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PROFILE CHARACTERISTICS OF NEW ENGLAND FOREST SOILS

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CONNECTICUT AGRICULTURAL EXPERIMENT STATION

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PROFILE CHARACTERISTICS OF NEW ENGLAND FOREST SOILS

Herbert A. Lunt

The study of the soil in the forest is a new phase of American soil science. To the early colonists and the westward-moving pioneers who followed, the vast areas of virgin forests were thought of largely as obstacles to the pursuit of agriculture, and much excellent timber was destroyed to make room for cultivated fields. It is natural, therefore, that the soil was first studied from the standpoint of its utilization in the production of farm crops.

Interest in the perpetuation of our forests was awakened near the beginning of the present century after it had become clear that our timber resources were not inexhaustible. As the practice of forestry developed it was inevitable that such an important factor as the soil of the forest should be given consideration. The result has been a demand for knowledge regarding the nature and properties of the soil in relation to the growth of trees. It is in response to this demand that investigations of forest soils have been undertaken in America.

Many years ago much of western Europe had reached the stage of forest depletion in which New England now finds itself and, as a result, Europeans have made excellent contributions to the study of forest soils. We find their work extremely valuable to us, but also it is imperative that we conduct our own research to determine how our soils compare with those of Europe before we can be justified in applying European recommendations to our conditions. The first task confronting the American investigator, then, is to discover the characteristics and properties of our forest soils in their natural state. Some of the questions that immediately present themselves are: In what respect do the several forest soil types differ from each other? What factor or factors are responsible for the development of these different types? What part does the forest and minor vegetation play in the development of the soil profile? The objective of this research has been to gather some factual knowledge relative to the foregoing questions, and others, particularly as they may apply to Connecticut forests.

PLAN OF INVESTIGATION

The first systematic investigation of forest soils undertaken by this Station was a study of soil type as a factor in determining the composition of natural, unmanaged mixed hardwood stands. The results of this work together with that on a study of the relation of soil factors to tree growth in red pine plantations appeared in bulletin form in 1931 (20).

In 1928 investigations were started which had as their objective the ascertaining of some of the basic properties of forest soils as found under various stands in different parts of the state. This bulletin is a progress report on these studies. It deals with some of the important physical, chemical and biological properties and relationships, as observed in the field and measured in the laboratory, of the soil in various kinds of pure and mixed natural stands and several pine plantations.

Other studies initiated more recently, which are not published in this bulletin, include:

1. Effect of litter removal by raking and by burning and the effect of liming upon the soil and upon the growth of the trees in a red pine plantation.
2. Fertilization of coniferous seedlings in the nursery.
3. Fertilization of young red pine trees (5 to 6 feet tall at the beginning of the experiment).
4. Moisture distribution and other miscellaneous studies.

DESCRIPTION OF THE REGIONS

New England lies east of the State of New York and north of Long Island Sound and constitutes the extreme northeastern tip of the United States. The work reported in this bulletin was carried on in Connecticut, and in a few localities in New Hampshire—in the latter instance in cooperation with Northeastern Forest Experiment Station of the United States Forest Service.

Connecticut

Since the geology and the soils of Connecticut have been very ably described by Morgan (33) it will suffice here to state that Connecticut is divided into a western highland, a central lowland, and an eastern highland. Granitic and dioritic gneisses and schists constitute the bulk of the highland rocks, and red sandstones and shales that of the central lowland. Massive intrusions of basaltic trap rock are conspicuous features of the landscape in the central lowland.

Elevations vary from sea level in the south to a maximum of 2355 feet in the northwest portion. None of the localities in Connecticut described in this bulletin occur at either extreme.

The climate is characterized by relatively long cold winters and short rather humid summers. The mean annual temperature is 47-49° F.; mean maximum in winter 31-38°; mean minimum in winter 15-20°; length of growing season 150-170 days; mean annual precipitation 44-46 inches, well distributed throughout the year.

The forest vegetation of Connecticut has been classified by Lutz (28) into the following associations: Red cedar-gray birch association 20 per cent (of total forested area); hardwood association 70 per cent; hemlock-hardwood association 5 per cent and swamp association 5 per cent. He describes the hardwood association as follows:

"In the hardwood association there is great variation in composition, due to the large number of tree species in the region. An 'inferior hardwood' and a 'better hardwood' phase may be recognized; but these two phases are merely developmental stages within the larger association. Very often during the early development of a hardwood association the inferior hardwoods predominate; dogwood, hop hornbeam, blue beech, red maple, shad bush, choke cherry, sassafras, butternut, pignut hickory, bitternut hickory, and large-toothed aspen. In the early developmental stages of this association, red cedar and gray birch individuals are often present with the inferior hardwoods, representing relics from a preceding red cedar-gray birch association. As the hardwood association approaches maturity, the inferior hardwood species become subordinate and the better hardwoods attain dominance. Such species as the following are considered better hardwoods: red oak, scarlet oak, white oak, chestnut oak, black oak, white ash, shagbark hickory, mockernut hickory, black birch, paper birch, yellow birch, beech, yellow poplar, black cherry, white elm, sugar maple, and basswood. With the establishment of the better hardwoods, hemlock may begin to appear. This species presages the successional development of the association toward the hemlock-hardwood stage. . . . Over small areas pure stands of certain hardwood species may occur, but as a rule the forest is a mixture. With the loss of chestnut, due to chestnut blight disease (*Endothia parasitica* (Murr.) Ander. and Ander.), the oaks have gained greatly in dominance as compared with the other hardwood species. In fact, at the present time the oaks as a group make up a predominant part of the southern New England hardwood association. . . . The density of the undergrowth, and also the composition, depend largely on the past treatment of the area and to a less extent, on the character of the soil. The herbaceous vegetation is rich, both in number of species and of individuals."

The soils are quite sandy or gravelly in texture with fine sandy loam and loam constituting perhaps the largest percentage. Silt loams and clays are very limited in extent and are rarely forested.

From the standpoint of soil profile development Connecticut lies on the border line between the gray brown soils to the south and west and the strongly podzolized soils to the north. Hence it is of considerable interest to know the controlling factor or factors that determine the kind of profile that is formed in this region.

New Hampshire

Lying farther north and generally at a higher elevation New Hampshire has a climate that is somewhat cooler than that of Connecticut. The Weather Bureau cites the following data as applicable to New Hampshire and its neighbor state on the west, Vermont:

Mean annual temperature 41-42° F.; mean maximum in winter 25-30°; mean minimum in winter 4-10°; length of growing season 120-132 days; mean annual precipitation 44-46 inches, fairly well distributed throughout the year. Due to the great differences in elevation—sea level to 6293 feet as the extremes—local climates vary greatly, and must be taken into consideration in each instance.

Westveld (51) has described the following forest type in the White Mountains section of the state: (1) spruce-flat, (2) spruce-hardwoods, (3) spruce-slope, (4) spruce-swamp, and (5) old-field spruce. "Nearly all the so-called pure spruce stands have an admixture of hardwood species. Stands containing the highest percentage of spruce and fir are usually found in the old-field and spruce-slope types."

Morgan and Conrey (32) describe the origin of the soils of a typical area as follows: "The soils of the Cherry Mountain tract are formed from glacial deposits of crystalline rocks, of which a gray granite gneiss is the most important. For the most part these deposits are fairly deep, unstratified glacial drift (till), although on a considerable portion of Plot 1 a typical 'Kame' occurs."

The samplings at Waterville were taken on similar glacial deposits. The samples at Keene collected for this study were obtained under white pine occurring on a level terrace not dissimilar to the terraces of central Connecticut.

CLASSIFICATION OF THE PROFILES

At the beginning of this study the classification of the profiles was based upon the one used by Hesselman. The inadequacy of this or any other previously developed system is well discussed by Romell and Heiberg in a recent paper (38) in which they present a new classification better adapted to American conditions. Although Hesselman's classification is more or less adhered to in this bulletin an effort has been made to apply Romell and Heiberg's nomenclature whenever practicable.

The groupings we have employed are as follows:

(1) Podzol type (Figure 69) in which a definite leached layer is present, usually one-half inch or more in thickness. This segregation is made irrespective of the condition of the organic horizon, which, however, is usually of the raw humus type.

(2) Raw humus type (with no gray podzolized layer, or at most with only a very thin layer) Figure 70. The F layer is frequently rather thin, matted and woven with mycelial threads. The H layer is usually thick (one-half inch to several inches), mouse gray or black, felt-like and rather tough. This probably corresponds to Romell and Heiberg's "Greasy Duff."

(3) Humus type, in which there is a definite humus layer unincorporated with the mineral soil, but which is not felty. The nearest approach in Romell and Heiberg's classification would probably be fibrous duff.

(4) Mild humus type, a term not wholly satisfactory but fairly descriptive of the condition. It is characterized by the presence of a rather rapidly decomposing F layer but no H layer. This type is usually found

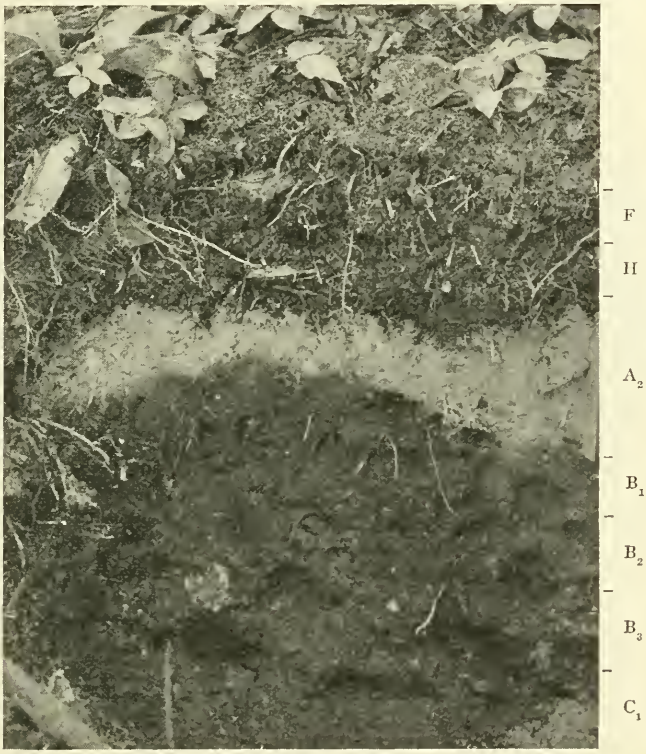

FIGURE 69. Strongly podzolized soil. Profile No. 3. Cherry Mountain, New Hampshire.

in young pine plantations on the better soils and is not considered by Romell and Heiberg. They speak of it as "Juncker's poorly humified type."

(5) Mull type (Figure 71) which includes Romell and Heiberg's crumb mull and grain mull.

It must be accepted, of course, that these designations are not sharp and absolute. Many border line conditions are observed that could be put into either of two types, and some are found that almost defy classification.

SOIL AND VEGETATION OF THE LOCALITIES SAMPLED

Selection of most of the localities sampled was based upon information furnished by Henry W. Hicock, Assistant Forester at this Station. Other areas were found by more or less random observation in the field. M. Westveld, silviculturist at the Northeastern Forest Experiment Station, located the areas sampled in the White Mountains. The accompanying map, Figure 72, shows the distribution of the localities sampled.

FIGURE 70. Upper portion of a raw humus profile from a scarlet oak stand. Profile No. 13. Bethany, Conn.

In all cases samples were collected by horizons from one or two pits dug in a representative portion of the forest. Identification of the vegetation was made for the most part by Henry W. Hicock, M. Westveld, or Henry Bull. In all cases the common name of the plants has been used in the text. The complete list of tree and ground vegetation together with their scientific names will be found just preceding the bibliography, page 832.

In this descriptive material the following abbreviations are used:

c. s.	= coarse sand	M	= mycorrhiza
s. l.	= sandy loam	R. D.	= root development
f. s. l.	= fine sandy loam		
l. s.	= loamy sand		
l. f. s.	= loamy fine sand		

Strongly Podzolized Types, New Hampshire

1. **Cherry Mountain Plot 1.** Clear cut plot. Elevation range 1973 to 2002 feet. Laboratory Nos. 9 - 16. Sept., 1928.

Soil. Northern counterpart of Hinckley s. l. Hummocky topography; excellent to excessive drainage.

F: 0 - ½ in. Readily decomposing soft and hard wood litter. Fair R. D. and good M.

H: ½ - 2½ in. Chocolate brown, powdery, fluffy raw humus, classified between a root duff and a greasy duff. Good R. D. but no M observed.

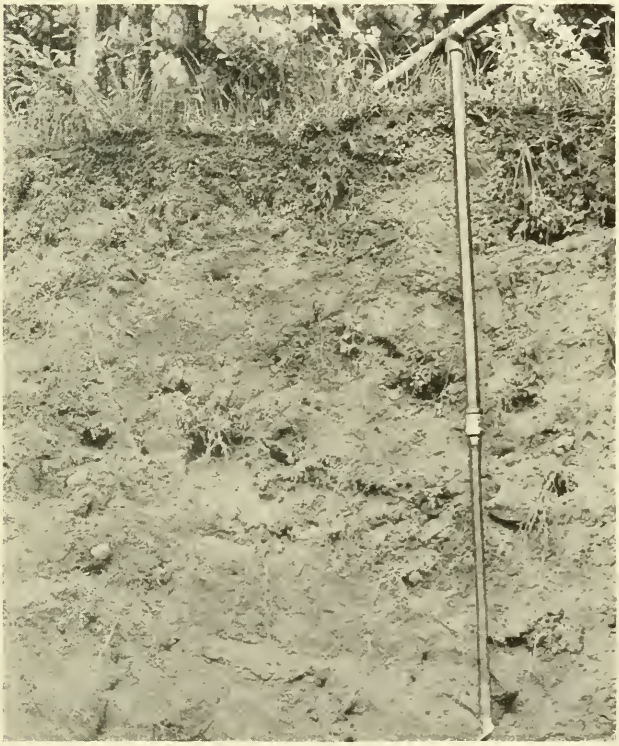

FIGURE 71. Mull soil profile exhibiting almost no horizon differentiation. Simsbury, Conn.

A_2: 2½ - 4 in. Light gray, structureless l. s. Poor R. D.

B_1: 4 - 6 in. Very dark brown, dense, compact loam with fair R. D.

B_2: 6 - 9 in. Deep rust brown soft to firm s. l. Fair R. D.

B_3: 9 - 22 in. Reddish yellow brown, loose and open l. s. Fair R. D.

C_1: 22 - 30 in. Yellowish gray sand. Fair R. D.

C_2: 30 in. +. Gray sand. Some R. D.

Forest cover. Spruce and fir had been cut to about 8 inches d. b. h. and the hardwoods to 10 - 12 inches d. b. h. At the time of sampling there were left scattered trees of yellow birch, spruce 6 inches to 30 feet high (although most of the taller ones had blown down), yellow birch, and balsam fir seedlings.

Ground cover. Hobblebush, striped maple, and red maple seedlings. Rather sparse herbaceous growth with some moss.

2. **Cherry Mountain Plot 2.** Spruce-hardwood type Fig. 73. El. 1994-2014 ft. Nos. 17 - 24. Sept., 1928.

Soil. Bench type. Similar to Peru loam except for podzolization. Slope E. 15 per cent. Slow drainage.

F: 0 - ¾ in. Moderately decomposing litter. Fair R. D. and good M.

H: ¾ - 6 in. Nearly black raw humus of the "greasy duff" type. Excellent R. D. and good M.

A_2: 6 - 8½ in. Gray, structureless, soft l. s. Very little R. D.
B_1: 8½ - 10 in. Dark brown, moderately compact loam. Fair R. D.
B_2: 10 - 14 in. Dark yellow brown, friable f. s. l. Little R. D.
B_3: 14 -20 in. Mottled dark brown and gray, firm, s. l.
C_1: 20 - 26 in. Mottled olive and brown, compact f. s. l.
C_2: 26 in.+. Slightly mottled grayish to olive structureless, firm, l. s. Practically no R. D.

Forest cover. Balsam fir, red spruce, red maple, mountain maple, striped maple, yellow birch, fire cherry.

Ground cover. Reproduction of the above species, Clintonia, painted trillium, Indian cucumber, wood sorrel, Canada Mayflower, aster, spring woodfern, moss on rotting logs.

3. **Cherry Mountain Plot 3.** Spruce-hardwoods type. El. 2061-2100 ft. Nos. 25-31. Sept., 1928.

Soil. Upland till type, probably Hermon f. s. l. by present U. S. Soil Survey classification. A hill top with excellent drainage.

F: 0 - 1 in. Loose, slightly matted material undergoing fair decomposition. Some mycelial growth. Excellent R. D. and M.

H: 1 - 1¾ in. Mellow, slightly granular black raw humus with excellent R. D. and M.

A_2: 1¾ - 3½ in. Mouse gray, structureless, soft f. s. l. Good R. D.

B_1: 3½ - 6 in. Dark brown, firm to soft f. s. l. to loam. Excellent R. D.

B_2: 6 - 18 in. Reddish yellow brown, soft, mellow f. s. l. Moderate R. D.

C_1: 18 - 25 in. Yellow brown to grayish yellow, structureless, loose, l. f. s. Slight R. D.

C_2: 25 in. +. Light yellowish gray, structureless, loose l. s. and gravel.

Forest cover. Yellow birch, beech, red maple, sugar maple. A mature stand.

Ground cover. Mountain maple and striped maple, fire cherry, hobblebush, red-berried elder, sugar maple, beech, and yellow birch seedlings. Also spring woodfern, Canada Mayflower, raspberry, aster, wood sorrel.

4. **Waterville,** vicinity of Cascade Falls. Spruce-hardwoods type, about 2000 feet. Nos. 185-191. Sept., 1929.

Soil. Similar to Brookfield loamy sand of the Connecticut classification except for podzolization. Slope N. E. 30 per cent. Good drainage.

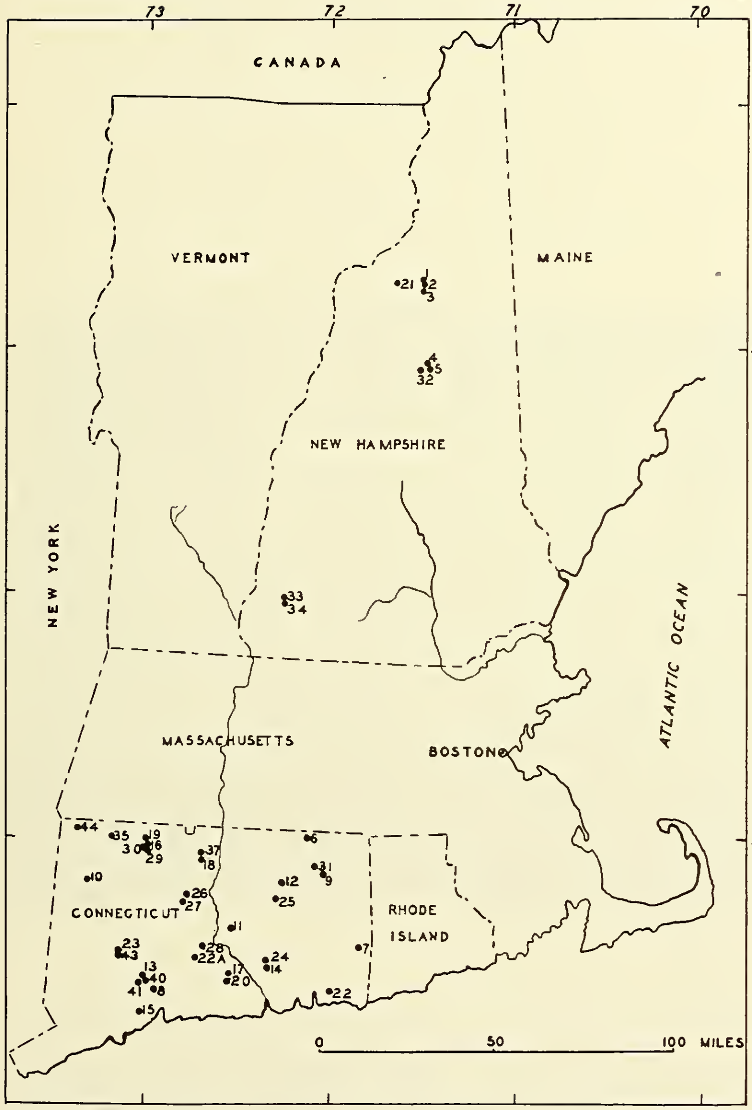

FIGURE 72. Map of New England (exclusive of Maine) showing the locations at which samples were taken.

