No. 70. Boston. Dec. 1942.
5. BALDWIN, MARK, KELLOGG, CHARLES E. AND THORP, JAMES. Soil classification. *In* Soils and Men. U.S.D.A. Yearbook of Agriculture, 1938:979-1001. 1938.
6. BREWER, WILLIAM H. Woods and Woodlands. 10th Annual Rpt. Conn. Board of Agr. pp. 180-204. 1876-7.
7. CHANDLER, ROBT. F., JR. The calcium content of the foliage of forest trees. Cornell Univ. Mem. 228. 1939.
8. COILE, T. S. Distribution of forest tree roots in North Carolina Piedmont soils. Jour. Forestry 35:247-251. 1937.
9. DAVIS, I. G. AND HENDRICKSON, C. I. A description of Connecticut agriculture. Storrs Agr. Expt. Sta. Bul. 127. 1925.
10. DEINES, GEORG. Die Forstliche Standortslehre. M. & H. Schaper, Hannover. 1938.
11. DENGLER, A. Waldbau auf Ökologischer Grundlage. Julius Springer, Berlin. 2d Ed. p. 164. 1935.
12. GARIN, GEORGE I. Distribution of roots of certain tree species in two Connecticut soils. Conn. Agr. Expt. Sta. Bul. 454. 1942.
13. GARSTKA, W. U. The calcium content of Connecticut forest litter. Yale School of Forestry dissertation (unpublished). 1930.
14. GAST, P. R. Contrasts between the soil profiles developed under pines and hardwoods. Jour. For. 35:11-16. 1937.
15. GRAVES, HENRY S. Forest economics and policy in New England. New England Prospect: 1933. Amer. Geogr. Soc. Special Publ. No. 16. 1933.
16. HEIBERG, S. O. AND CHANDLER, R. F., JR. A revised nomenclature of forest humus layers for the Northeastern United States. Soil Sci. 52(2) :87-99. 1941.
17. HESSELMAN, H. Studier över Barrskogens Humustacke, dess egenskaper och beroende av Skogsvården. (With German resumé). Meddelanden Från Statens Skogsförsoksanstalt. 22: 169-552. 1926.
18. HICOCK, H. W., MORGAN, M. F., LUTZ, H. J. AND LUNT, H. A. The relation of forest composition and rate of growth to certain soil characters. Conn. Agr. Expt. Sta. Bul. 330. 1931.
19. HOPKINS, F. W. An historical sketch of local finance in Connecticut until 1930, with special reference to forest resources, forest industries, and the taxation of forests. Ann Arbor. [Cited by Baldwin (4)]. 1936.
20. JACOBSON, H. G. M., SWANSON, C. L. W. AND SMITH, EVELYN. Effect of various fertilizer cations and anions on soil reaction, leaching, nitrification of urea, and related characteristics in an uncropped soil. Soil Sci. 65 (6) :437-460. 1948.
21. JENNY, HANS. Klima und Klimabodentypen in Europa und in den Vereinigten Staaten von Nordamerika. Soil Research 1 (3) : 139-189. 1929.
22. JOFFE, JACOB S. Pedology. Rutgers Univ. Press, New Brunswick, N. J. 1947.
23. LYFORD, W. H., JR. The morphology of the Brown Podzolic soils of New England. Soil Sci. Soc. Amer. Proc. 11:486-492. 1947.
24. LUNT, HERBERT A. Profile characteristics of New England forest soils. Conn. Agr. Expt. Sta. Bul. 342. 1932.
25. ———————— Effect of weathering upon dry matter and composition of hardwood leaves. Jour. Forestry 33:607-609. 1935.

26. ——————— The application of a modified procedure in nitrogen transformation studies. Jour. Amer. Soc. Agron. 27(5):346-355. 1935.

27. ——————— Forest lysimeter studies under red pine. Conn. Agr. Expt. Sta. Bul. 394. 1937.

28. ——————— Soil characteristics, topography and lesser vegetation in relation to site quality of second-growth oak stands in Connecticut. Jour. Agr. Research 59(6):407-428. 1939.

29. ——————— Soil analyses significant in forest soils investigations and methods of determination: 1. Exchangeable bases, exchangeable hydrogen, and total base capacity. Soil Sci. Soc. Amer. Proc. 5:344-349. 1940.

30. ——————— A pot culture experiment with undisturbed forest soil. (Abstract). Soil Sci. Soc. Amer. Proc. 6:403. 1941.

31. ——————— Forest lysimeter studies under hardwoods. Conn. Agr. Expt. Sta. Bul. 449. 1941.

32. ——————— AND BALTZ, MARY. Basal area in relation to soil-site factors in two Connecticut forests. Soil Sci. Soc. Amer. Proc. 8:415-419. 1944.

33. LUTZ, HAROLD, J. Trends and silvicultural significance of upland forest successions in southern New England. Yale Forestry School Bul. 22. 1928.

34. ——————— AND CHANDLER, ROBERT F., JR. Forest Soils. John Wiley & Sons, N. Y. 1947.

35. MCHARGUE, J. S. AND ROY, W. R. Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season. Bot. Gaz. 94(2): 381-393. 1932.

36. MARBUT, C. F. Soils of the United States. U. S. Dept. Agr. Atlas of American agriculture, Pt. 3. Advance Sheets No. 8. 1935.

37. Mar: MÖLLER, CARL. The effect of thinning, age, and site on foliage, increment, and loss of dry matter. Jour. Forestry 45:393-404. 1947.

38. MATTSON, SANTE AND LÖNNEMARK, HENNING. The pedography of hydrologic podzol series: I. Loss on ignition, pH and amphoteric reactions. Annals Agric. Coll. Sweden Vol. 7: 185-227. 1939.

39. MELIN, E. Biological decomposition of some types of litter from North American forests. Ecology 11: 72-101. 1930.

40. MITCHELL, HAROLD L. Pot culture tests of forest soil fertility. Black Rock Forest Bul. No. 5. 1934.

41. ——————— AND FINN, R. F. The relative feeding power of oaks and maples for soil phosphorus. Black Rock Forest Papers I, No. 2:6-9. 1935.

42. MORGAN, M. F. The soils of Connecticut. Conn. Agr. Expt. Sta. Bul. 320. 1930.

43. ——————— The soil characteristics of Connecticut land types. Conn. Agr. Expt. Sta. Bul. 423. 1939.

44. ———————, JACOBSON, H. G. M. AND LECOMPTE, S. B., JR. Drainage water losses from a sandy soil as affected by cropping and cover crops. Conn. Agr. Expt. Sta. Bul. 466. 1942.

45. NĚMEC, A. AND KVAPIL, K. Über den Einfluss verschiedener Waldbestände auf den Gehalt und die Bildung von Nitraten in Waldböden. Ztschr. f. Forst.-u. Jagdwesen, 59:321-412. 1927.

46. Northeastern Forest Experiment Station, 1946 Annual Report. 1946.

47. PALLMANN, H. Über Waldböden. Beiheft zu den Zeitschriften des Schweizerischen Forstvereins, No. 21: 113-140. 1943.

48. Soil Survey Division, Bureau of Chemistry and Soils. Soils of the United States. *In* Soils and Men. U.S. Dept. Agr. Yearbook of Agriculture, 1938, pp. 1019-1161. 1938.

49. TAMM, OLOF. Om de lågproduktiva sandmarkerna å Hökensås och i övre Lagadalen. (Über die schwachproduktiven Sandböden auf dem Hökensås und in oberen Lagatal, Südschweden). Meddel. från Statens Skogsförsöksanstalt häfte 30, n:r 1. 1937.

50. THORNTHWAITE, C. WARREN. The climates of North America according to a new classification. Geog. Rev. 21 : 633-655. 1931.

51. ———————— The climates of the earth. Geog. Rev. 23 : 433-440. 1933.

52. ———————— Atlas of climatic types in the United States 1900-1939. U.S.D.A. Misc. Publ. No. 421. 1941.

53. WESTVELD, M. ET AL. Recommended forest practice for New England. Report of Committee on Silviculture, New England Sec., Soc. Amer. Foresters, Springfield, Mass., Feb. 6, 1941. The Forestry Chronicle 17 : 155-161. 1941.

54. WILDE, S. A. Classification of gley soils for the purposes of forest management and reforestation. Ecology 21 (1) : 34-44. 1940.

55. ———————— Forest Soils and Forest Growth. Chronica Botanica Co. Waltham, Mass. 1946.

APPENDIX

PART I. COMMON AND SCIENTIFIC NAMES OF SPECIES

Trees

Alder	*Alnus* spp.
Ash, white	*Fraxinus americana* L.
Aspen	*Populus* spp.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, black	*Betula lenta* L.
Birch, gray	*B. populifolia* Marsh.
Birch, white	*B. papyrifera* Marsh.
Birch, yellow	*B. lutea* Michx. f.
Blue beech	*Carpinus caroliniana* Walt.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, fire	*P. pennsylvanica* L. f.
Cedar, red	*Juniperus virginiana* L.
Cedar, southern white	*Chamaecyparis thyoides* (L.) B.S.P.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Dogwood	*Cornus* spp.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Hickory	*Carya* spp.
Locust, black	*Robinia Pseudo-Acacia* L.
Maple, red	*Acer rubrum* L.
Maple, sugar	*A. saccharum* Marsh.
Oak, black	*Quercus velutina* LaMarck.
Oak, chestnut	*Q. montana* Willd.
Oak, red	*Q. borealis* Michx. f. var. *maxima* Ashe
Oak, scarlet	*Q. coccinea* Muenchh.
Oak, white	*Q. alba* L.
Pine, jack	*Pinus Banksiana* Lambert
Pine, pitch	*P. rigida* Mill.
Pine, red	*P. resinosa* Ait.
Pine, white	*P. strobus* L.
Spruce, black	*Picea mariana* (Mill.) B.S.P.
Spruce, Norway	*P. Abies* (L.) Karst. (*P. excelsa* Link.)
Tulip tree (yellow poplar)	*Liriodendron tulipifera* L.
Walnut, black	*Juglans nigra* L.