F: 0 - 1 in. Moderately decomposing litter.
H: 1 - 4 in. Dark brown raw humus.
H: 4 - 5 in. Black, well decomposed material with good R. D. and some M.
A_2: 5 - 9 in. Gray, structureless, loose l. s., some R. D.
B_1: 9 - 10 in. Dark reddish brown (coffee brown) angular slightly compact s. l. to loam.
B_2: 10 - 18 in. Dark reddish brown, granular, fairly compact s. l. to l. s. Some R. D.
C_1: 18 in. +. Yellowish brown, granular, fairly compact s. l.

Forest cover. Spruce, fir, hemlock, birch, beech, maple. Advance reproduction largely red spruce with scattering of fir.

Ground cover. Hobblebush, wood sorrel, Clintonia, club moss, spring woodfern, and painted trillium.

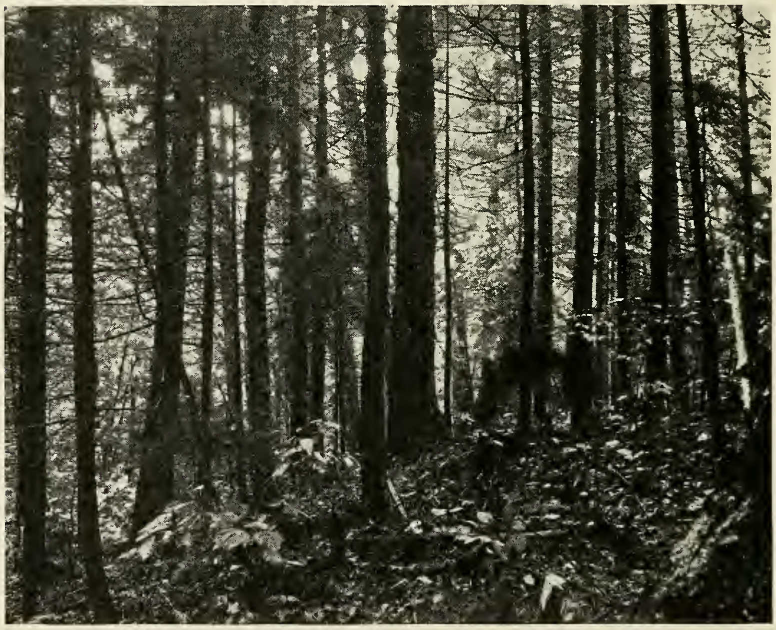

FIGURE 73. Spruce-hardwoods type of forest, Cherry Mountain, New Hampshire. The soil is podzolized. (U. S. Dept. Agric.)

5. **Waterville,** vicinity of Greeley Ponds. Spruce slope type. El. about 2300 feet. Nos. 192-197. Sept., 1929.

Soil. A shallow, very variable soil, somewhat similar to the Hinsdale series of the Connecticut classification, except for degree of podzolization. E. slope, 20 per cent, granite rock. Excellent drainage.

Litter—freshly fallen leaves.
F: 0 - 1½ in. A somewhat matted raw humus with much mycelia. Fair R. D. and M.

H: $1\frac{1}{2}$ - 7 in. Very dark brown, greasy duff with excellent R. D. and considerable M.

H: 7 - 8 in. Black, smooth muck-like material quite high in mineral matter.

A_2: 8 - 11 in. Gray to brownish gray, loose, structureless, stony c. s. Very few roots.

B_1: 11 - 13 in. Dark reddish brown (coffee brown) granular, fairly compact, med. to c. s. Fair R. D.

B_2: 12 in. +. Reddish yellow-brown granular, quite compact med. to c. s. Few roots.

Extreme stoniness prevented deeper sampling.

Forest cover. Nearly pure stand of mature, virgin red spruce 12-18 inches d. b. h. with small admixture of yellow and paper birch and red maple. Understory of spruce and fir reproduction.

Ground cover. Hobblebush, some striped maple. Herbaceous: wood sorrel, gold thread, clintonia.

Moderately Podzolized, Connecticut

6. **Bigelow Brook,** near Union, Hemlock-Hardwoods. Nos. 44-50.

Soil. Brookfield loam. Fairly level, in a narrow valley bordered by much higher land. Good drainage.

F: 0 - $\frac{1}{2}$ in. Moderately decomposed leaf litter. Some white mycelial growth in spots, but no matting. Excellent R. D. Mycorrhiza.

H: $\frac{1}{2}$ - $2\frac{1}{2}$ in. Dark chocolate colored, mellow, porous, spongy pure humus. Not matted. Little or no mycelia. Very well interwoven with fibrous roots. Good M. development.

A_2: $2\frac{1}{2}$ - $3\frac{1}{2}$ in. Mouse gray leached layer; f. s. l., firm but not compact. Roots penetrate but with little branching.

B_1: $3\frac{1}{2}$ - 5 in. Brown to reddish yellow brown loam, slightly compact. Breaks into coarse angular lumps. Poor R. D.

B_2: 5 - 12 in. Reddish yellow brown loam to f. s. l., less compact than B_1 and more yellow in color. Fairly good R. D.

C_1: 12 - 20 in. Yellow fine s. l. to loam. Soft, structureless. Fair R. D.

C_2: 20 in. +. Not examined but appeared to be fairly typical of Brookfield loam of a good depth for N. E. Connecticut.

Forest cover. Hemlock 75-100 years old, with black birch, red maple, sugar maple and white birch. Fairly deep shade.

Ground cover. Very sparse except in openings. Partridgeberry, whorl pogonia and some hemlock and red maple reproduction were present in vicinity of pit.

7. **Voluntown** (7 or 8 miles south of the village) mixed hardwoods. Nos. 51-59.

Soil. Gloucester s. l. to f. s. l. Level, good drainage.

F: 0 - $\frac{1}{4}$ in. Slightly matted material with but little mycelial growth. Fair R. D. and M.

H: $\frac{1}{4}$ - $1\frac{1}{4}$ in. Fairly open material, not felty, with good R. D. and very good M. Probably a fibrous duff.

A_2: $1\frac{1}{4}$ - 2 in. Purplish gray leached layer, l. s. to sand. Very little R. D.

B_1: 2 - 4 in. Dark reddish brown, friable f. s. l. Some R. D.

B_2: 4 - 6 in. Reddish yellow brown, granular, friable f. s. l. Practically no R. D. in this horizon or below.

B_3: 6 - 13 in. Yellowish brown, granular f. s. l.

B_4: 13 - 19 in. Grayish yellow brown, granular, firm f. s. l.
C_1: 19 - 23 in. Yellowish gray, structureless, slightly compact f. s. l.
C_2: 23 in. +. Gray, compact f. s. l.

Forest cover. Black, scarlet and white oak, red maple, hickory, and chestnut sprouts. Reproduction of the foregoing and also chestnut oak.

Ground cover. Hazelnut, blueberry, shadbush, star flower, wintergreen, and brake fern.

8. **Lake Wintergreen,** near New Haven, mixed hardwoods Nos. 119-125.

Soil. Wethersfield f. s. l. Gentle slope N. Fair to good drainage.
F: 0 - 3/8 in. Slightly matted. Some mycelia.
H: 3/8 - 1 in. Porous, black, spongy material; a fibrous duff approaching a greasy duff. Good R. D. and fair M.
A_2: 1 - 2 in. Purplish gray s. l.
B_1: 2 - 4 in. Reddish brown f. s. l. somewhat compact.
B_2: 4 - 12 in. Light purplish brown f. s. l. compact.
B_3: 12 - 22 in. Same color but a little coarser and more compact.
C_1: 22 in. +. Brownish purple very compact s. l. There was some R. D. in B_1 but practically none below that horizon.

Forest cover. Red oak, white oak, chestnut oak, beech, gray birch.

Ground cover. Laurel, huckleberry and low bush blueberry in great abundance, witch-hazel, male-berry, arrow wood. Red pine and white pine underplanting.

9. **Eastford - Pomfret.** Between Phoenixville and Abington on the Eastford - Pomfret town line. Oak stand. Nos. 180, 370-372, 175. July and Nov., 1929.

Soil. Charlton f. s. l., but not typical. Gently rolling, good drainage.
Litter: 1/2 in. Loose, undecomposed leaves.
H: 0 - 1 1/2 in. Raw humus, the upper part of which contains an admixture of charred organic matter.
A_1: 1 1/2 - 1 3/4 in. Mouse gray f. s. l.
A_2: 1 3/4 - 2 3/4 in. Dark gray leached f. s. l.
B_1: 2 3/4 - 4 1/2 in. Dark reddish yellow brown f. s. l.
B_2: 4 1/2 - 12 in. Yellowish brown f. s. l. very granular.
B_3: 12 - 27 in. Light yellowish olive f. s. l. very granular and lacking coherence.
C_1: 27 - 32 in. Light yellowish olive structureless f. s. l. It should be noted that the thickness of the various horizons is very variable in this locality. A very definite "ortstein" was found in several places at depths of 28 - 34 inches.

Forest cover. Chestnut, scarlet, and black oak. A severe burn occurred in this area in 1926, killing most of the trees. At the present time the new growth is beginning to add again to the forest floor.

Ground cover. Mostly blueberry and young oak sprouts.

10. **Mohawk Mountain.** Mohawk State Forest, Cornwall. Worthington Lot. Conifer-hardwoods. Nos. 379-385. Nov., 1929.

Soil. Hermon f. s. l. Topography rolling, surface very rough due to boulders of granitic gneiss. Detailed information relative to the several horizons is lacking, although the following horizons were sampled: Litter, F, H, B_1, B_2, C_1, and C_2.

Forest cover. Hemlock, white pine, yellow birch, black birch, red oak. A fully stocked stand, 150 years old.

Raw Humus Types, Connecticut

11. **Meshomasic Mountain,** Meshomasic State Forest, Portland. Oak forest. Nos. 305-308. Oct., 1929.

Soil. Gloucester f. s. l. shallow phase. Nearly flat mountain top. Drainage good. Moderate amount of granitic gneiss rocks and boulders.

Litter - current leaf fall.

F: 0 - ½ in. Matted to fragmentary, slow decomposition. Good mycelia growth. Fair R. D. and very few M.

H: ½ - 3½ in. Dark brown to black, very fibrous, quite felty, spongy raw humus. To be classed as fibrous duff. Good to very good mycelia growth with excellent R. D. Moderate M development.

A_2: Very thin. Brownish gray leached layer f. s. l.

B_1: 3¾ - 6¾ in. Reddish yellow brown f. s. l. Finely granular structure. Very good R. D. No M.

B_2: 6¾ - ? in. Light yellowish brown f. s. l., finely granular, firm. Fair to poor R. D.

Bed rock reached at about 2 feet.

Forest cover. Scarlet oak 98 per cent, occasional white oak. An extremely open, ragged stand, 80 years, with practically no younger trees. Formerly much chestnut existed here.

Ground cover. Huckleberry, smilax, brake fern, sheep sorrel, maleberry, red maple, sassafras, shadbush, high bush blueberry, low bush blueberry, chokeberry, mosses. Very little oak reproduction.

12. **Mansfield.** On Route 109 just East of Houston Nurseries, Oak forest. Nos. 426 - 432. Sept., 1930.

Soil. Probably Brookfield f. s. l. Nearly level on top of rounding hill. Quite stony (gneiss). Excellent drainage.

Litter - current leaf fall.

F: 0 - ½ in. Slightly matted material undergoing decomposition at a moderate rate. Good development of mycelia and poor R. D. Very little M.

H: ½ - 1¼ in. Dark, moderately raw, somewhat felty. Mycelia, R. D., and M. well developed.

A_2: 1¼ - 4¼ in. Dull reddish brown, granular, firm f. s. l. with good R. D. and M.

B_1: 4¼ - 9½ in. Bright reddish brown, with other characteristics similar to A_2.

B_2: 9½ - 16½ in. Yellowish red brown, granular, firm f. s. l. Fair R. D. and no M.

C_1: 16½ in. +. Yellowish brown with grayish olive cast. F. s. l. single grain structure, firm to slightly loose. R. D. poor.

Forest cover. Black and scarlet oak with some white oak constituting 98 per cent, about 22 years. Gray birch, large toothed aspen, mockernut hickory also present.

Ground cover. Low bush blueberry, black cherry, oak and hickory seedlings, hazelnut, sarsaparilla, huckleberry, shadbush, arrowwood, grasses, and mosses.

13. **Bethany,** on Rainbow Road. Oak stand (Figs. 74 and 70.) Nos. S358-361. June, 1931.

Soil. Gloucester f. s. l. Level area on top of hill. Similar in many respects to the Meshomasic locality with elevation considerably higher at the latter place. Drainage good.

F: 0 - 1 in. Matted material containing considerable mycelia. Fair R. D. and some M.

H: 1 - 2½ in. Black, felty, raw humus with good R. D. and some M. A fibrous duff.

A_2: Very thin, slightly grayish leached layer. Hardly more than a trace.

A_3: 2¾ - 5 in. Medium brown with yellowish cast. Granular, firm f. s. l.

B_1: 5 - 10 in. Yellowish brown with slight reddish cast f. s. l. Granular, firm. Some rocks.

B_2: 10 - 17 in. Yellowish brown f. s. l. Quite rocky.

FIGURE 74. Slow growing stand of scarlet oak, Bethany, Conn. Profile No. 13. The soil is a typical raw humus. (Figure 70.)

Forest cover. Scarlet oak and chestnut oak, with some red and black oak, wild black cherry.

Ground cover. Reproduction of the above species, arrow-wood, huckleberry, spikenard.

14. **Devil's Hop Yard** State Park, East Haddam. Hemlock-hardwoods. Nos. 32 - 37. 1928.

Soil. Brookfield loam to f. s. l. Nearly level, on a bench considerably above a stream. Excellent drainage.

F: 0 - ½ in. Normally decomposing mixed hardwood and hemlock leaves.
H: ½ - 3½ in. Dense, very dark brown, slightly felty. Considerable mycelia present, but few roots.
A_1: 3½ - 5 in. Brown, light loam, firm.
A_2: 5 - 10 in. Light brown f. s. l. Mellow.
B_1: 10 - 15 in. Yellowish brown with dull red cast.
B_2: 15 - 21 in. Yellowish brown with bright reddish cast.

Forest cover. Hemlock about 100 years, black birch, aspen, laurel, witch hazel. Dense shade.

Ground vegetation. Ground pine, rattlesnake plantain, partridgeberry, Canada mayflower, sweet pepperbush.

Humus Types, Connecticut

15. **Maltby Lakes.** West of New Haven, red pine plantation of New Haven Water Co. Nos. 112 - 118. Aug., 1928.

Soil. Hollis f. s. l. Nearly level, considerable small stone, good drainage.
F: 0 - ¾ in. Rather open needle layer containing considerable mycelia. Good R. D. and M.
H: ¾ - 1¼ in. Matted with roots and red moss. A tendency to become raw humus. Some mycelia present; excellent R. D. and M. Some evidence of earthworm activity.
A_1: 1¼ - 1½ in. Dark gray-brown f. s. l. Fine crumb structure, mellow. Good R. D. and M. Some worms.
A_2: 1½ - 6 in. Brown f. s. l., same characteristics otherwise.
B: 6 - 22 in. Light to yellowish brown f. s. l. Single grain, firm. Very few roots and no M. or earthworms.
C_1: 22 - 26 in. Yellowish brown sandy loam.
C_2: 26 in. +. Grayish yellow-brown l. s., slightly compact.

Forest cover. Pure red pine, 18 years. Site index 18. No ground cover.

16. **Peoples Forest,** Barkhamsted. Beech-hemlock stand 100-150 years old, with a little maple reproduction. Full stand. Nos. 317, 318, 319. Oct., 1929.

Soil. Beckett f. s. l. Gentle slope. Litter, H and A_2 sampled.

17. **Cockaponset State Forest,** Haddam, Beaver meadow district, Compartment 7. Hemlock-hardwoods. Nos. 367-369. Nov., 1929.

Soil. Haddam s. l., on a steep S. W. slope. Considerable gray sandstone and granite present. Excellent drainage.
F: 0 - 1 in. ±. A mixture of hardwood leaves and needles.
H: 1 - 2 in. ±. Black, well decomposed humus, fairly open.
A_2: Trace. Dark gray podzolized s. l.
A_3: 2 - 8 in. Reddish brown, loose sand.
B: 8 in. +. Brownish red, loose sand.

Forest cover. Hemlock, beech, 70 - 90 years, butternut, black birch, white oak, mountain laurel, red maple. Ground cover not recorded.

Mild Humus Types, Connecticut

18. **Rainbow** Red pine plantation, Windsor. Block 24. Unthinned. 30 years. Site index about 8. Sept., 1928.

Soil. Merrimac c. s., level terrace, very uniform. Excessive drainage.
F: 0 - ½ in. Slightly matted needle accumulation. Some mycelia present. Very few M. Fair to good R. D.
A_1: ½ - 1 in. Brownish gray c. s., single grain loose. Fair R. D.
A_2: 1 - 8 in. Grayish brown c. s.
B_1: 8 - 20 in. Yellowish brown with reddish cast, c. s. Poor R. D.
B_2: 20 - 28 in. Yellowish brown, c. s.
C_1: 28 in. +. Yellow-gray brown c. s. Some fine gravel present.

Forest cover. Red pine pure stand, planted 1902. No ground cover.

19. **Peoples Forest,** Barkhamsted. Old field white pine immature. 35 years full stocking. Oct., 1929. Nos. 311, 311½, 312.

Soil. Merrimac l. s. nearly level, excellent drainage. F, H and A_2 sampled.

20. **Cockaponset State Forest,** Haddam. Ponsett pine lot. Pine-hardwoods. Nos. 363 - 366. Nov., 1929.

Soil. Hinsdale f. s. l. Gentle slope S. W. near summit of hill. Good drainage. Very little stone.
F: 0 - ½ in. ±. Moderately rapid decomposition. Some mycelia. No R. D. or M.
H: ½ - 1 in. ±. Open, rather loose structure with some mycelia. Good R. D. and M.
A_2: Trace. Gray f. s. l.
A_3: ¾ - 7 in. Yellowish brown, mellow f. s. l.
B: 7 in. +. Reddish yellow-brown f. s. l.

Forest cover. Old field white pine 35 - 40 years, full stand. Considerable gray birch, some dogwood, red maple and black oak.

Ground cover. Ground pine. This was formerly a cultivated soil. The pine is becoming stunted. Growth has decreased from approximately 1½ feet per year to less than 1 foot during the past 5 or 6 years.

Mull Types

21. **Bethlehem,** N. H. W. of village 1 mi. El. 1400 feet. Nos. 400 - 403. June, 1930.

Soil. Loam, not named. Gentle slope W. Fair to good drainage.
Litter - Rapidly decomposing leaves of rather unequal distribution.
A_1: 0 - 7 in. Black, mellow crumb mull, loam. Excellent R. D. but no M. observed.
B: 7 - 17 in. Dark yellowish brown, granular, firm, s. l. to loam. Good R. D.
C_1: 17 in. +. Grayish brown, coarsely granular, firm, s. l. Few roots.

Forest cover. Beech, yellow birch, sugar maple, 40 - 80 years; basswood, white ash, spruce, striped maple, American hop hornbeam.

Ground cover. Adders tongue, clintonia, spring woodfern, twisted stalk, painted trillium, violet, Canada mayflower.

22. **Groton,** between old Mystic and New London. Mixed hardwoods. Nos. 60 - 65, Oct., 1928.

Soil. Gloucester f. s. l. Nearly level, excellent drainage. Some stone and gravel. Each annual leaf fall decomposes within the year, so no accumulation takes place.
A_1: 0 - 1 in. Brown with slightly grayish cast. A good earthworm mull. Crumb structure, mellow. Good R. D. Few M.

A_2: 1 - 7 in. Brown f. s. l. Crumby and mealy.
B_1: 7 - 13 in. Reddish brown s. l. Granular and friable. Fair R. D. No M.
B_2: 13 - 19 in. Yellowish brown s. l.
B_3: 19 - 23 in. Grayish yellow-brown, very f. s. l. slightly compact.
C_1: 23 in. +. Yellowish gray to gray very f. s. l. slightly compact.

FIGURE 75. Vigorous growing stand of mixed hardwoods. Middlefield, Conn. Profile No. 23a. The soil is an excellent mull. Compare with Figure 74.

Forest cover. Red oak, black oak, white oak and hickory 75 - 100 years with understory of sugar maple, blue beech, white ash, and American hop hornbeam.

Ground cover. Reproduction of forementioned species together with black cherry, arrow-wood, chestnut, blueberry, huckleberry, golden rod, spotted wintergreen, greenbrier, aster.

22a. **Middlefield.** Property of Beseck Fish and Game Club, near Durham Town Line. Mixed hardwoods, Fig. 75. Nos. S362 - 363.

Soil. Cheshire f. s. l. to loam. Slope E. 10 per cent. Fair drainage. The block is subject to some seepage from adjacent higher land. An excellent mull.

Litter - current year's leaf fall.

A_1: 0 - 3 in. Dark brown with reddish cast, mellow f. s. l. to loam. Very good R. D. Fair M.

A_2: 3 - 8 in. ±. Pale reddish brown to medium brown, mellow f. s. l. to loam.

B: 8 - 24 in. ±. Light reddish to yellowish brown coarsely granular firm to compact f. s. l.

Forest cover. Red, black, chestnut and white oaks (70 - 80 per cent) basswood, pignut and bitternut hickories, white ash, beech, sugar maple, tulip-tree, black birch, sassafras. A high forest with abundant small trees and large shrubs.

Ground cover. Tall dogwood, arrow-wood, witch-hazel. Asters, grasses, partridgeberry, several ferns, and a number of small herbs.

This is an excellent stand containing some fine timber.

23. **Middlebury,** Whittemore property, red pine plantation. Nos. 76 - 81. Oct., 1928.

Soil. Charlton f. s. l. to loam on a 5 per cent slope E. Some stone. Drainage moderate to good.

F: 0 - 1 in. Red pine needle litter undergoing moderate decomposition. Fairly open. Considerable mycelia. Very good earthworm activity. Fair F. D. and some M.

A_1: 1 - 5 in. Very dark brown f. s. l. to loam. An excellent crumby mull, very mellow. Good R. D. and M.

A_2: 5 - 8 in. Dark brown mellow mull with good R. D. and M.

B_1: 8 - 13 in. Reddish yellow-brown, granular, friable. Fair R. D. Poor M.

B_2: 13 - 17 in. Light reddish yellow-brown, granular but firm. Poor R. D. and no M.

B_3: 17 - 23 in. Yellowish brown with reddish cast, f. s. l.

C_1: 23 - 25 inches. Olive gray, heavily mottled with reddish brown. Firm. Very f. s., micaceous.

C_2: 25 in. +. Olive gray, slightly mottled.

Forest cover. Pure red pine, about 19 years. Site index 21. No ground cover.

This profile is characterized by the exceptionally good mull condition of A_1 and A_2.

24. **Devil's Hop Yard** State Park, Haddam. Hemlock. Nos. 38 - 43. 1928.

Soil. Hinckley f. s. l. on a 50 - 60 per cent slope E. Small boulders present and much coarse gravel. Drainage excellent.

F: 0 - ½ in. Rather loose, rapidly decomposing needle and leaf litter, showing some earthworm activity.

A_1: ½ - 2½ in. Dark gray brown f. s. l. An excellent crumb mull, very mellow. Good R. D. and fair M. Much earthworm activity.

A_2: 2½ - 5 in. Dark brown f. s. l. Fair crumb mull, mellow. Fair R. D.

A_3: 5 - 10 in. Light brown with yellowish cast, granular, friable.

B: 10 - 20 in. Yellowish brown f. s. l.

C_1: 20 in. +. Bright yellowish brown sandy and gravelly loam.

Forest cover. Hemlock 75 - 100 years. Reproduction of sugar maple.

Ground cover. A sparse covering of ferns and some partridgeberry.

25. **South Coventry,** Pine Lake Shores, real estate development, Coventry. Red pine. Nos. 373-376. Nov., 1929.

Soil. Hinsdale f. s. l. on the lower end of a long rather steep slope. Excellent drainage. The forest floor was an average plantation accumulation undergoing moderately rapid decomposition.

F, A_1, B_1, and B_2 sampled.

Forest cover. Red pine 18 years old making exceptionally rapid growth. Site index 22, which is the highest recorded in the state (20, p. 745).

Ground cover. None.

26. **West Hartford.** Hartford Water Board land; near block No. 42. Mixed hardwoods. Nos. 178, 179. Aug., 1929.

Soil. Holyoke f. s. l. to loam on gentle slope. Good drainage. Litter and A_1 sampled. An excellent mull.

Forest cover. Red oak, sugar maple, white ash, white oak, bitternut hickory.

Ground cover. Reproduction of the above; dogwood, hobblebush.

27. **Farmington,** about 2.5 miles N. of the village. Mixed hardwoods. Nos. 377, 378. Nov., 1929.

Soil. Holyoke f. s. l. to loam, very similar to profile 26. A very good mull. Litter and A_1 sampled.

Forest cover. High forest of red, black and white oaks, sugar maple. Some white ash, pignut hickory, black birch, shagbark hickory and American hop hornbeam.

Ground cover. Dogwood, arrow-wood, Christmas fern, grape fern, aster, bittersweet, grasses, woodbine, and many herbs.

28. **Middletown - Middlefield.** Mr. Comp's property near the town line. Oak. Nos. 309, 310. Oct., 1929.

Soil. Cheshire f. s. l. Nearly level upland. Good drainage. An excellent mull. Litter and A_1 sampled.

Forest cover. White oak 90 per cent, black oak, shagbark hickory, sugar maple.

Ground cover. Seedings of the above, dogwood, huckleberry, high bush blueberry, low bush blueberry, sassafras, toothed viburnum, grasses, small herbs and some ferns.

29. **Peoples Forest,** Barkhamsted, North of Whittemore camp ground. Young hardwood stand of mixed oaks 30 - 35 years. Full stand. Nos. 313, 314. Oct., 1929.

Soil. Merrimac l. s. Litter and A_1 sampled.

30. **Peoples Forest,** Barkhamsted. Pure beech stand, 100 - 150 years, full stand. Nos. 315, 316. Oct., 1929.

Soil. Litchfield f. s. l. on a nearly level portion of a long slope. Litter and A_1 sampled.

31. **Eastford,** 0.6 mile west of Phoenixville on road to Mansfield. Oak stand. Nos. 419 - 425. Aug., 1930.

Soil. Hinsdale f. s. l. Upland, 8 per cent slope S.

F: 0 - ¼ in. Flaky, fragmentary material.

H: ¼ - ½ in. Very thin and not uniformly present. Crumby, black fine grained material with very good root development. Few M.

A_1: ½ - 1½ in. Very dark to blackish brown mellow f. s. l. with good R. D.

A_2: 1½ - 5½ in. Brown with reddish yellow cast, f. s. l., mealy and mellow with very good R. D.

B: 5½ in. +. Yellowish brown with slight reddish cast, finely granular friable f. s. l.

This soil is not a true mull, but it scarcely fits into any other classification.

Forest cover. White, red, black and scarlet oaks 40 years. Occasional hickory.

Ground cover. Witch-hazel, oak seedlings, arrow-wood, dogwood, wintergreen, partridgeberry, dewberry, low bush blueberry, red maple, grasses, mosses, some herbs.

In addition to the foregoing profiles, some additional ones were sampled for volume weight and associated determinations. These are briefly described as follows (the sampling depths of the various horizons are given in Table 3):

32. **Waterville,** N. H., between Mad River Farm and Waterville. White birch, yellow birch and sugar maple with an understory of spruce. A strongly podzolized profile overlaid by a six inch greasy duff layer. B_2 very compact; C_1 firm to compact; C_2 firm c. s. with some fine gravel.

33. **Keene,** N. H. Five Mile Drive. El. about 530 ft. White pine stand probably 100 years old with some hemlock and maple. This is a well developed podzol profile in sandy terrace material similar to the Merrimac sand at Rainbow, Conn., though not as coarse. Ortstein occurs at a depth of 15 - 18 in. C_1 is very compact.

34. **Keene,** N. H. Another part of the same stand described in No. 33. The leached layer is 6 in. thick instead of 3 in. and no "ortstein" was encountered to the depth of the excavation (17 in.) although the B_2, 10 - 17 in., was very compact.

35. **Norfolk,** on Windrow Road, a short distance east of Toby Pond. On the edge of a terrace. Merrimac f. s. Sampled at a road cut. A most unusual condition as will be seen by the following description:

A_1a: 0 - 5 in. Dark brown, f. s., crumb structure.

A_1b: 5 - 10 in. Medium brown, f. s., fine crumb.

A_2: 10 - 17 in. Grayish white structureless leached l. s.

B: 17 - 33 in. Reddish yellow, somewhat compact l. s.

C_1: 33 in. +. Brownish yellow sand.

Grass is the only cover.

The above measurements are subject to great variation, the A_2, for example, varying from 0 to 12 in. in thickness, while the overlaying brown A_1 is between 5 and 17 in. thick. According to Professor R. F. Flint of the Department of Geology, Yale University, there is no evidence that the brown surface soil was deposited mechanically upon the leached layer.

36. **Norfolk.** Sample taken on opposite side of the road from No. 35. A scrubby growth of gray birch and some smaller shrubs resulted in the A_1 being a fairly good mull. Here it was only 5 in. thick, with the leached A_2 only 4 to 5 in.

37. **Windsor Locks,** Conn., on road to East Granby. Hardwood stand of white oak, red oak, maple, ash, cherry. Ground cover of oak, maple and chestnut reproduction, huckleberry, vaccinium, hazelnut, ferns, wintergreen. The soil is Merrimac sand similar to Profile 18 except that the forest has brought about a greater modification of the upper layers. There is a definite H layer, overlaying a slight podzolization. The former agricultural A horizon is thinner, somewhat lighter in color and shows a definite trend away from an agricultural soil profile. The F is ½ in. in thickness, H ¾ in., A_2 (leached) trace to ⅛ in., and A_3 5 to 6 in.

38. **Lake Wintergreen.** Hardwoods, mull, located further up the slope than No. 8. Younger trees and a larger percentage of gray birch present. Otherwise similar to No. 8.

39. **Lake Wintergreen.** Red pine plantation, 18 years. Not very distant from the previous locality. A mull type.

40. **West River.** Porter Hill Road, Bethany. Red pine plantation. Brookfield f. s. l. A mull.

41. **Lake Chamberlain,** Bethany. Red pine plantation. Hollis f. s. l. to loam. A mull.

42. **Middlebury.** Whittemore property, opposite big bend in road. Red pine plantation. Charlton v. f. s. l. to loam. A mull type.

43. **Middlebury pasture.** Across road from No. 36. Similar soil but in pasture instead of forest.

44. **Salisbury,** East side of Miles Mountain between the summit and the Housatonic River. Pasture land. Probably Dover f. s. l.

Summary List of Profiles

Strongly Podzolized, New Hampshire
1. Cherry Mountain, Plot 1
2. Cherry Mountain, Plot 2
3. Cherry Mountain, Plot 3
4. Waterville, Cascade Falls
5. Waterville, Greeley Ponds

Moderately Podzolized, Connecticut
6. Bigelow Brook
7. Voluntown
8. Lake Wintergreen
9. Eastford - Pomfret
10. Mohawk Mountain

Raw Humus Types, Connecticut
11. Meshomasic Mountain
12. Mansfield
13. Bethany
14. Devil's Hop Yard

Humus Types, Connecticut
15. Maltby Lakes
16. Peoples Forest
17. Cockaponset State Forest

Mild Humus Types, Connecticut
18. Rainbow
19. Peoples Forest
20. Cockaponset State Forest

Mull Types
21. Bethlehem, New Hampshire
22. Groton, Connecticut
22a. Middlefield
23. Middlebury
24. Devil's Hop Yard
25. South Coventry
26. West Hartford
27. Farmington
28. Middletown - Middlefield
29. Peoples Forest
30. Peoples Forest
31. Eastford

Additional Profiles
32. Waterville, New Hampshire, Podzol
33. Keene, Podzol
34. Keene, Podzol

35. Norfolk, Connecticut, Podzol
36. Norfolk, Podzol
37. Windsor Locks, Podzol
38. Lake Wintergreen, Mull
39. Lake Wintergreen, Mull
40. West River, Mull
41. Lake Chamberlain, Mull
42. Middlebury, Mull
43. Middlebury, Pasture
44. Salisbury, Pasture

PHYSICAL PROPERTIES

Total Weight of Forest Floor

One outstanding characteristic of forest soil, particularly in the northern forests, is the layer of organic debris upon its surface. Measurements of the amount of this material on the ground were made in a number of stands. The procedure was to collect carefully all of the debris in one square foot, using a hollow iron square of this dimension. The material was then dried, weighed and the amount calculated to an acre basis. From two to four samplings were made of each profile. Since thickness was noted also, it was possible to calculate the approximate weight per acre inch. These results are shown in Table 1.

Table 1. Weight of Forest Floor

Pounds per acre

Profile type	Forest type	Profile No.	F layer Thickness inches	F layer Total	F layer Per acre inch	H layer Thickness inches	H layer Total	H layer Per acre inch
New Hampshire Podzol types	White pine	33	1¾	42981	24560	1½	75697	50464
	White pine	34	¾	21107	28142	1¼	46531	37224
	Spruce-hdws.	32	—	—	—	5¾	263547	43924
	Spruce-hdws.	32a[1]	¾	15350	20466	2½	95460	38184
Connecticut Podzol types	Hardwoods	8	⅝	10361	16576	¾	45860	61148
	Hardwoods	9	—	—	—	1¾	88553	50600
	Hardwoods	37	½	12760	25520	¾	80781	107708
Humus types	Hardwoods	13	⅞	11800	13500	1½	53726	35818
	Red pine	18	1⅞	42981	22920	—	—	—
Mull types	Hardwoods	38	⅜	7579	20208	—	—	—
	Red pine	39	¼	7942	31768	—	—	—
	Red pine	40	¾	7051	9400	—	—	—
	Red pine	41	1½	13824	9216	—	—	—
	Red pine	42	1	14928	14928	—	—	—
			Average		**19767**			**53133**

[1]32a. Check plot in a girdling experiment near Waterville, N. H. Not previously described.

Measurements made in 1929 on the Station's plantation at Rainbow are given in Table 2.

TABLE 2. WEIGHT OF FOREST FLOOR IN CONIFEROUS PLANTATIONS

Red pine 27 years old, thickness of duff, ½ - 1½ inches		White pine 27 years old, thickness of duff, ¼ - 1 inch	
	Pounds per acre		Pounds per acre
Plot 1	21024	Plot 7	26400
2	21024	8	16800
3	32736	9	15072
4	25920	10	30240
5	32064	11	15648
6	34176	12	25344
Average	**27920**	Average	**21590**

This table shows that for the same age of trees, the accumulation under red pine is greater than under white pine.

Considering the data in both tables, it is evident that even in Connecticut forests there is a rather large accumulation of the F portion of the duff and, where it occurs, a large amount of the more decomposed H material, equal in many cases to that found in the more strongly podzolized white pine region of Keene and the spruce-hardwood region of the White Mountains of New Hampshire. The total amount of duff is always greater in the podzol or raw humus types than in the case of mull or mild humus.

While the total amount of H material found under the northern spruce and spruce-hardwood forests may vary tremendously, yet the variation in weight per acre inch is much narrower. Apparently an increase in thickness does not result in a corresponding increase in compactness.

Taking all the facts into consideration, we may assume the following weights per acre inch of duff as being approximately correct for the types given:

	Weight per acre inch F	H
Northern forests with strongly podzolized soils	20,000 pounds	40,000 pounds
Connecticut mild podzol	15,000 pounds	40,000 pounds
Connecticut mull	15,000 pounds	—

These figures have been used in this bulletin in calculating the weight of duff of those profiles whose thickness, but not weight, was taken at the time of sampling.

In studies carried on by Alway and Harmer (2) on forest floor material from three different localities in Minnesota, they found amounts varying from 25,000 to 56,000 pounds under virgin or nearly virgin maple-basswood-oak type, and 47,000 to 193,000 under spruce-balsam-birch type, with an average of 42,108 pounds in the first instance and 100,188 pounds in the second.

Auten's (4) observations in the Mont Alto State Forest of Pennsylvania reveal values ranging from 23,000 to 121,000 pounds per acre. In every case a slope had more duff than a ridge, and a valley more than a slope.

Henry (18) gives the following figures as the average total air dry weight of the forest floor under three forest types: Beech, 9297 pounds per acre; spruce 12,369 pounds; and Scotch pine, 16,317 pounds. These values found under Central European conditions are not greatly dissimilar to the results of measurements made in Southern New England, but are considerably lower than the values found in the more northern forests, as would be expected.

Volume Weight

In order to make comparisons on an acre basis it is necessary to know the density or volume weight of each soil horizon. The commonly accepted value of 2,000,000 pounds of soil for the surface 6⅔ or 7 inches, and 4,000,000 pounds for the 7 to 20 inch depth for arable soils, is wholly inadequate in the forest. Harland and Smith (16) have shown variations of approximately 1,800,000 to 2,400,000 pounds per acre for the upper 6⅔ inches, even in agricultural soils.

In the present work profiles typical of various conditions were selected and density determinations were made by the methods described below. Because of the stoniness of the soil, the presence of tree roots, and the relative thinness of some of the forest soil horizons, only two of the several methods (11, 16) that have been used by other investigators to study soil in place were considered practical for our conditions. These methods were (a) the tube or cylinder[1] method as recommended by Burger (7) and Craib (10) in which a steel cylinder 10 cm long and having a capacity of 1000 cc. is driven into the soil and the contents weighed after drying; and (b) the paraffine-immersion method as described by Shaw (40).

In some cases both methods were used, in others only the one more suitable. The paraffine-immersion method was very satisfactory for horizons less than 4 inches in thickness, provided the soil was moist enough to prevent crumbling. Correction was made for the weight and volume of stones present that were larger than one-quarter inch.

[1]The writer is indebted to the late Prof. J. W. Toumey of the Yale School of Forestry for loaning cylinders for this work.

In addition to density, the following related soil properties were determined on these samples: Moisture equivalent (48), loss on ignition, organic carbon by the Parr method (3, 6), clay and silt plus clay, by the hydrometer method (5), and several size fractions of sands obtained by sieving the material remaining after determining the silt plus clay. The results are to be found in Table 3.

Segregation of the profiles in the table was based upon the type of A horizon rather than upon soil series as would normally be true of non-forested soils. In forest soils the A and upper B horizons are of considerably more importance than the remainder of the profile due to the greater role these horizons play in the nutrition of the forest, and due also to the fact that these horizons are greatly affected morphologically by the forest and its environment.

In studying the volume weight values in this table it will aid one who is accustomed to thinking in terms of 2,000,000 pounds of soil per acre 6⅔ inches, to keep in mind that a density of 1.0 means 1,510,835 pounds per acre. Two million pounds per acre mean a density of 1.324. It is well to note the following points:

a. The low volume weights of the A horizon of the mull types, particularly in contrast to those of the two pasture soils included.

b. The lower volume weight of the zone of accumulation, B_1, and to a lesser extent B_2 in the podsols.

c. The high volume weight of the "ortstein" samples. (See end of table).

These results are in agreement with those of Burger (7) and Simpson (41). They sampled by arbitrary depths only, hence only their upper sample, 0 - 10 cm, can be compared with the writer's results.

Volume Weight of Soil
(0 — 10 cm)

(Burger)		(Simpson)	
Unmanured meadow	1.034	Denuded site	1.186
Field soil	1.326	Forest site	0.952
Cutting	1.071		
50 - 60 year conifers	0.796		
100 year hardwoods	0.855		

By referring to Figures 76 and 77 one observes the relationships between several other physical properties and volume weight. Neither clay alone nor silt and clay are correlated to any definite degree, and therefore these values were not plotted. On the other hand organic carbon, loss on ignition, and moisture equivalent all show a very good correlation. When the data are treated statistically, the correlation is $-.800 \pm .033$ for carbon and $-.511 \pm .0678$ for moisture equivalent. Thus it is the organic rather than the inorganic colloids that control the density of these soils.