Lesser Vegetation

Arrowwood	*Viburnam acerifolium* L.
Blueberry	*Vaccinium* spp.
Canada may flower	*Maianthemum canadense* Desf.
Dewberry	*Rubus hispidus* L.
Ferns, bracken	*Pteridium latiusculum* (v. *verum*)
Huckleberry	*Gaylussacia baccata* (Wang.) C. Koch
Laurel, mountain	*Kalmia latifolia* L.
Pinxter flower (wild honeysuckle)	*Rhododendron nudiflorum* (L.) Torr.
Wild sarsaparilla	*Aralia nudicaulis* L.
Witch-hazel	*Hamamelis virginiana* L.

Part II. Soil Reaction, Total Nitrogen, Exchangeable Calcium, Total Bases, And Base Capacity By Soil Series Groups

(Averages and ranges for several closely related series in each group)

	Well drained till									Poorly drained till		
	Friable subsoils Gloucester group			Very firm to compact subsoils Charlton group			Triassic parent material Cheshire group			Leicester group		
	No.	Av.	Range	No.	Av.	Range	No.	Av.	Range	No.	Av.	Range
						pH						
L	23	4.3	3.5 - 5.1	4	4.4	3.9 - 4.8	9	4.3	4.0 - 4.5	2	4.2	4.2 – 4.2
F	35	4.5	3.6 - 5.3	8	4.8	4.2 - 5.5	9	4.6	4.3 - 5.0	2	5.6	5.5 – 5.7
H	32	4.1	3.5 - 5.1	6	4.3	3.8 - 4.8	2	3.7	3.6 - 3.7	1	5.3	....
A_{11}	25	4.5	4.0 - 5.6	10	4.7	4.4 - 5.1	13	4.6	4.3 - 4.8	2	5.0	4.6 – 5.3
A_{12}	21	4.6	4.1 - 5.3	5	4.6	4.2 - 5.1	6	4.7	4.6 - 4.7	2	5.4	5.3 – 5.5
A_2	9	3.9	3.5 - 4.2	1	4.2	....	1	3.8	....	..	....	....
B_{21}	39	4.8	4.0 - 5.6	12	4.7	4.1 - 5.5	7	4.9	4.6 - 5.3	1	5.5	....
B_{22}	32	4.9	4.6 - 5.7	9	5.1	4.7 - 6.0	3	4.8	4.7 - 5.3	..	....	....
B_3	9	4.9	4.6 - 5.1	4	5.1	4.8 - 5.6	1	4.4	....	..	....	....
C_1	29	5.1	4.6 - 5.9	9	5.2	4.7 - 5.8	2	4.9	4.8 - 5.3	1	5.6	....
						Nitrogen, %						
L	23	0.73	0.48- 1.11	4	0.81	0.71- 0.91	9	0.89	0.70- 1.26	1	0.86	....
F	44	1.29	0.91- 1.84	11	1.26	0.95- 1.59	12	1.24	0.93- 1.68	3	1.25	0.58– 1.63
H	31	1.18	0.82- 1.52	5	1.12	0.77- 1.40	2	1.01	0.92- 1.11	1	0.99	....
A_{11}	27	0.26	0.11- 0.60	10	0.37	0.23- 0.94	13	0.26	0.17- 0.46	2	0.62	0.34– 0.90
A_{12}	29	0.17	0.06- 0.34	9	0.20	0.13- 0.39	12	0.14	0.09- 0.21	1	0.21	....
A_2	10	0.13	0.09- 0.28	..	....	....	1	0.07	....	..	....	....
B_{21}	40	0.09	0.02- 0.24	11	0.09	0.04- 0.21	13	0.06	0.03- 0.07	2	0.15	0.12– 0.19
B_{22}	40	0.04	0.01- 0.13	11	0.05	0.01- 0.09	9	0.03	0.02- 0.03	1	0.08	....
B_3	10	0.04	0.02- 0.06	3	0.03	0.02- 0.04	2	0.01	0.01- 0.02	..	....	....
C_1	33	0.02	<0.01- 0.04	9	0.02	<0.01- 0.4	10	0.01	<0.01- 0.03	..	....	....

Exchangeable Calcium, Mgm Eq. per 100 g Soil

L	12	19.0	9.00-41.1	1	18.6	....	8	26.7	12.7 -32.8	2	26.0	18.0 –34.0
F	36	19.2	7.35-45.6	4	20.8	17.3 -24.1	8	28.5	18.5 -39.4	2	47.3	35.4 –59.3
H	33	8.82	3.32-32.8	4	8.05	3.88-16.4	1	1.95	....	1	17.8	....
A_{11}	24	0.70	0.05- 2.00	10	1.84	0.35- 4.01	12	1.35	0.42- 2.80	2	17.1	3.06–31.1
A_{12}	21	0.60	0.07- 2.75	4	0.22	0.13- 0.29	7	0.46	0.20- 1.00	2	4.18	0.72– 7.65
A_2	11	0.23	0.0 - 0.45	..	....	....	2	0.36	0.30- 0.42	..	....	....
B_{21}	39	0.33	0.0 - 1.25	10	0.42	0.09- 0.87	7	0.72	0.20- 1.81	1	0.46	....
B_{22}	29	0.23	0.0 - 1.00	7	0.32	0.10- 0.73	8	0.63	0.36- 1.13	..	....	....
B_3	8	0.12	0.0 - 0.34	2	0.12	0.09- 0.14	1	0.45	....	..	....	....
C_1	25	0.23	0.0 - 0.50	6	0.31	0.14- 0.50	6	0.45	0.13- 0.66	1	0.17	....