TABLE 3. VOLUME WEIGHT AND RELATED PROPERTIES OF TYPICAL FOREST SOIL PROFILES

Horizon	Depth of sampling inches	Volume weight (Water = 1.0)	M. E.[1] %	Loss on ignition %	Organic carbon %	Coarse and med. sand .25–2 mm. %	Silt plus clay %	Clay %	Color (Dry soil)
Profile No. 32 Waterville, N. H.; Spruce hardwoods, Podzol, medium sand									
A_2	6– 10	1.122	4.58	0.7	0.80	50.9	20.2	8.7	Light gray
B_1	10– 15	0.890	12.05	11.5	5.48	53.3	19.3	7.9	Very dark reddish brown
C_1	22– 26	1.518	1.73	0.6	0.33	60.2	8.6	4.6	Yellowish gray
Profile No. 33 Keene, N. H.; White pine, podzol, medium sand									
A_1	0– 2½	—	20.40	14.5	9.85	39.5	25.0	7.7	Grayish black
A_2	2½– 5½	1.410	6.68	2.9	1.60	47.0	21.3	14.8	Dark gray
B_1	5½– 7½	0.989	14.03	—	—	49.8	24.5	9.6	Very dark reddish brown
B_2	7½–12½	1.110	14.76	12.0	5.37	50.4	21.6	9.1	Very dark reddish yellow
C_1	18– 22	—	2.52	2.1	0.69	84.5	7.3	4.8	Brownish yellow
Profile No. 34 Keene, N. H.; White pine, podzol, medium sand									
A_2	1– 7	1.324	5.52	2.1	1.12	44.4	21.8	11.8	Dark gray
B_1	7– 11	0.837	17.97	14.4	7.48	38.6	24.0	7.6	Very dark brown with reddish cast
B_2	11– 17	1.047	15.66	18.1	6.60	43.1	19.0	7.9	Very dark reddish yellow
Profile No. 35 Norfolk; Field, thick podzol, Merrimac fine sand									
A_1a	0– 4	1.305	4.11	1.5	0.91	31.1	12.0	7.0	Dark brown
A_1b	7– 12	1.385	4.75	2.5	—	—	—	—	Medium brown
A_2	12– 16	1.381	1.98	0.2	0.22	38.0	11.0	4.0	Grayish white
B_1	16– 20	1.178	7.78	3.1	0.98	36.7	17.6	8.5	Reddish yellow
B_2	25– 29	1.193	8.93	3.7	1.14	37.0	14.6	9.5	do
B_3	29– 33	1.385	4.85	2.6	0.67	38.4	12.4	8.4	do
C_1	33– 37	1.372	3.66	1.6	0.36	36.3	11.8	5.8	Brownish yellow

Profile No. 36 Norfolk; Scrubby hardwoods, podzol, Merrimac fine sand									
A_1	0– 4	0.960	6.46	3.5	1.80	32.8	16.4	9.4	Dark gray
A_2	9– 13	1.379	2.44	0.4	0.36	47.6	13.3	6.3	Grayish white
B_1	15– 19	1.253	6.16	1.5	0.66	44.2	16.9	8.9	Reddish brown
C_1	24– 28	1.425	3.05	0.5	0.34	50.3	10.3	5.3	Yellowish brown
Profile No. 8 Lake Wintergreen; Hardwoods, moderately podzolized, Wethersfield f.s.l. B and C horizons compact									
A_2	¾– 2	1.098	8.37	3.5	1.87	33.6	30.7	16.6	Purplish gray
B_1	2– 6	1.121	14.46	4.8	2.18	28.4	36.3	17.7	Reddish brown
B_2	6– 12	1.532	10.14	2.4	0.58	30.6	35.8	20.5	Light purplish brown
B_3	12– 18	1.788	10.02	2.4	0.36	30.3	34.9	20.7	do
C_1	18– 27	1.915	5.98	1.7	0.14	33.1	25.4	13.3	Brownish purple
Profile No. 9 Eastford-Pomfret; Hardwoods, moderately podzolized, Charlton f.s.l.									
A_2	1¾–3¼	1.070	7.28	3.9	2.04	26.1	27.4	13.9	Dark gray
B_1	3¼–4½	0.938	13.45	10.5	4.64	26.3	28.9	10.4	Dark reddish yellow brown
B_2	4½– 12	1.197	9.87	3.5	1.01	25.4	29.2	19.1	Yellowish brown
B_3	12– 22	1.370	8.47	2.6	0.39	26.0	30.9	18.4	do
B_4	22– 27	1.405	8.81	1.8	0.24	—	—	—	Light yellowish olive
C_1	27– 32	1.394	7.90	1.4	0.17	25.1	32.0	18.4	do
C_2	32+	1.471	5.78	1.0	—	—	—	—	do
Profile No. 37 Windsor Locks; Hardwoods, moderately podzolized, Merrimac c.s.									
A_3	¾– 6	1.005	5.18	5.1	2.42	67.3	11.2	7.7	Dark brown
Profile No. 13 Bethany; Hardwoods, raw Humus but not definitely podzolized, Gloucester f.s.l.									
A_2	1¾– 4	0.832	15.62	10.6	5.50	18.4	37.9	15.0	Med. brown with yellow cast
B_1	4– 9	0.934	14.05	5.9	2.34	18.0	37.5	16.4	Yellow brown with sl. yellow cast
B_2	9– 16	1.179	11.70	3.8	1.14	19.5	38.2	18.3	Yellowish brown

TABLE 3. VOLUME WEIGHT AND RELATED PROPERTIES OF TYPICAL FOREST SOIL PROFILES *(Continued)*

Horizon	Depth of sampling inches	Volume weight (Water = 1.0)	M. E.[1] %	Loss on ignition %	Organic carbon %	Coarse and med. sand .25–2 mm. %	Silt plus clay %	Clay %	Color (Dry soil)
Profile No. 18; Rainbow, red pine, mild humus, Merrimac c.s.									
A_1	0– 2	1.266	4.61	3.6	1.85	55.3	16.7	9.2	Grayish brown
A_2	2– 7	1.388	4.25	2.9	1.06	57.2	15.7	7.7	Grayish brown
B_1	9– 13	1.450	4.22	1.8	0.32	52.7	17.2	10.2	Yel. brown with sl. reddish cast
B_2	20– 24	1.453	3.41	1.3	0.22	56.5	13.2	6.2	Yellow
C_1	24– 28	1.445	—	—	—	—	—	—	Yellowish brown
Profile No. 38 Lake Wintergreen; Hardwoods, mull, Wethersfield f.s.l.									
A_1	0– ¾	1.028	11.50	5.0	2.15	30.2	32.6	17.9	Reddish brown
A_2	¾– 3½	1.112							
B_1	3½– 8	1.419	9.40	2.5	0.69	30.4	33.4	19.7	Brownish red
B_2	8– 12	1.531	—	—	—	—	—	—	Light purplish brown
C_1	16– 20	1.707	—	—	—	—	—	—	Brownish purple
Profile No. 39 Lake Wintergreen; Red pine, mull, Wethersfield f.s.l.									
A_1	0– 2	0.978	12.59	6.0	2.30	24.5	42.5	22.0	Reddish brown
A_2	2– 6	1.127							
B_1	6– 12	1.297	12.09	3.9	1.22	22.6	46.5	24.5	do
B_2	12– 23	1.365	12.62	3.5	0.76	16.2	43.5	22.1	do
B_3	23– 28	1.473	13.17	2.8	0.49	16.6	44.2	21.2	Brownish red
Profile No. 40 West River, Porter Hill Road; Red pine, mull, Brookfield f.s.l.									
A_1	0– 2	0.838	15.32	7.0	3.21	19.7	41.8	20.1	Dark brown
A_2	2– 8	1.116	13.61	5.5	2.26	18.4	44.1	23.9	Light brown
B_1	8– 18	1.368	11.88	4.5	1.34	19.7	40.2	23.2	do
B_2	18– 22	1.484	9.09	2.0	0.38	23.5	34.7	18.0	Yel. brown with sl. reddish cast

	Profile No. 31 Eastford; Hardwoods, mull, Hinsdale f.s.l.								
A_2	½–3½	0.845	12.93	—	—	19.3	30.8	10.3	Very dark brown
	Profile No. 41 Lake Chamberlain; Red pine, mull, Hollis f.s.l. to loam								
A_1	0– 2	0.746	17.29	9.8	5.35	16.3	50.0	18.9	Dark brown
A_2	2– 7	1.113	13.95	5.8	2.48	15.4	55.0	25.2	Med. brown with yellow cast
B_1	7– 11	1.265	13.78	3.5	1.34	12.9	57.5	26.6	Light brown with reddish cast
B_1b	11– 15	1.118	14.83	—	—	13.3	55.7	27.8	do
	Profile No. 42 Middlebury; Red pine, mull, Charlton v.f.s.l. to loam								
A_1	0– 4	0.784	17.04	9.3	3.91	18.3	45.5	24.3	Dark brown
A_2	4– 9	0.980	16.47	6.0	3.10	17.8	46.0	22.2	do
B_1	9– 19	1.352	11.89	2.8	0.49	20.8	42.4	25.6	Yellowish brown
C_1	19– 27	1.546	10.66	2.2	0.25	24.8	33.9	24.3	do
	Profile No. 43 Middlebury; Pasture across road from No. 11								
A_1	0– 4	1.139	14.2	5.9	2.57	22.8	38.6	23.2	Grayish brown
	Profile No. 44 Salisbury Pasture; Probably Dover f.s.l.								
A_1	0– 4	1.341	9.6	3.9	1.60	7.1	31.6	18.0	Med. brown with reddish cast
	"Ortstein" samples, No. 1 from Profile 33; No. 2 from Profile 9; 3 and 4 from Adirondack Mts., N. Y.								
No.									
1	15– 18	—	—	4.7	1.50	70.5	10.4	5.9	Reddish yellow brown
2	30– 32	1.862	5.68	1.6	0.16	29.3	23.7	11.7	Yellowish gray
3	—	1.525	7.14	9.7	3.48	48.3	11.1	5.1	Very dark reddish brown
4	—	1.628	3.20	—	—	87.4	5.6	5.6	do

[1]Moisture equivalent.

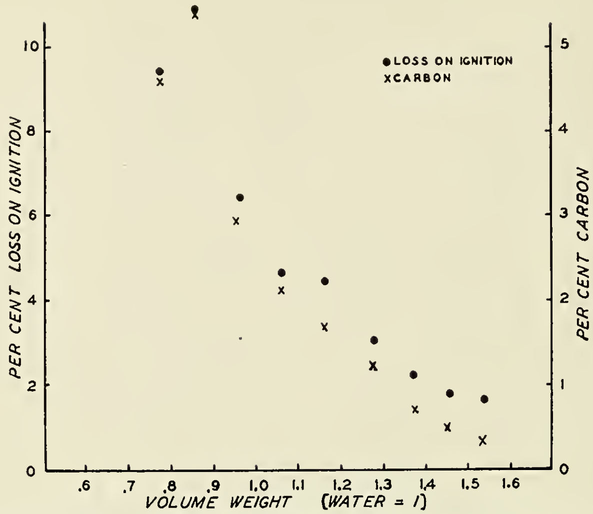

FIGURE 76. Relation between loss on ignition, organic carbon and volume weight. (Each point is a group average.)

To present the density of forest soils a little more concretely, Table 4 gives the total weight per acre of the several horizons making up some typical profiles.

The value of the foregoing data will be more apparent in another part of the bulletin where the chemical data are presented.

Color

Included in Table 3 are the colors of the various soils collected. All color observations were made on air dry soil in the laboratory

TABLE 4. TOTAL WEIGHT PER ACRE OF SOME TYPICAL FOREST SOIL PROFILES TO A DEPTH OF 24 INCHES

Horizon	Strong Podzol Profile No. 2		Moderate Podzol Profile No. 6		Mull Profile No. 23	
	Thickness inches	pounds	Thickness inches	pounds	Thickness inches	pounds
F	¾	15,000	½	7,500	1	15,000
H	5¼	210,000	2	80,000		—
A_1		—		—	4	724,800
A_2	2½	707,800	1	260,500	3	679,500
B_1	1½	305,800	1½	322,800	4	1,177,900
B_2	4	996,600	7	1,585,600	5	1,585,600
B_3	6	1,766,800	8	2,718,100	6	1,970,700
C_1	4	1,359,100	4	1,359,100	1	339,800
Total		5,361,100		6,333,600		6,493,300

under natural daylight from a north window. Most of the samples, particularly the browns and yellows, were compared directly with a set of standard samples that Morgan had previously collected and analyzed for color by the Munsell color disk method (33). Others were compared with a portion of a set of standard soils furnished by the Bureau of Chemistry and Soils, Washington.

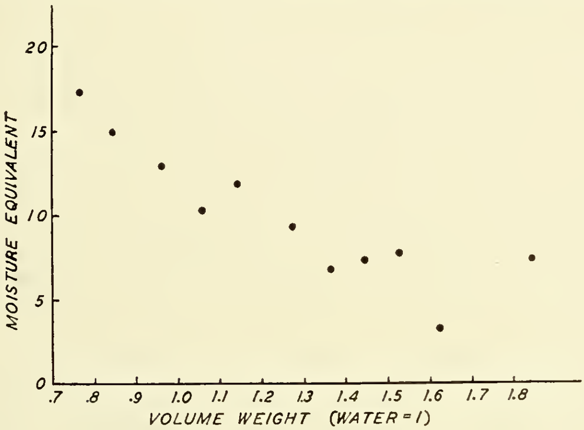

FIGURE 77. Correlation of moisture equivalent and volume weight.

The remaining samples, which differed from any of the soils in either set of standards, were analyzed for color by the writer with results given in Table 5.

TABLE 5. COLOR ANALYSIS OF CERTAIN SOILS FOUND IN NEW ENGLAND

Descriptive term	White (Neutral 9)	Yellow (Yellow 8/8)	Red (Red 4/9)	Black (Neutral 1)
Light gray	34	7	10	49
Brownish purple	20	10	42	28
Light yellowish olive	15	33	6	46
Brownish yellow	2	16	23	59
Reddish yellow brown	2	12	20	66
Very dark reddish yellow	1.5	9	11	78.5
Very dark reddish brown (coffee brown)	5	7	10	78
Do	2	5	7	86
Very dark brown with reddish cast	5	7	8	80
Very dark brown	5	6	5	86
Grayish black	5	3	3	89
Black	0	2	2	96

CHEMICAL PROPERTIES

Methods

All total analyses were made on 100 mesh air dry soil, while unground soil passed through a two-millimeter sieve was used for the determination of pH and the elements in the exchangeable or water soluble form. Acid soluble iron, R_2O_3 (oxides of Fe, Al, P, Mn), and calcium 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 (14, 39, 42). 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.

Reaction was determined with the quinhydrone electrode, and often checked by the Lamotte-Morgan colorimetric test. Nitrogen and calcium were run by the usual methods; organic carbon was determined by means of the Parr apparatus (3, 6). Exchangeable calcium and magnesium were obtained by leaching the soil with normal ammonium acetate solution, and exchangeable potassium by leaching with 0.5 normal acetic acid. Truog's magnesium nitrate method was used for total phosphorus, while soluble phosphorus was determined by a modification of Truog's method in which the soil was treated with 0.004N H_2SO_4 (47). Exchangeable hydrogen and total adsorptive capacity were estimated by the method of Pierre and Scarseth (37).

Presentation of Data

Reaction

One of the outstanding characteristics of a northern forest soil is the high acidity of its upper horizons, particularly the H layer. Generally speaking, the thicker the humus and the more nearly it approaches the raw or greasy state, the greater its acidity. Stated in another way, such a state is indicative of maximum unsaturation, the bases being replaced by hydrogen.

The reaction of the soils investigated is given in Table 6. It will be observed that the pH of the C_1 layers varies but relatively little in the different profiles. The relatively low pH of the podzol B_1 horizon is quite noticeable. In practically all of the profiles reported by Tamm (45) the pH of the B_1 layer is greater than that of the A_2.

Hesselman (19) found the raw humus types to be more acid as a rule than the better humus and mull types. After discussing the pH values found in different forest types he says, "While it is important to know the reaction of forest soil, yet by no means is that the controlling factor. Mull and raw humus may be of the same pH and a good, highly productive beech forest soil can be decidedly acid (pH about 4). Such acidity is no hindrance therefore to good production or a favorable soil condition, but on the contrary it is characteristic of very highly productive soils. A change in acidity in an alkaline direction is generally favorable, however, since a marked acid reaction, as has been observed, is detrimental, not in itself, but in conjunction with other factors."

Table 6. Reaction Expressed as pH

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	4.2	**—**	—	—	—	3.9	4.4	**4.2**
F	5.7	4.7	5.4	4.5	3.9	**4.8**	4.7	4.3	4.4	—	4.6	**4.5**
H	3.7	4.4	5.8	3.3	3.8	**4.2**	3.9	3.9	3.7	4.6	3.9	**4.0**
A_2	3.8	5.8	5.0	3.7	3.7	**4.4**	3.5	4.0	3.8	—	—	**3.8**
B_1	4.0	4.0	4.0	3.7	3.8	**3.9**	4.2	4.5	4.2	4.5	4.0	**4.3**
B_2	4.5	4.8	4.8	4.3	4.3	**4.5**	4.6	5.1	4.3	4.7	4.5	**4.6**
B_3	4.8	5.7	—	—	—	**5.3**	—	4.7	4.4	—	—	**4.6**
C_1	5.0	5.8	6.7	4.3	—	**5.5**	5.1	5.1	4.8	5.3	5.3	**5.1**
C_2	5.1	6.0	6.7	—	—	**5.9**	5.5	5.3	—	—	5.5	**5.4**

	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	4.0	4.4	—	—	—	4.7	—	**4.4**	—	—	—	**—**
F	4.0	4.7	4.6	4.3	4.5	—	4.3	**4.4**	4.7	4.4	4.9	**4.7**
H	3.5	4.4	4.1	3.9	4.2	4.2	4.0	**4.0**	—	3.8	4.5	**4.2**
A_1	—	—	—	4.1	4.2	—	—	**4.2**	4.6	—	—	**—**
A_2	—	4.8	4.4	4.3	4.3	4.8	4.4	**4.5**	4.9	4.3	5.0	**4.7**
B_1	4.4	4.9	—	4.6	—	—	—	**4.6**	4.8	—	—	**—**
B_2	—	4.8	—	4.6	5.0	—	—	**4.8**	5.4	—	5.0	**5.2**
C_1	—	5.2	—	—	5.2	—	—	**5.2**	5.5	—	—	**—**
C_2	—	—	—	—	5.2	—	—	**—**	—	—	—	**—**

	Mull type												
	21	22	22a	23	24	25	26	27	28	29	30	31	Ave.
Litter	4.8	—	—	—	—	—	4.4	4.3	4.4	4.6	5.1	4.6	**4.6**
F	—	—	4.8	5.5	5.3	4.9	—	—	—	—	—	5.3	**5.2**
A_1	4.5	4.6	5.1	4.9	5.5	5.0	3.9	5.2	4.8	4.6	4.7	5.6	**4.9**
A_2	—	4.7	—	5.1	5.6	—	—	—	—	—	—	5.2	**5.2**
B_1	—	4.8	—	5.2	—	5.3	—	—	—	—	—	5.6	**5.2**
B_2	5.3	4.9	—	6.0	5.5	5.7	—	—	—	—	—	5.5	**5.5**
B_3	—	5.0	—	5.6	—	—	—	—	—	—	—	—	**5.3**
C_1	5.3	4.9	—	5.8	5.6	—	—	—	—	—	—	5.9	**5.5**
C_2	—	—	—	6.0	—	—	—	—	—	—	—	—	**—**

Romell and Heiberg (38) found a rather wide range of pH values in the various humus classes, but the greasy and fibrous duffs were all more acid than 5.5 and their twin and crumb mulls less acid than 4.1. The average pH values for Danish heath podzol soils, according to Weis (50) are as follows:

Raw humus	3.6	(3.5—3.6)
Bleached sand	3.9	(3.7—4.5)
Humus hardpan	4.1	(3.9—4.3)
Iron hardpan	4.5	(4.0—4.7)
Subsoil	4.8	(4.4—5.9)

The relatively small variation in this group of 12 profiles studied by Weis was due to the fact that all were located adjacent to one another where the land was level and quite uniform.

Iron, R_2O_3, and Insoluble Matter

No analysis of forest soils is more interesting than that showing the vertical distribution of iron, R_2O_3 and insoluble matter (Table 7). The data on several of these profiles are shown graphically in Figure 78. Note the definite accumulation of iron in the B horizon of the podzols, with B_2 possessing a higher percentage than B_1. Even in the mull types a slight accumulation is apparent.

The insoluble matter generally decreases with the increase in iron content. In the case of the mull types, on the other hand, the insoluble matter increases with depth regardless of iron content.

These data furnish the laboratory sanction for the horizonal designation given to the soils in the field—the B layer being the zone of accumulation. This point will be brought out further on in connection with the carbon data.

An interesting comparison may be made with some data obtained by Tamm (43). An average of five or six of his profiles (profiles Nos. 1, 2, 3, 4, 12 and 13) is as follows:

	Fe_2O_3	Al_2O_3	"Humus" (loss on ignition)
A_2	1.8	9.8	2.19
B	4.0	12.0	2.32
C	3.2	12.0	0.56

All these profiles are quite strongly podzolized, the B horizon being either "orstein" or "orterde." Note that the iron content of the C horizon is higher proportionally in relation to B than are the strongly podzolized soils in New England (profiles 1, 2, 3). The same may be said for Al_2O_3 It will be observed also that the humus content of the A_2 in relation to that of the B is higher in the Swedish soils than it is in our New England podzolized soils.

All of Tamm's soils considered above are what he calls *iron podzols*. The A_2 of his *humus podzols* (45) is much higher in humus—seven profiles (Nos. 6, 7, 8, 9, 10, 11, 12) averaging 6.70 per cent, B horizon 6.28 per cent, and C horizon 0.90 per cent (data on B and C given on first three profiles only).

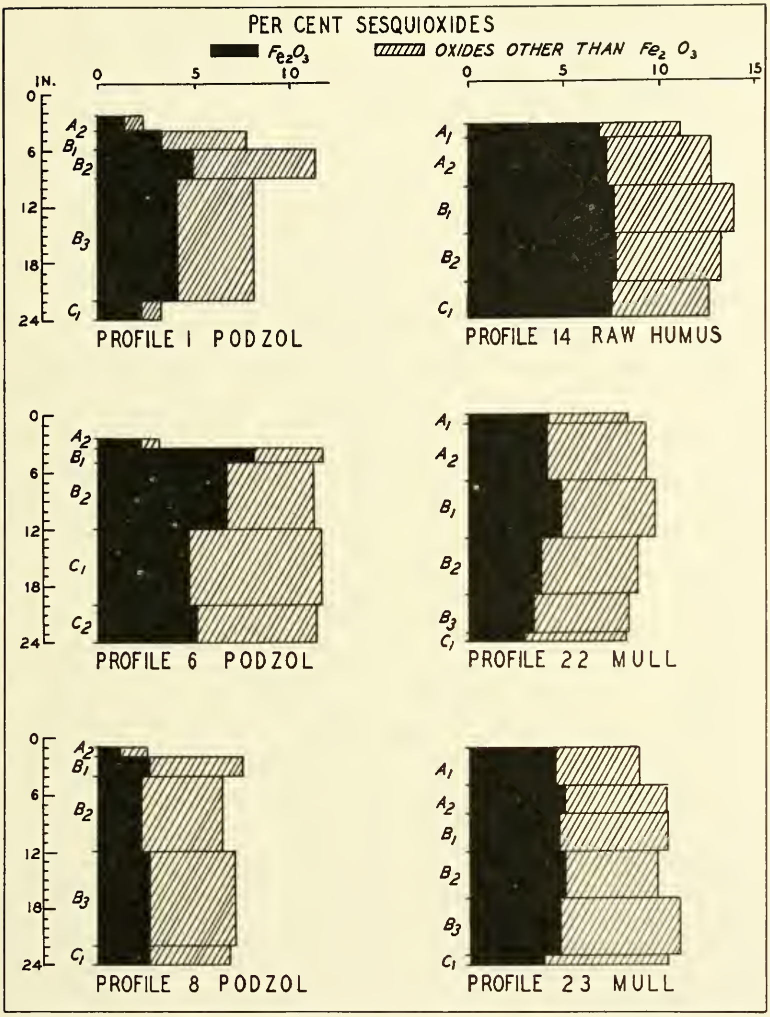

FIGURE 78. Vertical distribution of sesquioxides in six typical profiles. (Table 7.)

In this connection Jenny (23) studying alpine soils reports the following analyses.

	Iron podzol		Humus podzol	
	Fe_2O_3 $+Al_2O_3$	Humus	Fe_2O_3 $+Al_2O_3$	Humus
A_2	3.99	2.87	1.79	4.61
B	17.00	3.51	4.56	11.22
C	9.70	2.68	2.91	6.12

TABLE 7. SESQUIOXIDES AND INSOLUBLE MATTER

Horizon	Strong podzol				Moderate podzol				Humus type					Mull type				
	1	2	3	Ave.	6	7	8	Ave.	14	14a[1]	15	18	Ave.	22	23	23a[1]	24	Ave.
	Fe_2O_3 in percentage																	
A_1	—	—	—		—	—	—	—	6.33	3.07	2.94	1.94	**3.57**	4.15	4.49	4.65	4.58	**4.47**
A_2	1.37	1.51	1.85	**1.58**	2.13	1.89	1.12	**1.71**	6.65	2.94	2.76	1.62	**3.49**	4.04	4.98	3.67	5.04	**4.43**
B_1	3.29	4.66	8.25	**5.40**	8.21	2.62	2.68	**4.50**	7.10	3.00	—	2.04	**4.05**	4.75	4.65	—	—	**4.70**
B_2	4.98	4.05	5.44	**4.82**	6.75	3.04	2.22	**4.00**	7.15	2.54	2.46	1.74	**3.47**	3.77	4.98	4.78	4.92	**4.61**
B_3	4.10	2.01	—	**3.06**	—	2.41	2.67	**2.54**	—	—	—	—		3.40	4.72	—	—	**4.06**
C_1	2.19	2.23	3.61	**2.68**	4.77	2.44	2.64	**3.28**	—	2.98	2.50	1.58	**2.35**	2.83	3.93	—	4.23	**3.66**
C_2	1.66	1.98	5.25	**2.96**	5.14	1.81	—	**3.48**	—	—	2.02	—		—	3.20	—	—	
	Al_2O_3 and other oxides exclusive of Fe_2O_3																	
A_1	—	—	—		—	—	—		4.25	3.51	3.34	2.06	**3.29**	3.66	4.32	3.88	7.64	**4.88**
A_2	0.96	0.87	1.43	**1.09**	1.01	1.33	1.41	**1.25**	5.57	4.17	3.44	3.32	**4.13**	4.70	5.33	4.34	3.59	**4.49**
B_1	4.45	1.91	1.55	**2.64**	3.58	2.41	4.92	**3.64**	6.35	4.54	—	2.99	**4.63**	4.53	5.72	—	—	**5.13**
B_2	6.49	3.45	6.11	**5.35**	4.54	4.70	4.28	**4.51**	5.56	3.67	4.24	2.06	**3.88**	4.58	4.83	5.70	6.51	**5.41**
B_3	4.08	2.20	—	**3.14**	—	4.82	4.50	**4.66**	—	—	—	—		4.44	6.30	—	—	**5.37**
C_1	1.19	2.77	3.70	**2.55**	6.92	3.99	4.27	**5.06**	—	3.28	3.38	1.65	**2.77**	4.85	6.47	—	4.77	**5.36**
C_2	1.21	2.27	0.15	**1.21**	6.35	2.60	—	**4.48**	—	—	2.60	—		—	6.72	—	—	
	Insoluble matter																	
A_1	—	—	—		—	—	—		69.7	83.7	78.3	91.4	**80.8**	74.6	73.5	80.5	73.8	**75.6**
A_2	95.1	94.8	89.6	**93.2**	92.8	85.0	94.5	**90.8**	79.0	86.7	83.3	93.5	**85.6**	82.0	78.0	82.0	78.0	**80.0**
B_1	74.8	81.4	67.4	**74.5**	74.9	85.3	84.6	**81.6**	79.8	88.9	—	93.6	**87.4**	85.4	82.2	—	—	**83.8**
B_2	66.9	78.6	76.3	**73.9**	72.3	88.0	90.0	**83.4**	80.5	91.5	90.6	95.9	**89.6**	87.7	85.2	85.6	83.5	**85.5**
B_3	87.2	88.0	—	**87.6**	—	89.0	90.4	**89.7**	—	—	—	—	—	88.3	85.0	—	—	**86.7**
C_1	94.6	90.0	87.2	**90.6**	83.3	90.5	91.0	**88.3**	—	91.0	91.9	96.5	**93.1**	83.4	86.2	—	87.0	**85.5**
C_2	95.4	92.3	98.5	**95.4**	83.8	93.3	—	**88.6**	—	—	93.6	—	—	—	86.0	—	—	

[1]White pine plantations in vicinity of No. 23.

He makes this statement: "Typical of the *iron podzol* is the great accumulation of iron compounds in the B-horizon, which gives to the profile the distinct redbrown color. The main feature of the humus podzol is the extreme humus accumulation in the B-horizon, giving it a chocolate color." Jenny refers to Frosterus' statement that iron podzols contain less than 3 per cent humus in the B horizon.

It would appear, therefore, that the strongly podzolized soils of New England would be classified as iron-humus profiles, for both iron and organic matter are quite low in A_2 and high in B.

A profile of considerable interest has been reported from South Africa. The Frenchhock profile in Western Province (12) was taken in a valley surrounded by high mountains. The rainfall is about 40 inches. The soil that now supports a luxuriant vegetation was formerly covered with a poplar forest, which had been cut before sampling. The soil, formed from sandstone, "is deep, has lain undisturbed for a very long period and has a hard iron-humus pan a few inches below the surface." A portion of the data is as follows:

	Loss on Ignition	$Fe_2O_3 + Al_2O_3$	Fe_2O_3	$\frac{Fe_2O_3}{+Al_2O_3}$	pH
A	4.25	3.35	1.328	.42	5.3
B_1	6.45	12.25	6.540	.73	4.71
B_2	7.45	5.75	1.991	.34	5.16
C	4.15	5.50	1.896	.34	4.81

This profile is interesting in that the greatest concentration of organic matter is in the B_2, but iron and aluminum are concentrated in B_1. Since loss on ignition was used as a measure of organic matter these results may be due to a hydration of the colloids. The fact that the water table fluctuates considerably but seldom falls more than a few feet below the surface may help to explain the condition found by analyses. If the iron and aluminum were equal to or greater in concentration in the B_2 than in B_1, this profile would compare very favorably with New England podzol soils.

Forest profiles XV, XVI, and XVII reported by C. F. A. Tuxen in Müller's "Natürliche Humusformen" (34) compare in both humus and iron oxide with the distribution found in New England soils.

The virgin *Culluna*-heath soils investigated by Weis (50) are very interesting in several ways, but particularly so from the standpoint of iron and humus distribution. The average of 10 profiles is as follows:

	Thickness cm	Fe_2O_3 %	Al_2O_3 %	"Humus" %
A_1 Raw humus	8.9	0.11	0.12	27.03
Transition zone	3.8	—	—	—
A_2 Pure bleached sand	7.0	0.04	0.03	1.79
A_3 Humus hardpan	7.4	0.57	0.96	12.65
B_1 Iron hardpan	6.2	0.95	0.59	2.65
B_2 Transition zone	34.4	—	—	—
C_1 Subsoil begins at 67.8 cm		0.17	0.17	0.24

Here we see a very distinct differentiation between the accumulation of the humus and that of the iron. This may be called an iron-humus podzol with the bulk of the iron occurring separately and below the bulk of the humus. As has been previously mentioned, many of the forest soils lying in the podzol zone of Europe are either humus podzols or iron podzols. Those in this country appear to be iron-humus podzols, but the iron and humus are not so distinctly segregated as in the case of the heath soils investigated by Weis.

Nitrogen

The data for total nitrogen are given in Table 8. In the podzols we find, in agreement with Edington and Adams (13) the duff proportionately high in nitrogen, A_2 very low, a decided rise again in B, and C as low or lower than A_2. Considering the averages of the several types we find the nitrogen content of the duff to be highest in the strongly podzolized types and decreasing through the humus to the mull types. In every case it is higher in the F layer than in the litter. This is due, of course, to the relatively high proportion of carbon to nitrogen in the litter, as will be brought out later.

Owing to the extreme variations in weight and thickness of the several horizons in forest soils the presenting of the data on a percentage basis is somewhat misleading with respect to the total amount of nitrogen in the profile. When recalculated on this basis the figures for a few typical profiles to a depth of 24 inches are as follows:

Podzol type		Mull type	
Profile No.	Pounds N per acre	Profile No.	Pounds N per acre
1	8129	21	17628
6	5417	22	5717
8	3154	23	11004

If the vertical distribution of this nitrogen in these profiles were charted, the graph would be almost identical to that showing the

TABLE 8. TOTAL NITROGEN CONTENT EXPRESSED IN PERCENTAGE

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	1.175		—	—	—	0.913	1.028	**0.970**
F	2.207	1.348	1.890	1.481	1.606	**1.706**	1.512	1.654	1.680	—	1.233	**1.520**
H	1.906	1.918	3.153[1]	1.780	1.545	**1.789**	1.194	1.248	0.922	1.400	1.606	**1.274**
A_2	0.071	0.137	0.189	0.034	0.042	**0.094**	0.097	0.128	0.072	—	—	**0.099**
B_1	0.273	0.469	0.408	0.385	0.245	**0.356**	0.170	0.193	0.153	0.116	0.204	**0.167**
B_2	0.325	0.179	0.163	0.255	0.088	**0.202**	0.133	0.039	0.044	0.044	0.164	**0.085**
B_3	0.055	0.133	—	—	—	**0.094**	—	0.025	0.012	—	—	**0.019**
C_1	0.074	0.082	0.085	0.084	—	**0.081**	0.038	0.016	0.005	0.017	0.035	**0.022**
C_2	—	0.019	0.036	—	—	**0.028**	0.032	0.006	—	—	0.028	**0.022**

Horizon	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	0.828	0.720	—	—	—	0.870	—	**0.806**	—	—	—	—
F	1.624	1.610	1.843	1.369	1.348	—	0.792	**1.431**	1.137	0.901	1.016	**1.018**
H	1.517	0.825	1.373	1.097	1.210	1.722	1.228	**1.282**	—	1.159	1.495	**1.327**
A_1	—	—	—	0.227	0.352	—	—	**0.290**	0.071	—	—	
A_2	—	0.176	0.228	0.229	0.245	0.276	0.056	**0.202**	0.028	0.083	0.089	**0.067**
B_1	0.218	0.073	—	—	—	—	—	**0.146**	0.017	—	—	
B_2	—	0.045	—	—	0.035	—	—	**0.040**	0.006	—	0.041	**0.023**
C_1	—	0.024	—	—	0.017	—	—	**0.020**	0.004	—	—	

Horizon	Mull type												
	21	22	22a	23	24	25	26	27	28	29	30	31	Ave.
Litter	1.033	—	—	—	—	—	0.680	0.604	0.703	0.705	0.842	0.783	**0.764**
F	—	—	1.072	1.152	0.810	0.960	—	—	—	—	—	1.450	**1.089**
A_1	0.575	0.372	0.139	0.560	0.390	0.267	0.312	0.232	0.239	0.240	0.291	0.604	**0.352**
A_2	—	0.148	—	0.388	0.190	—	—	—	—	—	—	0.222	**0.237**
B_1	—	0.082	—	0.208	—	0.088	—	—	—	—	—	0.055	**0.108**
B_2	0.141	0.027	—	0.066	—	0.023	—	—	—	—	—	0.053	**0.062**
B_3	—	0.029	—	0.030	—	—	—	—	—	—	—	—	**0.030**
C_1	0.125	0.125	—	0.014	—	—	—	—	—	—	—	0.032	**0.074**

[1]Omitted from the average.

distribution of organic matter. The reader is referred, therefore, to Figure 79. It must be kept in mind that in actual amount the N values run approximately 1/30 to 1/50 of those for organic matter.

Organic Matter

The best measure of soil organic matter is the organic carbon content. The data in Table 9 are expressed in this form. To convert to organic matter it is customary to multiply the carbon content by the factor 1.724. This factor is considered satisfactory

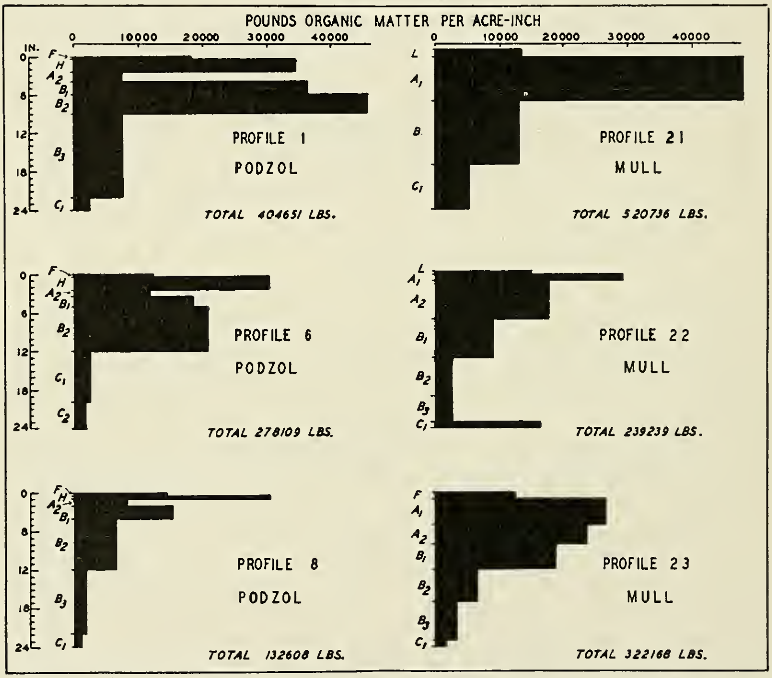

FIGURE 79. Vertical distribution of organic matter in pounds per acre inch, and the total amount per acre to a depth of 24 inches.

for the mineral horizons, but it is not correct for materials high in organic matter such as forest duff and peats. In a previous paper (27) the writer showed that the stage of decomposition of the duff must be taken into consideration when using a conversion factor. The factors recommended are as follows:

Litter (freshly fallen leaves)	1.89
F layer (decomposing material whose original structure is still discernible)	1.85
H layer (well decomposed, structureless humus)	1.80

TABLE 9. ORGANIC CARBON CONTENT EXPRESSED IN PERCENTAGE

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	52.78		—	—	—	49.01	52.41	**50.71**
F	49.10	41.20	42.30	50.47	51.23	**46.86**	44.50	48.80	46.70	—	52.57	**48.14**
H	48.20	49.50	47.05	47.01	46.00	**47.55**	42.20	38.58	27.41	36.62	49.35	**38.83**
A_2	1.46	1.87	3.91	0.85	0.97	**1.81**	2.62	5.12	1.87	—	—	**3.20**
B_1	10.38	6.86	10.22	8.28	7.94	**8.74**	5.01	3.97	3.48	3.22	5.78	**4.29**
B_2	10.70	5.85	3.81	8.34	3.27	**6.39**	5.33	0.77	1.06	0.57	4.71	**2.49**
B_3	1.57	3.24	—	—	—	**2.41**	—	—	—	—	—	—
C_1	0.39	1.38	—	1.83	—	**1.20**	—	—	—	0.28	0.86	**0.57**
C_2	—	0.44	0.44	—	—	**0.44**	—	—	—	—	0.84	