Total Bases, Mgm Eq. per 100 g Soil

L	9	26.5	1.50-48.3	..	....	....	7	15.5	4.70-28.3	1	13.0	....
F	10	30.0	8.60-42.2	1	23.5	....	7	18.8	2.70-33.1	2	38.8	16.0 –16.5
H	10	16.8	3.97-28.3	1	21.7	....	..	....	....	..	....	....
A_{11}	12	4.87	1.28-10.5	4	5.00	2.40- 7.40	8	5.34	2.50- 9.20	2	20.8	8.60–33.0
A_{12}	10	4.75	1.90- 9.01	2	3.50	2.50- 4.40	7	1.90	0.80- 4.30	..	....	....
A_2	8	1.68	0.00- 4.90	..	....	....	1	1.70	....	..	....	....
B_{21}	20	1.65	0.00- 3.59	3	1.80	0.40- 3.50	7	2.14	0.70- 3.30	1	9.20	....
B_{22}	21	1.08	0.00- 3.59	3	1.10	0.80- 1.30	2	1.60	1.40- 1.80	..	....	....
B_3	6	0.63	0.00- 2.11	..	....	....	..	....	....	..	....	....
C_1	20	0.89	0.00- 5.36	3	1.20	0.40- 1.80	5	1.40	0.30- 2.20	..	....	....

Base Capacity, Mgm Eq. per 100 g Soil

L	9	55.5	40.9 -69.8	..	....	....	7	56.0	51.0 -61.0	2	43.5	40.0 –47.0
F	10	59.6	52.0 -64.9	1	64.5	....	7	53.6	38.0 -65.4	1	78.0	....
H	10	55.5	40.8 -75.8	1	43.4	....	..	....	....	..	....	....
A_{11}	13	14.2	8.5 -26.9	5	15.6	11.3 -17.9	8	17.0	11.9 -20.5	2	34.1	19.5 –48.6
A_{12}	9	12.7	4.5 -22.6	2	10.3	9.6 -11.0	7	8.6	6.5 -10.7	..	....	....
A_2	8	11.7	7.1 -21.6	..	....	....	..	....	....	..	....	....
B_{21}	20	5.6	1.5 -13.2	4	6.1	3.6 - 9.2	8	5.4	3.1 - 7.0	1	13.8	....
B_{22}	20	3.3	0.9 - 6.1	3	3.9	3.4 - 4.8	2	3.6	3.5 - 3.6	..	....	....
B_3	6	2.1	1.2 - 3.4	..	....	....	..	....	....	..	....	....
C_1	20	1.7	0.0 - 4.2	4	3.1	1.7 - 4.3	6	3.2	2.1 - 4.2	..	....	....

	Glaciofluvial Deposits						Diabase (traprock) parent material Holyoke group			Limestone parent material Dover group	
	Coarse subsoils Hinckley group			Sandy subsoils Merrimac group							
	No.	Av.	Range	No.	Av.	Range	No.	Av.	Range	No.	Av.
					pH						
L	..	....	....	..	....	....	3	4.5	4.3 - 4.9	1	4.7
F	2	4.9	4.5 - 5.3	3	4.3	3.8 - 4.7	1	4.9	....	1	5.9
H	..	....	....	1	4.4	....	..	....	....	..	....
A_{11}	6	4.8	4.5 - 5.5	9	4.5	4.2 - 4.7	5	4.9	3.9 - 5.7	1	6.0
A_{12}	2	5.2	4.9 - 5.6	5	4.7	4.7 - 4.9	..	....	....	1	7.0
A_2	..	....	....	..	....	....	..	....	....	..	....
B_{21}	6	5.1	4.7 - 5.6	7	4.7	4.6 - 4.8	3	4.8	4.5 - 5.3	1	6.8
B_{22}	2	5.4	5.2 - 5.5	1	5.4	....	1	5.1	....	1	7.0
B_3	..	....	....	..	....	....	..	....	....	..	....
C_1	2	5.5	5.5 - 5.6	1	5.5	....	..	....	....	1	7.1
					Nitrogen, %						
L	..	....	....	..	....	....	3	0.69	0.60- 0.78	1	0.55
F	6	0.92	0.81- 1.05	7	0.77	0.46- 1.14	1	1.12	....	1	1.25
H	..	....	....	1	0.62	....	..	....	....	..	....
A_{11}	7	0.23	0.12- 0.39	9	0.07	0.05- 0.12	5	0.35	0.23- 0.71	1	0.19
A_{12}	7	0.15	0.06- 0.24	8	0.03	0.03- 0.05	..	....	....	1	0.29
A_2	..	....	....	..	....	....	..	....	....	..	....
B_{21}	6	0.06	0.02- 0.11	7	0.02	0.01- 0.04	3	0.22	0.10- 0.44	1	0.07
B_{22}	5	0.04	0.02- 0.06	3	0.02	0.01- 0.03	1	0.06	....	1	0.03
B_3	..	....	....	..	....	....	..	....	....	..	....
C_1	5	0.02	0.01- 0.04	4	0.01	$<$0.01- 0.01	..	....	....	1	0.02
					Exchangeable Calcium, Mgm Eq. per 100 g soil						
L	..	....	....	..	....	....	2	23.9	21.0 -26.7	..	....
F	2	13.32	13.0 -13.7	3	7.43	6.40-10.0	1	15.5	....	..	....
H	..	....	....	2	5.34	3.00- 7.67	..	....	....	..	....
A_{11}	6	1.14	0.27- 3.60	9	0.26	0.12- 0.55	5	5.60	4.05- 7.65	1	21.3
A_{12}	2	1.33	0.42- 2.25	5	0.12	0.08- 0.25	..	....	....	1	21.0
A_2	..	....	....	..	....	....	..	....	....	..	....
B_{21}	5	0.36	0.16- 0.63	6	0.11	0.08- 0.17	3	2.18	0.42- 3.63	1	5.41
B_{22}	1	0.67	....	..	....	....	1	1.11	....	1	4.61
B_3	..	....	....	..	....	....	..	....	....	..	....
C_1	..	....	....	..	....	....	..	....	....	1	4.34