Horizon	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	50.10	51.15	—	—	—	50.76	—	**50.66**	—	—	—	—
F	52.00	48.20	47.50	49.20	44.90	—	51.21	**48.84**	41.55	49.33	51.80	**47.56**
H	46.68	19.56	35.80	43.40	32.50	47.22	39.75	**37.84**	—	43.04	38.13	**40.59**
A_1	—	—	—	6.53	6.98	—	—	**6.76**	2.54	—	—	
A_2	—	3.97	5.40	4.90	4.30	4.61	1.92	**4.18**	1.39	1.97	1.81	**1.72**
B_1	5.02	—	—	—	—	—	—		—	—	—	—
B_2	—	—	—	—	0.72	—	—		—	—	1.06	

Horizon	Mull type												
	21	22	22a	23	24	25	26	27	28	29	30	31	Ave.
Litter	48.20	—	—	—	—	—	47.83	49.43	47.07	50.19	49.59	49.35	**48.81**
F	—	—	45.5	45.45	31.08	50.58	—	—	—	—	—	46.20	**43.76**
A_1	11.20	9.41	3.4	8.53	8.13	3.57	4.74	4.02	4.77	4.88	5.06	12.50	**6.68**
A_2	—	4.17	—	6.10	3.98	—	—	—	—	—	—	4.45	**4.68**
B_1	—	1.79	—	3.73	—	1.29	—	—	—	—	—	—	**2.27**
B_2	2.41	0.50	—	1.23	—	0.54	—	—	—	—	—	—	**1.17**
B_3	—	0.48	—	—	—	—	—	—	—	—	—	—	
C_1	0.94	2.84	—	—	—	—	—	—	—	—	—	—	**1.89**

TABLE 10. CARBON-NITROGEN RATIO ($C/N = R$)

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	45.0		—	—	—	53.8	51.0	**52.4**
F	22.2	30.6	22.4	34.0	31.9	**28.2**	29.4	29.5	27.8	—	42.6	**32.3**
H	25.3	25.8	14.9	26.7	29.6	**24.5**	35.4	30.9	29.8	26.2	30.7	**30.6**
A_2	20.6	13.7	20.7	25.3	23.2	**20.7**	27.0	40.0	25.9	—	—	**31.0**
B_1	41.6	14.6	25.1	21.5	32.3	**27.0**	29.5	20.6	22.7	27.8	28.4	**25.8**
B_2	32.9	32.8	23.4	32.6	37.1	**31.8**	40.0	19.6	24.1	13.1	28.7	**25.1**
B_3	28.5	24.4	—	—	—	**26.5**	—	—	—	—	—	—
C_1	5.3	16.8	—	21.9	—	**14.7**	—	—	—	16.3	24.9	**20.6**
C_2	—	23.9	12.4	—	—	**18.2**	—	—	—	—	29.7	

Horizon	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	60.5	71.0	—	—	—	58.4	—	**63.3**	—	—	—	—
F	32.0	29.9	25.8	36.0	33.3	—	64.7	**37.0**	36.6	54.7	51.0	**47.4**
H	30.8	23.7	26.1	39.6	26.9	27.4	32.3	**29.5**	—	37.2	25.5	**31.4**
A_1	—	—	—	28.8	19.8	—	—	**24.3**	35.9	—	—	
A_2	—	22.6	23.7	21.4	17.6	16.7	34.4	**22.7**	49.5	23.8	20.3	**31.2**
B_1	23.1	—	—	—	—	—	—		—	—	—	—
B_2	—	—	—	—	20.5	—			—	—	25.8	

Horizon	Mull type												
	21	22	22a	23	24	25	26	27	28	29	30	31	Ave.
Litter	46.8	—	—	—	—	—	70.5	81.8	67.0	71.1	59.0	63.0	**65.6**
F	—	—	42.4	39.4	38.4	52.7	—	—	—	—	—	31.9	**41.0**
A_1	19.5	25.3	24.6	15.2	20.8	13.4	15.2	17.3	20.0	20.4	17.4	20.7	**19.2**
A_2	—	28.2	—	15.7	20.9	—	—	—	—	—	—	20.0	**21.2**
B_1	—	21.9	—	17.9	—	14.7	—	—	—	—	—	—	**18.2**
B_2	17.1	18.6	—	18.7	—	23.2	—	—	—	—	—	—	**19.4**
B_3	—	16.2	—	—	—	—	—	—	—	—	—	—	
C_1	7.5	23.7	—	—	—	—	—	—	—	—	—	—	**15.6**

The graphs in Figure 79 were constructed from data in which the foregoing factors were used. Note the large quantity of organic matter present in the B horizons of the podzolized soils. There is a marked similarity between these graphs and those in Figure 78 showing the distribution of iron.

Nitrogen-Carbon Ratio

One characteristic of the majority of soils in the forests of New England is their wide carbon-nitrogen ratio as compared with agricultural soils. In no case have we found the ratio of the A horizon to be narrower than 13:1 (Table 10). This is no doubt due to the less rapid breaking down of the duff in the podzol types. The material—present in all stages of decomposition—remains on the surface for the most part. In the mull type, on the other hand, as fast as the material breaks down it is incorporated into the mineral soil primarily through the activity of earthworms.

The table shows also in the case of the B layers a wider ratio in the podzol types than in the mulls.

Inspection of the data on Danish heath soils presented by Weis (50) reveals that the proportion of C to N is invariably higher in the leached layer than in any other horizon. This is not true in the case of our New England soils.

Calcium

The data on total calcium is shown in Table 11. Based on the dry weight of the soil, the H, A_1, and A_2 layers are lowest in calcium content, and either the F or the litter the highest. As a rule the percentage of calcium increases from A_2 downwards. This distribution of calcium is more or less characteristic of all except very immature soils. In podzol profiles the calcium distribution does not coincide with that of iron or of organic matter, since the calcium must first be displaced before the podzolization process can take place. In this displacement the calcium is not concentrated in the B layer, but apparently is diffused throughout the whole of the subsoil. In a few cases there is a somewhat larger amount in the C horizon.

The entire profile at South Coventry, Conn., (profile 25) analyzes rather high in calcium, higher than any other profile studied. It will be recalled (page 761) that the red pine growing at this locality had the highest site index in the State.

TABLE 11. TOTAL CALCIUM EXPRESSED IN PERCENTAGE

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	0.68	—	—	—	—	1.01	0.92	**0.97**
F	1.33	0.81	1.26	0.85	0.34	**0.92**	0.69	0.41	0.86	—	0.95	**0.73**
H	0.40	0.37	0.67	0.14	0.48	**0.41**	0.29	0.13	0.12	0.61	0.39	**0.31**
A_2	0.44	0.32	—	0.11	0.14	**0.25**	0.28	0.95	0.08	—	—	**0.44**
B_1	0.70	0.42	—	0.24	0.09	**0.36**	0.23	1.01	0.09	0.49	0.64	**0.49**
B_2	0.66	0.47	—	0.24	0.17	**0.39**	0.22	1.37	0.11	1.30	0.78	**0.76**
B_3	0.94	0.43	—	—	—	**0.69**	—	—	0.28	—	—	—
C_1	0.81	0.73	—	0.25	—	**0.60**	—	—	0.19	0.57	1.08	**0.61**
C_2	0.93	—	—	—	—	—	0.41	1.13	—	—	1.56	**1.03**

	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	0.47	0.88	—	—	—	0.93	—	**0.76**	—	—	—	—
F	0.74	1.30	1.37	0.65	0.35	—	0.86	**0.88**	0.37	0.49	0.95	**0.60**
H	0.12	0.63	0.59	0.28	0.19	0.66	0.43	**0.41**	—	0.25	0.53	**0.39**
A_1	—	—	—	0.29	0.28	—	—	**0.29**	0.15	—	—	—
A_2	—	0.61	0.46	0.35	0.27	0.86	0.85	**0.57**	0.19	1.42	0.89	**0.83**
B_1	0.87	0.66	—	0.27	0.38	—	—	**0.55**	0.16	—	—	—
B_2	—	0.76	—	0.17	—	—	—	**0.47**	0.12	—	0.90	**0.51**
C_1	—	0.80	—	—	0.23	—	—	**0.52**	0.16	—	—	—

	Mull type												
	21	22	22a	23	24	25	26	27	28	29	30	31	Ave.
Litter	1.21	—	—	—	—	—	1.82	1.44	1.28	1.05	0.82	1.32	**1.28**
F	—	—	1.74	0.68	0.70	1.03	—	—	—	—	—	1.22	**1.07**
A_1	1.83	0.54	0.31	0.31	0.76	1.14	0.74	0.59	0.48	1.52	0.83	0.63	**0.81**
A_2	—	0.69	—	0.28	0.88	—	—	—	—	—	—	0.26	**0.53**
B_1	—	0.63	—	0.20	—	1.09	—	—	—	—	—	0.23	**0.54**
B_2	2.03	0.72	—	0.27	0.86	0.50	—	—	—	—	—	0.27	**0.78**
B_3	—	0.66	—	0.18	—	—	—	—	—	—	—	—	**0.47**
C_1	1.80	0.68	—	0.16	1.04	—	—	—	—	—	—	0.39	**0.81**

Comparison of the analyses of the mineral horizons used in this study with those reported by Tamm (45) indicates that New England soils are considerably more deficient in lime. This difference was not apparent in a comparison of the pH values.

At the time of the analysis of acid soluble iron, acid soluble calcium also was determined. These data are given in Table 12, while that showing the proportion of total calcium which is acid soluble is in Table 13. The greater percentage of acid soluble calcium in the A horizon of the mull is particularly conspicuous.

Table 12. Acid Soluble Calcium Expressed in Percentage

	Strong podzol				Moderate podzol			
Horizon	1	2	3	Ave.	6	7	8	Ave.
A_2	0.068	0.068	0.103	**0.080**	0.009	0.127	0.033	**0.056**
B_1	0.084	0.075	0.090	**0.083**	0.052	0.120	0.034	**0.069**
B_2	0.107	0.116	0.227	**0.150**	0.018	0.320	0.070	**0.136**
B_3	0.284	0.083	—	**0.184**	—	0.172	0.044	**0.108**
C_1	0.203	0.356	0.320	**0.293**	0.090	0.273	0.058	**0.140**
C_2	0.239	0.350	0.337	**0.309**	0.075	0.336	—	**0.206**

	Humus type					Mull type				
	14	14a	15	18	Ave.	22	23	23a	24	Ave.
A_1	0.033	0.071	0.090	0.042	**0.059**	0.134	0.157	0.041	0.279	**0.153**
A_2	0.036	0.068	0.073	0.043	**0.055**	0.122	0.155	0.016	0.238	**0.133**
B_1	0.014	0.189	—	0.068	**0.090**	0.119	0.082	—	—	**0.101**
B_2	0.007	0.063	0.072	0.025	**0.042**	0.153	0.155	0.024	0.183	**0.129**
B_3	—	—	—	—	—	0.189	0.090	—	—	**0.140**
C_1	—	0.179	0.066	0.064	**0.103**	0.135	0.073	—	0.155	**0.121**
C_2	—	—	0.089	—	—	—	0.096	—	—	—

Table 13. Percentage of Total Calcium that Is Acid Soluble

	Strong podzol type				Moderate podzol type			
Horizon	1	2	3	Ave.	6	7	8	Ave.
A_2	15.4	21.4	—	**18.4**	3.2	13.4	40.7	**19.1**
B_1	12.1	17.8	—	**15.0**	22.2	11.9	36.2	**23.4**
B_2	16.3	24.6	—	**20.5**	8.1	23.4	61.4	**30.9**
B_3	30.1	19.2	—	**24.7**	—	—	15.5	—
C_1	25.1	48.6	—	**36.9**	—	24.2	30.4	**27.3**
C_2	25.8	—	—	—	18.2	—	—	—

	Humus type					Mull type				
	14	14a	15	18	Ave.	22	23	23a	24	Ave.
A_1	11.3	—	32.4	28.0	**23.9**	25.0	50.6	—	36.8	**37.5**
A_2	10.4	—	27.4	23.0	**20.3**	17.8	56.2	—	27.1	**33.7**
B_1	5.1	—	—	42.7	**23.9**	18.8	40.6	—	—	**29.7**
B_2	4.2	—	19.2	21.4	**14.9**	21.2	57.5	—	21.3	**33.3**
B_3	—	—	—	—	—	29.1	49.1	—	—	**39.1**
C_1	—	—	29.3	40.5	**34.9**	19.9	45.3	—	14.9	**26.7**

A somewhat different picture of the calcium relations may be seen when the data are based on the ash instead of dry weight. Table 14 contains such data. Differences in the calcium content of the various horizons are decidedly more pronounced. In profile No. 4, for example, calcium based on dry weight (Table 11) is approximately the same in the upper H layer as it is in B_1, B_2, and C_1. Calculated on the ash basis, however, it is readily seen that the calcium content of upper H is 12 or 13 times as great as that of the B and C horizons. Again, differences in the Ca content of the F layers of the several profiles are much more conspicuous and not always in the same order when based on the ash content.

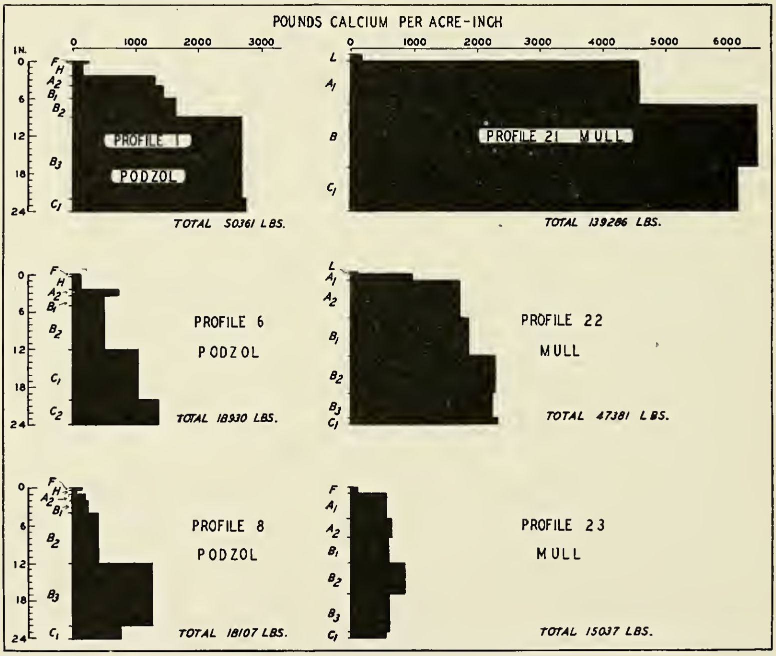

FIGURE 80. Vertical distribution of calcium in pounds per acre inch, and the total amount per acre to a depth of 24 inches.

In the discussion of nitrogen the differences between data given in percentage and those given in pounds per acre were pointed out. These differences are even more striking in the case of calcium, as seen in Figure 80. Although the percentage composition of the duff is high (Table 11), yet in total amount per acre it is quite insignificant when considered in relation to the Ca in the lower mineral horizons.

TABLE 14. CALCIUM CONTENT BASED ON WEIGHT OF ASH, EXPRESSED IN PERCENTAGE

	Strong podzol, 4			Moderate podzol, 6			Mull, 21			Mull, 25		
	Ca based on dry wt.	Ash	Ca based on ash	Ca based on dry wt.	Ash	Ca based on ash	Ca based on dry wt.	Ash	Ca based on ash	Ca based on dry wt.	Ash	Ca based on ash
F	0.85	5.43	15.71	0.69	13.40	5.15	1.21[2]	7.47[2]	16.20[2]	1.03	8.14	12.69
H_1	0.24	7.15	3.41	0.29	17.84	1.62	—	—	—	—	—	—
H_2	0.03	20.94	0.15									
A_1	—	—	—	—	—	—	1.83	78.90[1]	2.32	1.14	93.95[1]	1.21
A_2	0.11	98.53[1]	0.11	0.28	95.48[1]	0.29	—	—	—	—	—	—
B_1	0.24	85.73[1]	0.28	0.23	91.35[1]	0.25	2.03	94.80[1]	2.14	1.09	97.78[1]	1.11
B_2	0.24	85.63[1]	0.28	0.22	90.81[1]	0.24				0.50	99.07[1]	0.51
C_1	0.25	96.84[1]	0.26	—	—	—	1.80	97.20[1]	1.85	—	—	—

[1]Calculated from C analysis (100—(C x 1.724) = ash).
[2]Litter.

On the other hand it must be recognized that only a relatively small portion of the total is available to the plant at any one time, and that the bulk of the available calcium is to be found in the organic portion of the profile. This is shown in the data for exchangeable calcium (Table 15).

Table 15. Exchangeable Calcium in Percentage

Horizon	Strong podzol type						Moderate podzol type					
	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	.431	—	—	—	—	.372	.289	.331
F	—	.700	—	.505	.256	.487	.380	.235	.370	—	.414	.350
H	.266	.264	—	.047	.332	.227	.214	.073	.039	.328	.260	.183
A_2	.011	.007	.023	.003	.006	.010	.009	.009	.006	—	—	.008
B_1	.028	.012	.014	.003	.003	.012	.008	.005	.004	.009	.019	.009
B_2	.012	.007	.004	.004	.002	.006	.005	.004	.007	.006	.006	.006
B_3	.004	.023	—	—	—	.014	—	—	.009	—	—	.009
C_1	.001	.015	—	.006	—	.007	.004	—	.016	.008	.007	.009
C_2	.002	.001	—	—	—	.002	.004	—	—	—	.006	.005
	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	.180	.313	—	—	—	.256	—	.250	—	—	—	—
F	.310	.562	.570	.290	.147	—	.260	.357	.200	.158	.315	.224
H	.083	.138	.190	.138	.113	.414	.295	.196	—	.125	.340	.233
A_1	—	—	—	.008	.006	—	—	.007	.011	—	—	
A_2	—	.011	.008	.007	.006	.037	.006	.013	.005	.007	.020	.011
B_1	.004	.006	—	—	.026	—	—	.012	—	—	—	—
B_2	—	.007	—	—	—	—	—		—	—	.009	
C_1	—	.006	—	—	—	—	—		—	—	—	—
	Mull type											
	21	22	23	24	25	26	27	28	29	30	31	Ave.
Litter	.517	—	—	—	—	.535	.420	.552	.455	.259	.396	.448
F	—	—	.422	.273	.432	—	—	—	—	—	.804	.483
A_1	.167	.025	.074	.072	.027	.116	.081	.049	.037	.023	.290	.087
A_2	—	.008	.072	.045	—	—	—	—	—	—	.021	.037
B_1	—	.006	—	—	.024	—	—	—	—	—	.008	.013
B_2	.042	—	—	—	.020	—	—	—	—	—	.007	.023
C_1	.013	—	—	—	—	—	—	—	—	—	.009	.011

The relation of exchangeable to total calcium is to be found in Table 16. Here it is seen that the exchangeable calcium in forest soils appears to comprise from 30 to 75 per cent of the total calcium in many of the duff layers and less than 5 per cent in the B and C horizons. The percentage in the case of the A horizon is rather variable but may be said to be between 2 and 20 per cent. It is quite apparent that the proportion of calcium in the exchangeable form in the mineral horizons of these forest soils is considerably less than in the agricultural soils of the Middle West where in the better soils the proportion is about 40 to 60 per cent (26).

The "pumping" action of forest trees—removing nutrients from the mineral soil and depositing them in the debris on the surface—is strongest in the case of calcium (25). This is particularly true of the exchangeable Ca, since it is the portion most likely to be utilized by the plant.

Magnesium.