Total Bases, Mgm Eq. per 100 g soil

L	..	....	....	..	....	....	..	....	....	..	....
F	..	....	....	1	10.9	....	..	....	....	..	....
H	..	....	....	..	....	....	..	....	....	..	....
A_{11}	1	5.90	....	1	5.70	....	3	10.4	9.0 -11.7	1	21.0
A_{12}	1	4.50	....	1	0.95	....	..	....	....	1	24.3
A_2	..	....	....	..	....	....	..	....	....	..	....
B_{21}	1	2.80	....	1	0.81	....	3	5.20	3.2 - 8.1	1	6.30
B_{22}	..	....	....	..	....	....	1	3.40	....	1	5.70
B_3	..	....	....	..	....	....	..	....	....	..	....
C_1	..	....	....	..	....	....	..	....	....	1	5.20

Base Capacity, Mgm Eq. per 100 g soil

L	..	....	....	..	....	....	..	....	....	..	....
F	..	....	....	1	57.0	....	..	....	....	..	....
H	..	....	....	..	....	....	..	....	....	..	....
A_{11}	1	14.9	....	1	11.5	....	3	22.9	16.0 -35.2	1	23.6
A_{12}	..	....	....	1	3.3	....	..	....	....	1	24.3
A_2	..	....	....	..	....	....	..	....	....	..	....
B_{21}	1	5.9	....	1	2.2	....	3	14.6	9.4 -24.2	1	6.9
B_{22}	1	3.6	....	..	....	....	1	6.6	....	1	5.7
B_3	..	....	....	..	....	....	..	....	....	..	....
C_1	1	2.0	....	..	....	....	..	....	....	1	5.2

Part III. Preliminary Catena[1] Key For The Soils Of Connecticut

(Adapted from Special Bulletin III, Supplement to Bulletin 423, April 20, 1948, by C. L. W. Swanson. Mimeographed)

Catena parent material and profile characteristics of the normal, well-drained soil series	Profile features ⇛	Shallow Less than 30" to bedrock	Normal (30") to deep Coarse textured B and C	Free of mottling	Mottled in lower B and in C	Mottled in lower A, and in B and C	Dark surface; mottled to gray B and C
	Drainage ⇛	Excessively to well drained	Somewhat excessively to well drained	Well drained	Moderately well drained	Poorly drained	Very poorly drained
I. Upland Soils Derived from Glacial Till, Unstratified							
Non-Calcareous — Brown Podzolic (BP), Polzol (Po), Gray Hydromorphic (GH), and Half Bog (HB)							
Granite and gneiss dominant							
Quartzitic sandy till on terminal moraines. **A**: dark-br.; **B**: li. yel.-br., loose; **C**: li. gray to li. yel.-br., sandy loose till	0		Plymouth BP				
Granite & gneiss. **A**: Gr.-br.; **B**: yel.-br.; **C**: gray, gritty loose till	1	Shapleigh BP		Gloucester BP	Acton BP	Leicester GH	Whitman HB
Compact till	2			Essex BP	Candia BP	Ridgebury GH	Whitman HB
Fine-grained gneiss or granite. **A**: dark gray-br.; **B**: yel.-br.; **C**: li. olive-gray to gray, fine-textured, firm to compact till	3			Narragansett BP	Scituate BP	Ridgebury GH	Whitman HB
Light gray gneiss & quartz schist. **A**: dark to very dark gray-br.; **B**: gray-yel.-br. firm to sl. compact; **C**: olive-gray to li. gray, compact till, variable	4				Taugwank BP	Ridgebury GH	Whitman HB
Granite & granite gneiss, ferruginous mica schist & some Triassic ss. **A**: brown; **B**: red.-yel.-br.; **C**: li. yel.-br. to gray br. loose to firm till	5			Killingworth BP	Acton BP	Leicester GH	Whitman HB
Compact till	6			Haddam BP	Candia BP	Ridgebury GH	Whitman HB

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[1] Soil Catena—A group of soils within one zonal region developed from similar parent material but differing in characteristics of the solum (that portion of the profile above the parent material) owing to differences in relief or drainage. From the Latin for chain. (48, p. 1164)

Schists dominant						
Gray mica quartz schist with some granitic material; **A**: gray br.; **B**: yel.-br. to yel.-olive-br.; **C**: olive-gray to olive, firm to sl. compact till	7	Hollis BP	Charlton BP	Sutton BP	Leicester GH	Whitman HB
Compact till	8		Paxton BP	Woodbridge BP	Ridgebury GH	Whitman HB
Chlorite schist till mixed with glaciofluvial deposits. **A**: brown; **B**: red.-yel.-br. to bright yel.-br.; **C**: li. gray to pinkish gray, loose to firm till, chiefly chlorite schist fragments	9	Hollis BP	Grafton BP	Sutton BP	Leicester GH	Whitman HB
Rusty-br. pyritiferous mica schist. **A**: br.; **B**: bright yel.-br. to red.-yel.-br.; **C**: yel.-br. to br.-yel., "rusty" micaceous, loose to film till	10	Brimfield BP	Brookfield BP	Sutton BP	Leicester GH	Whitman HB
Compact till	11		Sturbridge BP		Ridgebury GH	Whitman HB
Phyllite & slate. **A**: med. to dark gray.-br. **B**: yel.-olive to ol.-drab; **C**: blue.-gray to dark ol.-gray, loose to firm till, high in phyllite & slate fragments	12		Ansonia BP			
Diorite schist. **A**: med. to dark br.; **B**: yel.-br. to sl. red.-yel.-br.; **C**: gray-br., loose to firm till having "salt and pepper" effect	13	Wilton,sh.ph.BP	Wilton BP			
Gray, mica quartz schist. **A_2**: gray, leached; **B_{21}**: br. to red-br. (coffee br.); **B_{22}**: yel.-br. to li. yel.-br. to olive; **C**: ol.-gray to ol., firm to sl. cpt. till	14	Lyman Po	Berkshire Po	Peru Po	Leicester GH	Whitman HB
Compact till	15		Marlow Po	Peru (cpt.) Po	Ridgebury GH	Whitman HB
Red Triassic material dominant						
Triassic sh., ss. & congl. **A**: brown; **B**: red.-yel.-br.; **C**: red.-br. to br.-red sandy loose to firm till or disintegrated ss.	16	Sunderland BP	Cheshire BP	Ludlow BP	Wilbraham GH	Menlo HB
Compact till	17		Wethersfield BP	Ludlow (cpt.) BP	Wilbraham GH	Menlo HB
Triassic pinkish-gray congl. with some ss. & sh. **A**: br. to gray.-br. with many rounded congl. fragments; **B**: li. red.-yel.-br.; **C**: pale red.-gray loose to firm till, chiefly pebbly congl. fragments	18	Sunderland BP	Middletown BP	Ludlow BP	Wilbraham GH	Menlo HB
Diabase dominant						
Diabase (traprock). **A**: br. to dark br.; **B**: br. to yel.-br.; **C**: yel.-br. loose to firm till	19	Towaco BP	Holyoke BP			Whitfield HB
Compact till	20		Lidyhites BP	Montowese BP	Totoket GH	Whitfield HB
Diabase mixed with Triassic sh. & ss. Characteristics intermediate between Cheshire and Holyoke.						
Loose till	21	Towaco BP	Southington BP	Ludlow BP	Wilbraham GH	Whitfield HB
Compact till	22		Northford BP	Foxon BP	Gaillard GH	Whitfield HB

		Shallow	Normal (30″) to deep				
	Profile features ➳	Less than 30″ to bedrock	Coarse textured B and C	Free of mottling	Mottled in lower B and in C	Mottled in lower A, and in B and C	Dark surface; mottled to gray B and C
Catena parent material and profile characteristics of the normal, well-drained soil series	Drainage ➳	Excessively to well drained	Somewhat excessively to well drained	Well drained	Moderately well drained	Poorly drained	Very poorly drained
Strongly Calcareous — Gray Brown Podzolic (GB), GH, and HB							
Limestone dominant							
Limestone, with some schist, sh., slate & ss. **A**: dark gray.-br. to ol.-br., sl. acid; **B**: dark br. to dark yel.-br. to ol., neut.; **C**: ol. to dark ol., alk., firm to sl. compact till	23	Farmington GB		Pittsfield GB	Amenia GB	Kendaia GH	Lyons HB
Gray limestone with some ss., slates, schists, quartz & gneiss. **A**: faintly red.-br., sl. acid or neut.; **B**: li. br., sl. alk.; **C**: li. red-br., strongly alk., loose till	24	Wassaic GB					
Crystalline ls. (marble) with some schist, quartzite & gneiss. **A**: med. to dark br., sl. acid; **B**: red.-yel.-br. to red.-br., neut. to alk.; **C**: variable gray-br. or li. ol.-gray to nearly white, strongly alk., loose to firm till	25	Wingdale GB		Dover GB	Amenia GB	Kendaia GH	Lyons HB
Moderately Calcareous — GB, GH, and HB							
Limestone not dominant							
Gray calc. ss. with some shale, slate & ls. **A**: dark gray.-br., med. to sl. acid; **B**: pale yel.-br. to yel.-br., many flakes & chips of slate & ss., sl. acid; **C**: gray to sl. mottled, neut. to sl. alk., loose to firm till	26	Cossayuna (sh.ph) GB		Cossayuna GB	Albia GB	Boynton GH	Burnham HB
Compact till	27			Troy GB	Albia GB	Boynton GH	Burnham HB
Limestone & gray & green slate. **A**: med. to dark gray.-br. very str. acid; **B**: li. yel.-br. to ol.-gray, str. to sl. acid; **C**: ol.-gray to greenish or bluish-gray, sl. acid to neut. compact till	28			Stockbridge GB		Boynton GH	Burnham HB