Rather incomplete data on the magnesium content indicate that, like calcium, it increases with depth below the A_1 horizon (Table 17). The only striking difference between types occurs in the case of the strongly podzolized soils in New Hampshire, which are considerably lower in magnesium than most of the other

TABLE 16. PROPORTION OF TOTAL CALCIUM THAT IS EXCHANGEABLE EXPRESSED IN PERCENTAGE

	Strong podzol type						Moderate podzol type					
Horizon	1	2	3	4	5	Ave.	6	7	8	9	10	Ave.
Litter	—	—	—	—	63.2	—	—	—	—	36.9	31.6	**34.3**
F	—	86.4	—	59.2	74.6	**73.4**	55.4	57.8	43.3	—	43.8	**50.1**
H	66.6	71.3	—	53.9	70.3	**65.5**	74.7	57.3	33.2	53.8	66.0	**57.0**
A_2	2.5	2.2	—	2.8	4.3	**3.0**	3.2	0.9	6.8	—	—	**3.6**
B_1	4.0	2.9	—	1.3	3.4	**2.9**	3.5	0.5	3.8	1.8	3.0	**2.5**
B_2	1.8	1.5	—	1.5	1.2	**1.5**	2.1	0.3	6.4	0.5	0.8	**2.0**
B_3	0.4	5.3	—	—	—	**2.9**	—	—	3.2	—	—	—
C_1	0.2	2.1	—	2.2	—	**1.5**	—	—	8.2	1.4	0.7	**3.4**
C_2	0.2	—	—	—	—	—	1.0	—	—	—	0.4	**0.7**
	Raw humus type				Humus type				Mild humus type			
	11	12	13	14	15	16	17	Ave.	18	19	20	Ave.
Litter	38.3	35.8	—	—	—	27.6	—	**33.9**	—	—	—	—
F	42.0	43.4	41.5	44.6	41.9	—	30.3	**40.6**	54.5	32.0	33.3	**39.9**
H	69.2	22.0	32.4	48.6	60.3	62.5	69.4	**52.1**	—	49.2	64.4	**56.8**
A_1	—	—	—	2.7	2.1	—	—	**2.4**	7.3	—	—	—
A_2	—	1.8	1.7	2.1	2.2	4.3	0.7	**2.1**	2.6	0.5	2.2	**1.8**
B_1	0.5	1.0	—	—	6.8	—	—	**2.8**	—	—	—	—
B_2	—	0.9	—	—	—	—	—	—	—	—	1.0	—
C_1	—	0.7	—	—	—	—	—	—	—	—	—	—
	Mull type											
	21	22	23	24	25	26	27	28	29	30	31	Ave.
Litter	42.7	—	—	—	—	29.4	29.2	43.3	43.4	31.4	30.0	**35.6**
F	—	—	61.9	39.1	41.8	—	—	—	—	—	66.0	**52.2**
A_1	9.1	4.7	2.4	9.4	2.4	15.7	13.7	10.3	2.4	2.8	46.2	**10.8**
A_2	—	1.1	2.6	5.1	—	—	—	—	—	—	8.0	**4.2**
B_1	—	1.0	—	—	2.2	—	—	—	—	—	3.3	**2.2**
B_2	2.1	—	—	—	4.0	—	—	—	—	—	2.5	**2.9**
C_1	0.7	—	—	—	—	—	—	—	—	—	2.4	**1.6**

TABLE 17. TOTAL MAGNESIUM EXPRESSED IN PERCENTAGE

Horizon	Strong podzol type					Moderate podzol type					
	1	2	4	5	Ave.	6	7	8	9	10	Ave.
F	—	—	—	0.07	—	—	—	—	—	—	—
H	—	—	—	0.11	—	—	—	—	—	—	—
A_2	—	0.17	0.02	0.00	**0.06**	0.43	0.43	0.18	—	—	**0.35**
B_1	0.22	0.20	0.06	0.04	**0.13**	0.31	0.46	0.25	0.25	0.30	**0.31**
B_2	0.24	0.29	0.06	0.01	**0.15**	0.36	0.71	0.31	0.77	0.40	**0.51**
B_3	—	0.13	—	—	—	—	—	0.37	—	—	—
C_1	—	0.34	0.07	—	**0.20**	—	0.85	0.35	0.43	0.68	**0.58**
C_2	0.28	—	—	—	—	0.85	—	—	—	0.94	**0.90**

Horizon	Raw humus type			Humus type			Mild humus type			
	11	12	14	15	16	Ave.	18	19	20	Ave.
F	0.26	—	—	—	—	—	—	0.11	—	—
H	0.08	0.38	—	—	—	**0.23**	—	0.08	—	—
A_1	—	—	0.56	0.43	—	**0.50**	0.30	—	—	—
A_2	—	0.57	1.10	0.34	0.47	**0.62**	0.27	0.58	0.27	**0.37**
B_1	0.25	0.59	0.73	0.26	—	**0.46**	0.29	—	—	—
B_2	—	0.62	0.96	—	—	**0.79**	0.29	—	0.31	**0.30**
C_1	—	0.55	—	0.38	—	**0.47**	0.25	—	—	—

Horizon	Mull type										
	21	22	23	24	25	26	28	29	30	31	Ave.
Litter	—	—	—	—	—	—	0.28	—	—	—	—
F	—	—	—	—	—	—	—	—	—	—	—
A_1	0.76	0.35	0.30	0.72	0.67	0.74	0.39	0.55	0.51	0.46	**0.55**
A_2	—	0.41	0.31	0.90	—	—	—	—	—	0.37	**0.50**
B_1	—	0.37	0.53	0.80	0.65	—	—	—	—	0.40	**0.55**
B_2	1.17	0.45	0.80	0.89	0.40	—	—	—	—	0.41	**0.69**
C_1	1.27	0.44	0.69	0.76	—	—	—	—	—	0.52	**0.73**

localities. Undoubtedly this is due to a difference in the parent material rather than to any process of soil development, as indicated by analyses of the C horizon.

When we compare the magnesium with calcium, Table 18, we see that the ratio Mg:Ca varies from less than 0.2 to as high as 5.72. As a group the New Hampshire soils show the lowest ratio. Within the profiles the ratio in the duff portion is lower, on the whole, than it is in the mineral horizons.

TABLE 18. RATIO OF MAGNESIUM TO CALCIUM $\left({}^{Ca}/_{Mg} = R\right)$

Horizon	Strong podzol type					Moderate podzol type					
	1	2	4	5	Ave.	6	7	8	9	10	Ave.
F	—	—	—	0.22	—	—	—	—	—	—	—
H	—	—	—	0.44	—	—	—	—	—	—	—
A_2	—	0.53	0.19	—	**0.36**	1.51	0.45	2.21	—	—	**1.39**
B_1	0.31	0.48	0.25	0.42	**0.36**	1.33	0.46	2.70	0.51	0.47	**1.09**
B_2	0.37	0.61	0.27	0.05	**0.33**	1.65	0.52	2.76	0.59	0.52	**1.21**
B_3	—	0.29	—	—	—	—	—	1.30	—	—	—
C_1	—	0.47	0.29	—	**0.38**	—	0.75	1.83	0.75	0.63	**0.99**
C_2	0.30	—	—	—	—	2.06	—	—	—	0.60	**1.33**

TABLE 18. (*Continued.*)

	Raw humus type			Humus type			Mild humus type			
	11	12	14	15	16	Ave.	18	19	20	Ave.
F	0.36	—	—	—	—	—	—	0.22	—	—
H	0.66	0.61	—	—	—	**0.63**	—	0.31	—	—
A_1	—	—	1.92	1.55	—	**1.73**	1.98	0.41	—	**1.20**
A_2	—	0.94	3.18	1.27	0.55	**1.49**	1.47	—	0.30	**0.89**
B_1	0.29	0.68	2.67	0.69	—	**1.08**	1.85	—	—	—
B_2	—	0.82	5.72	—	—	**3.27**	2.75	—	0.35	**1.55**
C_1	—	0.69	—	1.69	—	**1.19**	1.59	—	—	—

	Mull type										
	21	22	23	24	25	26	28	29	30	31	Ave.
Litter	—	—	—	—	—	—	0.22	—	—	—	—
F	—	—	—	—	—	—	—	—	—	—	—
A_1	0.41	0.66	0.95	0.94	0.59	1.00	0.83	0.37	0.61	0.73	**0.71**
A_2	—	0.59	1.13	1.03	—	—	—	—	—	1.40	**1.04**
B_1	—	0.59	2.62	0.96	0.59	—	—	—	—	1.77	**1.31**
B_2	0.58	0.62	2.96	1.04	0.79	—	—	—	—	1.53	**1.25**
C_1	0.71	0.64	4.25	0.72	—	—	—	—	—	1.35	**1.53**

Exchangeable Hydrogen, Total Base Capacity and Percentage Saturation.

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 more completely this displacement takes place the more thoroughly a soil is podzolized. Data relative to these soil properties are given in Table 19.

It is readily seen that exchange capacity is identified with the organic matter content. McGeorge (29, 30) working with peats, mucks and forest duff, found a good correlation between total replacement capacity and organic carbon. In this study it was found that a positive relation occurs within the group of samples analyzing less than 20 per cent carbon. Also the samples high in carbon possess a high exchange capacity. But within the high carbon group, that is, between 35 and 55 per cent, the correlation is practically negative. The relatively low proportion of hydrogen to base in the litter and F layer of the Meshomasic profile (No. 11) is surprising.

It will be noticed that in a number of samples the amount of hydrogen present exceeded the total exchange capacity. This would indicate the presence of free acid. Such a condition is highly probable in the podzol and raw humus types, but hardly in the mulls. Just why the hydrogen exceeds the total capacity in the Groton profile (No. 22) is not clear. The difference is small and may be partly experimental error.

TABLE 19. EXCHANGEABLE HYDROGEN AND TOTAL EXCHANGE CAPACITY IN MGM. EQUIVALENTS

Horizon	Podzol types												
	2				4				6				Exch. H Ave.
	Exch. H	Exch. Bases	Total Cap.	% Sat.	Exch. H	Exch. Bases	Total Cap.	% Sat.	Exch. H	Exch. Bases	Total Cap.	% Sat.	
F	43.2	31.1	74.3	42	48.6	9.4	58.0	16	62.0	—	59.2	—	51.3
H	123.2	—	107.5	—	141.1	—	98.0	—	92.5	—	60.6	—	118.9
A_2	2.5	3.4	5.9	58	2.6	0.2	2.8	7	9.9	—	5.7	—	5.0
B_1	22.5	2.7	25.2	11	33.6	—	29.5	—	24.9	—	17.7	—	27.0
B_2	22.2	3.6	25.8	14	28.0	1.0	29.0	3	—	—	—	—	25.1
B_3	10.2	2.0	12.2	16	—	—	—	—	—	—	—	—	10.2
C_1	4.3	1.7	6.0	29	6.4	1.6	8.0	20	—	—	—	—	5.3
	Raw humus types												
	11				12				13				
Litter	22.6	52.9	75.5	70	28.5	48.5	77.0	63	—	—	—	—	25.6
F	16.5	51.0	67.5	76	30.9	28.2	59.0	48	43.0	23.8	66.8	36	30.1
H	65.3	—	56.2	—	27.0	3.5	30.5	12	47.0	2.5	49.5	5	46.4
A_2	—	—	—	—	8.5	—	8.1	—	11.1	—	9.2	—	9.8
B_1	11.2	0.4	11.6	4	4.1	—	3.9	—	—	—	—	—	7.6
B_2	—	—	—	—	2.5	0.6	3.1	19	—	—	—	—	2.5
C_1	—	—	—	—	0.8	0.9	1.7	54	—	—	—	—	0.8

TABLE 19. EXCHANGEABLE HYDROGEN AND TOTAL EXCHANGE CAPACITY IN MGM. EQUIVALENTS—(*Continued*)

Horizon	Humus type				Mull type								
	18				21				22				Exch. H Ave.
	Exch. H	Exch. Bases	Total Cap.	% Sat.	Exch. H	Exch. Bases	Total Cap.	% Sat.	Exch. H	Exch. Bases	Total Cap.	% Sat.	
Litter	—	—	—	—	14.8	30.9	45.7	68	—	—	—	—	
F	56.2	2.8	59.0	5	—	—	—	—	—	—	—	—	
A_1	5.1	1.6	6.7	24	16.6	10.8	27.4	40	15.2	—	12.9	—	
A_2	1.5	2.2	3.7	60	—	—	—	—	10.5	—	8.5	—	
B_1	1.2	1.0	2.2	46	7.5	1.8	9.3	20	4.1	—	4.0	—	
C_1	0	0.7	0.7	100	3.0	2.6	5.6	46	—	—	—	—	
	Mull type												
	22a				23				31				(5 profiles)
Litter	17.3	46.0	63.3	73	—	—	—	—	23.8	50.7	74.5	68	**18.6**
F	—	—	—	—	27.0	22.2	49.2	45	24.2	44.4	68.6	65	**25.6**
A_1	4.3	4.5	8.8	51	18.3	6.4	24.7	26	10.8	16.8	27.6	61	**13.0**
A_2	—	—	—	—	13.8	5.8	19.6	30	8.4	3.2	11.6	27	**10.9**
B_1	—	—	—	—	8.9	4.5	13.4	34	2.7	1.1	3.8	28	**5.8**
B_2	—	—	—	—	1.6	5.4	7.0	78	2.4	1.9	4.3	44	**2.0**
C_1	—	—	—	—	2.3	4.1	6.4	64	1.5	2.0	3.4	58	**2.3**

Phosphorus and Potassium.

Eight profiles were analyzed for total and soluble phosphorus and replaceable potassium. The results are found in Tables 20 and 21. The high phosphorus content of the whole profile of the Bethlehem hardwoods is worthy of note, as is the relatively high amount in the B horizon of the Rainbow soil. The latter soil, it will be recalled, is a coarse sand.

By far the bulk of the *soluble phosphorus* is to be found in the organic horizons, very little of the phosphorus in the subsoil being soluble.

What has been said regarding soluble phosphorus applies equally well to exchangeable potassium, only a very little being found in the B and C horizons. The Bethlehem profile is outstanding again in the amount of replaceable potassium present in the A and B layers.

When compared with data obtained by Tamm (45) we find considerable similarity in total phosphorus content between our New England podzolized soils and those of Sweden. On the other hand the soluble phosphorus in the subsoils of podzol profiles appears to be higher in Sweden than in New England, although some allowance must be made for the difference in methods of analysis used. Tamm used citric acid as a dissolving agent. Nemec

Table 20. Total and Soluble Phosphorus

Horizon	Podzol				Raw humus			
	1		4		11		12	
	Total P %	Soluble P p.p.m.	Total P %	Soluble P p.p.m.	Total P %	Soluble P p.p.m.	Total P %	Soluble P p.p.m.
Litter	—	—	—	—	.080	355	.080	195
F	.175	345	.150	440	.093	285	.135	170
H	.127	96	.074	93	.095	136	.089	32
A_2	.014	3	.012	0	—	—	.050	8
B_1	.028	6	.037	5	.034	4	.046	3
B_2	.045	3	.048	3	—	—	—	—
C_1	.038	3	.049	4	—	—	.036	5
	Humus		Mull					
	18		21		23		31	
Litter	—	—	.102	205	—	—	.092	268
F	.139	110	—	—	.088	—	.139	209
H	—	—	—	—	—	—	—	—
A_1	.032	19	.077	37	.104	18	.100	29
A_2	.037	11	—	—	.087	9	.072	11
B_1	.070	42	.095	27	.034	Tr.	.049	6
B_2	—	—	—	—	.054	7	—	—
C_1	.026	9	.108	57	.022	6	.045	6

(35) found .040 to .215 per cent citric acid soluble P in the humus layers of coniferous woods, and .002 to .044 per cent in the mineral layer. Farm soils ranged from .035 to .220 per cent.

Aarnio (1) studying the brown soils of Finland reports 0.16, 0.08, 0.12, and 0.09 per cent phosphorus in the A_2, B_1, B_2, and C horizons respectively.

TABLE 21. REPLACEABLE POTASSIUM IN P.P.M.

Horizon	Podzol			Raw humus		Humus	Mull		
	1	4	6	11	12	18	21	23	31
Litter	—	—	—	3400	1374	—	928	—	1473
F	902	1342	1049	857	1151	465	—	840	1290
H	404	252	960	558	533	—	—	—	—
A_1	—	—	—	—	—	34	217	135	425
A_2	33	19	42	—	89	15	—	54	116
B_1	51	36	44	77	28	13	80	24	29
B_2	2	26	43	—	—	—	—	45	—
C_1	4	27	15	—	17	14	37	62	31

BIOLOGICAL STUDIES

Nitrogen Transformation

The work of Hesselman (19), Nemec and Kvapil (36), Melin (31), and others indicates the importance of nitrification in forest soils. In mull types, where there is little or no accumulation of duff, the A horizon of the *mineral* soil is most important in this nitrification process; but in the case of podzol types or where a thick layer of duff persists the feeding roots of the trees are confined quite largely to the organic accumulation *on the surface,* hence it is in this portion of the profile that the soluble nitrogen is utilized. In the underlying mineral layers practically no nitrogen transformation takes place.

Procedure and Method of Anaylsis

It would be desirable to determine the nitrogen changes in the field under natural conditions but such a procedure would require frequent samplings throughout a period of several years in order to overcome violent fluctuations resulting from marked changes in the weather and associated environmental conditions. Therefore the practice commonly followed is to bring the samples into the laboratory, and incubate them under optimum conditions. Although this does not simulate field conditions it puts all samples on a uniform basis and the results obtained are comparable. As far as possible, samples were collected in the fall after the deciduous leaves had fallen. This enables one to collect the fresh litter if desired, and the fermentation, or F, layer has had a year in which to decompose.

Some of the samples were kept in closed (but not air tight) containers until ready to use, which prevented their drying out. The others were allowed to air dry and were kept in this condition until the experiment was started. In either condition, they were chopped into particles one-fourth inch or less in size in a Hobart food chopper before incubation. Definite amounts were then made up to optimum moisture as determined by observation, lime or other material added if desired and the samples placed in either jelly glasses or 12-ounce wide-mouth bottles and kept at room temperature. Free movement of air was provided by one or two small holes in the stopper. The incubation period was usually 3 months. Ammonia and nitrates were determined at the beginning and the end of the incubation period.

For ammonia the samples were leached with half normal KCl solution and the leachate distilled upon the addition of magnesium oxide.

In determining nitrates the procedure for clarification recommended by Harper (17) was employed, generally with success. Nitrates in the clarified solution were estimated by the usual phenol-disulfonic acid method.

Inoculation was not practiced except in a few specific cases.

Presentation of Results

Owing to the lack of absolute control over all conditions under which the several experiments were carried on it is necessary to confine comparisons very largely to the samples within any one experiment. This is especially true in these tests since there was some variation in procedure.

Samples not previously dried. The first set was run during the early winter of 1928-29 on undried samples. The data are given in Table 22. In Figure 81 the untreated samples are grouped by horizons. By far the bulk of the available nitrogen is in the ammonia form, in all excepting sample No. 60. On the other hand, lime causes the accumulation of nitrates at the expense of ammonia. In general the increase in ammonia of the untreated soils is less for the H than for the F layers. The inoculation of sample 52, a raw humus layer, with a water extract of 60, the A_1 of a mull type, caused some reduction in the amount of ammonia produced. Partial sterilization before inoculation brought about a marked limitation in ammonia production.

On the other hand inoculation of No. 60 with No. 52 had a tendency to increase both the ammonia and nitrates. Sterilization

TABLE 22. NITROGEN TRANSFORMATION
Incubation at Room Temperature 3 Months, November to February, 1928-29

Profile No.	Classification	Soil No.	Horizon	Treatment in lab.	NH_3–N p.p.m.				NO_3–N p.p.m.	
					Start[1]	End[2]	Gain	Coeff.[3]	Gain[4]	Coeff.[3]
14	Raw	32	F	0	100	2045	1945	14.9	12	0.08
	Humus	33	H	0	259	1295	1036	11.8	12	0.10
		33	H	Lime	259	144	–115	—	411	3.75
24	Mull	38	F	0	132	1130	998	14.0	8	0.10
		39	H	0	56	167	111	4.3	21	0.54
		39	H	Lime	56	40	–16	—	417	10.7
6	Podzol	44	F	0	144	2625	2481	17.4	89	0.59
		45	H	0	114	1120	1006	9.4	9	0.07
		45	H	Lime	114	30	–84	—	373	3.13
7	Podzol	51	F	0	0	2075	2075	12.5	7	0.04
		52	H	0	86	1675	1589	13.4	5	0.04
		52	H	+extr. of #60	86	1460	1374	—	5	—
		52	H	Partially sterilized+extr. of #60	86	571	485	—	5	—
22	Mull	60	A_1	0	59	206	147	7.0	168	5.7
		60	A_1	+extr. of #52	59	222	161	—	180	—
		60	A_1	Sterilized+extr. of #52	59	206	145	—	1	—

[1]Determined directly on whole soil.
[2]Displaced with 600 cc N/2 KCl.
[3]Coefficient = percentage of total N in ammonia or nitrate form at end of incubation period.
[4]No nitrates at start.

before inoculation resulted in somewhat less ammonia and almost no nitrates.