Neutral to Weakly Calcareous — BP, GH, and HB							
Low in limestone							
Limestone & graphite schist. **A**: dark ol.-gray to dark olive, str. to mod. acid; **B**: dark yel.-br. to olive, sl. acid to neut.; **C**: dark to very dark ol.-gray, neut. to sl. alk. occa. calc., loose to firm till	29	Tinmouth BP		Lenox BP			
Quartzite & limestone. **A**: dark gray.-br.; **B**: yel.-br.; **C**: ol.-br., firm to compact till	30			Barrington BP			
Interbedded siliceous ls., mica schist & occa. phyllite. **A**: gray, br., str. acid; **B**: yel.-br. to ol.-yel.-br., sl. acid; **C**: pale ol. to olive, sl. acid to neut., firm till	31	Westminister BP		Colrain BP	Royalton BP	Cabot GH	Peacham HB
Compact till	32			Shelburne BP	Buckland BP	Cabot GH	Peacham HB

II. Soils of the Glaciofluvial Deposits (Glacial Outwash Plains and Terraces), Stratified, with Gravelly Substratum

Non-Calcareous—BP, GH, and HB						
Granite gneiss & schist. **A**: gray.-br. to br. **B**: yel.-br. to li. yel.-br.; **C**: li. gray to li. yel.-br.	33	Hinckley BP	Merrimac BP	Sudbury BP	Walpole GH	Scarboro HB
Brown, rusty pyritiferous mica schist, granite & gneiss. **A**: br. to dark yel.-br.; **B**: br. to yel.-red to yel.-br. to br.-yel.; **C**: yel.-br. to br.-yel.	34	Jaffrey BP	Barnsted BP	Sudbury BP	Walpole GH	Scarboro HB
Phyllite & chlorite schist. **A**: med. to li. br.; **B**: yel.-br. with sl. red-orange tinge; **C**: olive drab to bluish olive	35	Allingtown BP	Fairlea BP	Sudbury BP	Walpole GH	Scarboro HB
Triassic shale & ss., with some granite, schist, & diabase. **A**: gray.-br. to red.-br.; **B**: br. to red.-br.; **C**: red.-br. to dark red.-br.	36	Manchester BP	Hartford BP	Ellington BP	Meriden GH	Scarboro HB
Triassic congl., mixed with Triassic ss. & sh. **A**: gray.-br.; **B**: yel.-br. to li. yel.-br.; **C**: sl. red.-br.	37	Hampden BP	Chicopee BP	Ellington BP	Meriden GH	Scarboro HB
Diabase, mixed with Triassic ss. & sh., granite, & gneiss. **A**: brown; **B**: brown; **C**: dark-br.	38		Branford BP			
Strongly Calcareous—GB, GH, and HB						
Limestone, with some calc. ss. **A**: brown to gray.-br., sl. acid; **B**: yel.-br. to li. gray.-br., neut. to sl. alk.; **C**: li. to dark gray, sometimes ol.-gray, str. alk.	39	Groton GB	Palmyra GB	Phelps GB	Homer GH	Westland HB
Moderately Calcareous—BP, GH, and HB						
Gray shale, slate & some ls. **A**: brown; str. acid; **B**: yel.-br. to yel., str. acid; **C**: gray, neutral ...	40	Schodack BP	Copake BP	Hero BP	Homer GH	Westland HB
Granite, gneiss, schist, quartz, with marble & limestone fragments. **A**: gray.-br.; **B**: yel.-to red.-br.; **C**: gray to gr.-yel.-br.	41	Lanesville BP	Cornwall BP			

	Profile features ⋙	Shallow	Normal (30″) to deep				
		Less than 30″ to bedrock	Coarse textured B and C	Free of mottling	Mottled in lower B and in C	Mottled in lower A, and in B and C	Dark surface; mottled to gray B and C
Catena parent material and profile characteristics of the normal, well-drained soil series	Drainage ⋙	Excessively to well drained	Somewhat excessively to well drained	Well drained	Moderately well drained	Poorly drained	Very poorly drained
III. Soils of the Stream Terrace Deposits; Deep Sands							
Non-Calcareous—BP, GH, HB, and Ground Water Podzol (GWP)							
Granite, with some schist. **A**: dark yel.-br.; **B**: yel.-br.; **C**: pale yellow to gray, "salt & pepper" effect (Saugatuck has red.-br. ortstein at about 12″)	42			Nashau BP			Saugatuck GWP
Gray mica schist; some granite & gneiss. **A**: dark gray.-br. to yel.-br.; **B**: yel.-br. to li. yel.-br. to olive; **C**: li. yel.-br. to pale olive, deep to gravelly substratum	43			Agawam BP			
Mixture of Triassic ss. sh. & congl., with consid. granite & schist. **A**: br. to sl. red.-br.; **B**: li. yel.-br. or yel.-red with red.-br. tinge; **C**: weak red.-br.	44			Penwood BP			
Calcareous—BP							
Limestone, granite & schist. **A**: red.-br., neut.; **B**: ol.-br. to yel.-br., neut.; **C**: li. gray, coarse sand, neut.	45			Burdick BP			
IV. Soils of the Glaciolacustrine Deposits							
Non-Calcareous—BP, GH, and HB							
Reddish-brown silts and clays from Triassic shale & ss. **A**: med. to dark gray.-br. with red. cast; **B**: yel.-red.-br.; **C**: red.-br., compact	46			Berlin BP	Whippany BP	Parsippany GH	Rahway HB
Same as line 46 but underlain by sand and gravel..	47				Osborn BP	Passaic GH	Metuchen HB

Weakly Calcareous to Moderately Acid — BP, GH, and HB							
Olive, neut. to mod. acid, stratified silt & clay deposits. **A**: dark gray.-br. to gray.-br., str. acid; $\mathbf{B}_{21}$: yel.-br., str. acid; $\mathbf{B}_{22}$: li. yel.-br. to ol., sl. to mod. acid, very cpt.; **C**: ol. to ol.-gray, sometimes sl. mottled, neut. to sl. acid	48			Suffield BP	Buxton BP	Scantic GH	Biddeford HB
Outwash deposits of granitic or schistic sand, 2 ft. or more in depth, overlying neut. to mod. acid silt & clay. Profile reaction varies from very str. acid in A to neut. to mod. acid in C..................	49			Melrose BP	Elmwood BP	Swanton GH	Whately HB

V. Soils of the Recent Flood Plain Deposits (Bottomlands)

Non-Calcareous—Alluvial (A), GH, and HB							
Granite, gneiss & gray mica schist. **A**: gray.-br. to br.; **B**: li. yel.-br.; **C**: li. yel.-br., gravelly or sandy	50			Ondawa A	Podunk A	Rumney GH	Saco HB
Triassic ss. & shale, with some granite, ss. and sh. **A**: dk. gray-br. to dk. br.; **B**: dk. br.; **C**: dk. br. to br., loose, sandy	51			Newfield A	Cromwell A	Middlefield GH	Chalker HB
Neutral to Slightly Acid—A							
Dark colored schists, phyllites & slates with some siliceous ls. & granite. **A**: ol. to br., neut. to sl. acid; **B**: similar to A but lower in organic matter; **C**: ol., neut. to sl. acid	52			Hadley A	Winooski A	Limerick GH	Saco HB

VI. Soils Developed from Windblown Material (Aeolian)

Non-Calcareous—BP and Regolith (R)							
Fine-textured sands overlying either Triassic till or Triassic glaciofluvial deposits. **A**: brown, smooth or "floury"; **B**: yel.-br., grading to paler color below; **D**: red.-br. till or stratified sand & gravel..	53	Enfield (sh.ph.) BP*		Enfield BP			
Sandy, highly quartzose material. Stabilized dunes with some profile development. **A**: gray.-br. to br. sand; **B**: yel.-br. to li. gray sand; **C**: li. gray to li. yel.-br. sand	54		Windsor R				

* Sometimes on shallow bedrock; more often over till or glaciofluvial deposits.

	Profile features ⋙	Shallow	Normal (30") to deep				
		Less than 30" to bedrock	Coarse textured B and C	Free of mottling	Mottled in lower B and in C	Mottled in lower A, and in B and C	Dark surface; mottled to gray B and C
Catena parent material and profile characteristics of the normal, well-drained soil series	Drainage ⋙	Excessively to well drained	Somewhat excessively to well drained	Well drained	Moderately well drained	Poorly drained	Very poorly drained
VII. Organic Soils—Bog (B)							
Woody muck, acid, shallow (less than 3 ft.)	55						*Permanently Wet* Waterboro shallow muck B
Woody muck, acid, deep	56						Waterboro muck B
Coarse fibrous woody, acid material, usually 8-10 ft. Supports black spruce, larch, white cedar, hemlock & red maple	57						Balch peat B
Shallow (less than 3 ft.)	58						Balch peat (sh.) B
Fine fibrous, sedge, rush, & herbaceous material, usually 8-10 ft. Supports rushes, sedges & other aquatic plants, with trees around the margins ...	59						Littlefield peat B
Shallow (less than 3 ft.)	60						Littlefield peat (sh.) B
Sphagnum moss, relatively free of woody matter. Generally few to no shrubs. May be invaded by trees	61						Greenwood peat B

VIII. Miscellaneous Soils

62 Beach sand. 63 Dune sand. 64 Alluvial soils, undifferentiated. 65 Made land. 66 Coastal beach. 67 Marsh (fresh water). 68 Tidal marsh.

Abbreviations Used in Catena Key

Parent Rock	
congl.	conglomerate
ls.	limestone
sh.	shale
ss.	sandstone

Soil Colors	
br.	brown or brownish
gray.	grayish
ol.	olive
red.	reddish
yel.	yellow or yellowish

Miscellaneous	
alk.	alkaline
calc.	calcareous
cpt.	compact
consid.	considerable
dk.	dark
li.	light
med.	medium
mod.	moderate (ly)
neut.	neutral
occa.	occasional (ly)
sh.ph.	shallow phase
sl.	slight (ly)
str.	strongly

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