The second experiment ran from March to June, 1929, on a different set of soils. Ten, twenty-five or fifty grams of soil were used, depending upon its bulkiness. The results are recorded in Table 23.

In general the results are similar to the first experiment. Partial sterilization of No. 77 appeared beneficial to NH_3 production but hindered NO_3 formation. Inoculation of a partially sterilized sample with about one-ninth by weight (W. F. basis) of No. 98 decreased the NH_3 somewhat.

Inoculation of sample 85 with No. 126, which by itself ammonified strongly, brought about only a slight increase. Dextrose

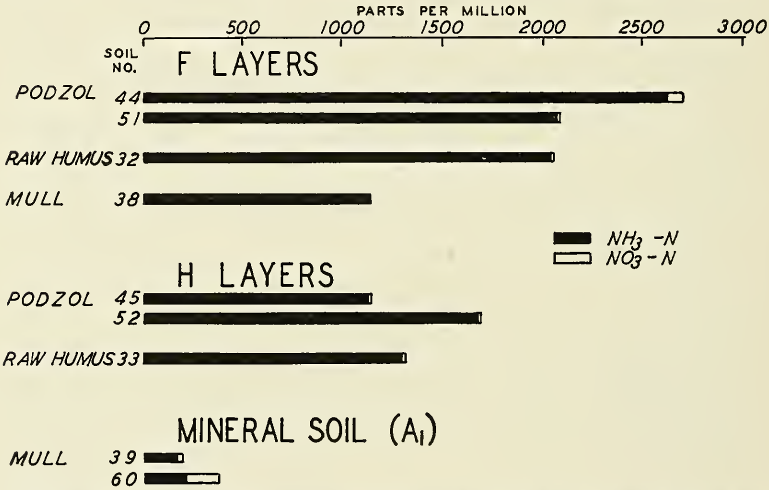

FIGURE 81. Amount of ammonia nitrogen and nitrate nitrogen in the soil after a three-month incubation. (Table 22.) First set, soil not previously dried.

added in addition had practically no effect. The inoculation of No. 120 with No. 85 and the further addition of lime brought about an enormous increase in nitrates. The sample was not tested for NH_3.

Lastly, inoculation of No. 126 with No. 85 greatly increased the NO_3 content, and the use of lime in addition more than doubled the nitrates.

Samples previously air dried. In the winter of 1929-30 a third experiment was carried out, this time on previously air-dried material. No inoculations or other treatments were applied. Table

24 and Figure 82 contain the data. Ammonia was determined at the end of one month as well as three months. Nitrates were run only after three months.

The ammonia content of the Cherry Mountain samples, particularly the F layers, was quite high at the beginning of the experiment but the increase during the incubation period was large,

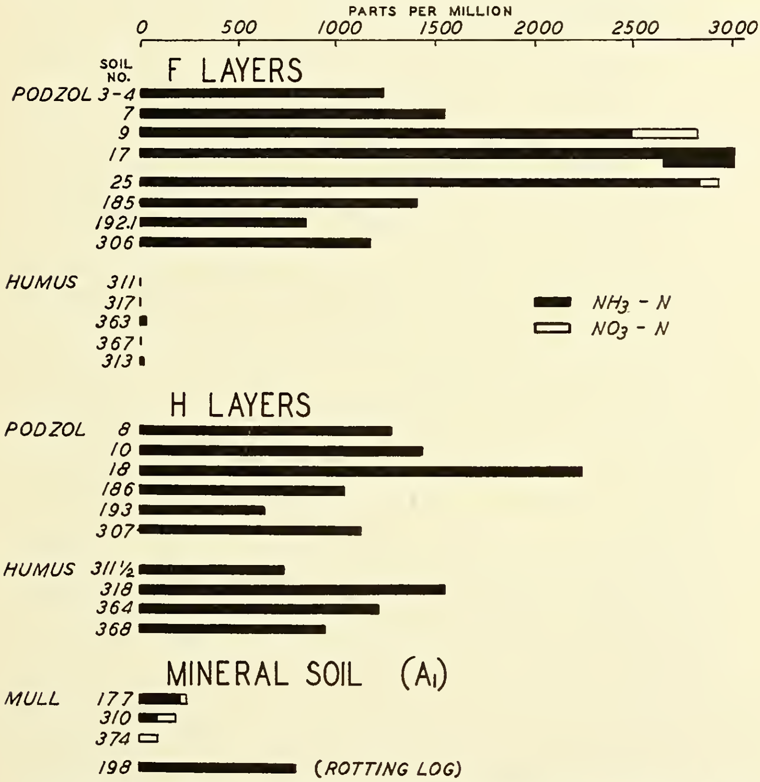

FIGURE 82. Amount of ammonia nitrogen and nitrate nitrogen in the soil after a three-month incubation. (Table 24.) Third set, soil previously dried.

nevertheless. As a rule the litter samples yielded little or no ammonia and, of course, no nitrates. This is due to the very wide carbon-nitrogen ratio of this material. All the available nitrogen present is used immediately by the decomposing organisms. In order to provide an accumulation of ammonia it would be necessary to add a large quantity of readily available nitrogen, as will be seen in later experiments.

TABLE 23. NITROGEN TRANSFORMATION

Incubation at Room Temperature 3 Months, March to June, 1929

Profile No.	Classification	Soil No.	Horizon	Treatment in lab.	NH_3–N p.p.m.				NO_3–N			
					Start	End	Gain	Coeff.	Start	End	Gain	Coeff.
—	Raw	69	F	0	507	1656	1149	16.0	2	864	862	8.3
	Humus	70	H	0	268	572	304	6.2	2	104	102	1.1
		70	H	Lime	—	—	—	—	2	460	458	5.0
23	Mull	76	F	0	424	188	–236	1.6	6	1142	1136	9.9
		76	F	Lime	—	—	—	—	6	1084	1078	9.4
		77	A_1	0	46	0	–46	—	20	272	252	4.9
		77	A_1	Lime	46	6	–40	—	20	776	756	13.9
		77	A_1	Partial sterile	46	372	326	6.7	20	28	8	0.5
		77	A_1	Partial sterile + #98	46	332	286	5.9	20	28	8	0.5
—	Mull	85	A_1	0	21	4	–17	—	65	262	195	—
		85	A_1	+ #126	21	29	8	—	—	—	—	—
		85	A_1	+ #126 + dextrose	21	23	2	—	—	—	—	—
—	Mull	91	F	0	498	583	85	4.6	8	558	550	4.4
		91	F	Lime	—	—	—	—	8	1254	1246	9.9
		92	A_1	0	23	28	5	1.0	17	132	115	4.6
		92	A_1	Lime	—	—	—	—	17	411	394	14.5
18	Humus	97	F	0	410	2172	1762	19.1	3	0	–3	—
		98	A_1	0	0	62	62	8.7	1	0	–1	—
		98	A_1	Lime	0	35	35	—	1	6	5	1.5
		98	A_1	+ #77	0	71	71	10.0	1	20	19	2.9

TABLE 23. NITROGEN TRANSFORMATION—(*Continued*)

Incubation at Room Temperature 3 Months, March to June, 1929

Profile No.	Classification	Soil No.	Horizon	Treatment in lab.	NH_3–N p.p.m.				NO_3–N			
					Start	End	Gain	Coeff.	Start	End	Gain	Coeff.
		98	A_1	Partial sterile + #77	0	40	40	5.6	1	7	6	1.0
—	Humus	103	F	0	196	1025	829	9.3	0	0	0	—
		105	A_1	0	0	72	72	7.5	0	0	0	—
		105	A_1	Lime	—	—	—	—	0	15	15	3.1
—	Humus	106	F	0	0	823	823	6.9	0	0	0	—
—	Humus	109	F	0	72	1148	1076	2.4	0	0	0	—
		109	F	Lime	—	—	—	—	0	5	5	0.1
15	R. H.	112	F	0	300	2189	1889	16.3	0	26	26	0.3
		113	H	0	286	1073	787	8.9	0	0	0	—
		113	H	Lime	—	—	—	—	0	1441	1441	11.9
8	Podzol	119	F	0	210	1875	1665	11.2	2	11	9	0.1
		120	H	0	170	563	393	6.1	0	0	0	—
		120	H	Lime	170	265	95	2.9	0	323	323	3.5
		120	H	+ #85	—	—	—	—	0	13	13	0.1
		120	H	Lime + #85	—	—	—	—	0	1120	1120	12.1
—	Humus	126	F	0	286	3675	3389	22.9	0	187	187	1.2
		126	F	Lime	286	33	–253	—	0	4466	4466	27.8
		126	F	+ #85	—	—	—	—	0	1291	1291	8.0
		126	F	Lime + #85	—	—	—	—	0	2926	2926	18.2

Table 24. Nitrogen Transformation, Forest Soils, Third Set.
Samples Previously Air Dried

Profile No.	Classification	Soil No.	Horizon	NH_3–N ppm						NO_3–N[1] Gain
				At start	1 month	Gain	3 months	Total Gain	Gain over 1 month	
—	Podzol	3–4	F & H	338	1045	707	1232	894	187	—
—	Podzol	7	F	355	1183	828	1543	1188	360	—
—	Podzol	8	H	425	1117	692	1279	854	162	—
1	Podzol	9	F	1055	2213	1158	2486	1431	273	333
	Podzol	10	H	403	1200	797	1439	1036	239	—
2	Podzol	17	F	1595	3133	1548	3359	1764	226	—
	Podzol	18	H	840	2069	1229	2235	1395	166	—
3	Podzol	25	F	565	1000	435	2828	2263	1828	92
.22a	Mull	176	Lit.	20	9	–11	8	–12	–1	—
		177	A_1	(a) 20	—	—	237	217	—	—
				(b) 7			54	47		47
26	Mull	178	Lit.	50	0	–50	12	–38	12	—
9	Podzol	180	Lit.	15	55	40	0	–15	–55	—
4	Podzol	185	F	145	896	751	1403	1258	507	—
		186	H	157	752	595	1032	875	280	—
5	Podzol	192	F	100	41	–59	845	745	801	—
		193	H	110	402	292	633	523	231	—

—	Rotting log	198		672	773	101	892	220	119	–20.5
11	R. H.	305	Lit.	80	106	26	71	–9	–35	—
		306	F	120	407	287	897	777	490	—
11	R. H.	307	H	130	—	—	465	335		—
		308	B_1	2	42	40	56	54	14	—
28	Mull	309	Lit.	30	6	–24	10	–20	4	—
		310	A_1	8	107	99	93	85	–14	88.7
19	Mild humus	311	F	30	0	–30	10	–20	10	—
		311½	H	60	383	323	736	676	353	—
29	Mull	313	Lit.	40	0	–40	10	–30	10	—
30	Mull	315	Lit.	70	32	–38	0	–70	–32	—
16	Humus	317	Lit.	25	52	27	15	–10	–37	—
		318	H	55	569	514	1545	1490	976	—
20	Mild humus	363	F	40	0	–40	43	3	43	—
		364	H	50	339	289	1215	1165	876	348.9
17	Humus	367	F	40	40	0	0	–40	–40	—
		368	H	25	274	249	940	915	666	—
25	Mull	373	F	25	5	–20	25	0	20	—
		374	A_1	4	43	39	0	–4	–43	86.4
27	Mull	377	Lit.	10	0	–10	26	16	26	—
10	Podzol	379	Lit.	60	5	–55	15	–45	10	—
		380	F	50	37	–13	0	–50	–37	—

[1]No NO_3–N at start in any of the samples except 198 which had 100.5 p.p.m.

Sample 198 is a rotting spruce log that was collected and preserved in a moist condition. Spruce seedlings survive and seem to grow quite vigorously on these rotting logs. In the foregoing experiment ammonification was not especially marked although the initial ammonia content is fairly high. Further consideration of this material is postponed for the present.

Inoculation Experiment

A special inoculation experiment was carried out in 1930 to supplement rather incomplete tests of a similar nature that had been previously made. This was done with air dried materials made up to optimum moisture, and inoculated with a water extract rather than with soil itself. The samples used were from the same group as those of the 1929-30 experiment. The plan was to inoculate a sample that normally did not ammonify with an extract of a sample that by itself yielded a large quantity of ammonia. Also the opposite was tried, inoculating a high ammonia sample with material from a low ammonia sample.

The results, shown in Table 25, indicate very little influence of inoculation. It is concluded, therefore, that if these materials contain any substances that either stimulate or inhibit ammonification such substances are not soluble in water.

TABLE 25. NITROGEN TRANSFORMATION, INOCULATION EXPERIMENT, 1930

Soil No.	Horizon	Treatment	NH_3–N p.p.m. Previous analysis	NH_3–N p.p.m. 1 month incubation
178	Lit.	—	0	6.7
"		Plus extract of 318	—	18.7
192	Lit.	—	41	13.3
"		Plus extract of 185	—	26.6
185	F	—	896	680.0
"		Plus extract of 178	—	608.0
317	Lit.	—	52	23.0
"		Plus extract of 318	—	5.0
318	H	—	569	588.0
"		Plus extract of 315[1]	—	593.0
367	F	—	40	40.0
"		Plus extract of 368[2]	—	0.0
"		Plus extract of 185	—	8.0

[1]Previous analysis of No. 315, 32 p.p.m.
[2]Previous analysis of No. 368, 274 p.p.m.

Effect of Treatment

A fifth experiment was carried out in the winter of 1930-31 in which several treatments were used. In connection with another greenhouse experiment, samples were collected from a scarlet oak stand in Bethany, Conn., under which there was a rather thick layer of raw humus, a typical poor condition for this locality and from a healthy, rapidly growing mixed hardwood stand near Lake Beseck in Middlefield, Conn. which had an excellent crumb mull. These samples were taken as follows:

Bethany (Profile 13)		Beseck (Profile 22a)	
S 358	F layer	S 362	Litter
359	H layer	363	A_1
360	A_2	364	Composite
361	Composite		

The composite consisted in each case of a mixture of the horizons in question in their natural proportions similar to what one would have were he to plow the soil to include about 4 inches of mineral soil. In addition there were included in the experiment samples from a mull type and a raw humus type in eastern Connecticut and a mull in Woodbridge, Conn. (Lake Chamberlain).

Treatments when specified consisted of the following materials: Lime = precipitated chalk; nitrogen = bloodmeal calculated to yield 800 to 1000 p. p. m. of nitrogen as used; PK = KH_2PO_4 20 mg. per sample. From 20 to 100 grams of soil were used, depending upon its bulkiness. These data are presented in Table 26.

The following points are worthy of note.

1. The large accumulation of ammonia in S 358 untreated, and the marked loss of ammonia in S 362. This again is identified with the differences in C–N ratios.
2. The striking decrease in ammonia and in most cases the resulting increase in nitrates where lime was used.
3. The increase in ammonia where nitrogen was added. In no case, however, did the whole of the added bloodmeal nitrify. Observe the rather close relation between the percentage of added N nitrified and the C–N ratio.
4. The NPK treatment giving slightly better results than N alone, except in the case of S 362.
5. LNPK causing a very marked increase over lime alone in samples S 360 and S 363, both mineral layers, but not in the other three samples so treated.
6. In sample S 362 none of the treatments had any appreciable effect in overcoming the handicap of a wide carbon nitrogen ratio. In the greenhouse it was necessary to add large quantities of soluble nitrogen in order to grow a crop on this material.
7. Comparing the check with the lime treatment, it is evident that in the F layers lime resulted in a much lower accumulation of soluble nitrogen than was the case in the untreated sample; in the H layers there was a slight reduction, but in the mineral horizons lime increased the soluble

TABLE 26. NITROGEN TRANSFORMATION, FOREST SOILS, FIFTH SET. EFFECT OF TREATMENT

Profile No.	Classification	Soil No.	Horizon	Treatment	NH_3–N At start	NH_3–N 3 months	NH_3–N Gain or loss	NO_3–N Gain	Total Gain NH_3–N NO_3–N	pH at end	C:N original soil
					p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.		
13	R. H.	S358	F	O	290	2272	1982	0	1982	6.70	25.8
				L 2 g.	290	50	–240	1067	1027	7.27	—
				N 1000 p.p.m.	290	2715	2425	0	2425	6.70	24.2
				NPK 1000 p.p.m.	290	2785	2495	0	2495	6.65	—
				LNPK 1000 p.p.m.	290	22	–268	1140	872	6.57	—
13		S359	H	O	245	1200	955	17	972	4.98	26.1
				L 2 g.	245	32	–213	1140	927	6.70	—
				N 800 p.p.m.	245	1570	1325	33	1358	5.31	24.6
				NPK 1000 p.p.m.	245	1610	1365	27	1392	5.13	—
				LNPK 1000 p.p.m.	245	48	–197	998	801	6.20	—
13		S360	A_2	O	30	130	100	12	112	5.34	23.7
				L 1 g.	30	4	–26	199	173	5.80	—
				N 1000 p.p.m.	30	473	443	171	614	5.00	16.4
				NPK 1000 p.p.m.	30	502	472	164	636	5.30	—
				LNPK 1000 p.p.m.	30	313	283	599	881	5.40	—
13		S361	Comp.	O	60	200	140	12	152	5.21	24.6
22a	Mull	S362	Lit.	O	380	75	–305	0	–305	5.97	42.4
				L 2 g.	380	15	–365	0	–365	7.80	—
				N 1000 p.p.m.	380	105	–275	Tr.	–275	6.88	38.7
				NPK 1000 p.p.m.	380	90	–290	0	–290	6.56	—
				LNPK 1000 p.p.m.	380	75	–305	0	–305	7.84	—

22a		S363	A_1	O	51	62	11	95	116	5.00	24.6
				L 1 g.	51	0	–51	196	145	6.60	—
				N 1000 p.p.m.	51	704	653	378	1031	5.65	14.3
				NPK 1000 p.p.m.	51	705	654	435	1089	5.25	—
				LNPK 1000 p.p.m.	51	244	193	861	1054	6.60	—
22a		S364	Comp.	O	100	48	–52	154	102	4.95	23.1
31	Mull	420	F	O	410	280	–130	342	212	5.84	31.9
				L 2 g.	410	35	–375	20	–355	6.98	—
31		421	H	O	85	244	159	484	643	—	20.7
				L 1 g.	85	0	–85	638	553	—	—
31		422	A_2	O	14	136	122	21	143	5.40	20.0
				L 1 g.	14	16	2	280	282	6.98	—
12	R. H.	427	F	O	185	1845	1660	Tr.	1660	6.65	29.9
				L 2 g.	185	75	–110	80	–30	7.10	—
12		428	H	O	835	992	157	13	170	6.38	23.7
				L 1.5 g.	835	12	–823	990	167	6.61	—
12		429	A_2	O	162	76	–86	40	–46	5.47	22.6
				L 0.5 g.	162	0	–162	218	56	7.30	—
—	Mull		F	Lake Chamberlain							
				O	88	15	–73	463	390	6.51	—
				L 2 g.	88	0	–88	110	22	7.47	—
—			A_1	O	12	60	48	196	244	5.45	—

nitrogen content. Although the C – N ratio has some part to play in this, it does not account for all the differences found. Nor can one find any correlation with the pH of the incubated soil at the end of 3 months. It may be identified with the organic constituents such as lignin and cellulose, as differences in these constituents in similar horizons have been found by Watson, Waksman and others.

Natural Moist Condition versus Previous Drying

Samples of the H layer collected in July, 1931, near Waterville, N. H., and North Colebrook, Conn., were divided into two portions, one being either wrapped in wax paper or put into a tin milk can and the other being allowed to air dry. In November all samples were prepared as usual and set up for incubation. Similar comparisons in a small way had been made in connection with some of the preceding experiments. All of the data bearing on this question are to be found in Table 27.

Apparently drying stimulates ammonia formation and, possibly to a limited extent, nitrate formation, although the data in the latter case are conflicting.[1] Where lime was used on these samples the results tend to be very erratic. From the foregoing data one is led to believe that previous drying makes but little difference in the amount of nitrogen transformed in a 3 months period of incubation. One should be consistent in his procedure, however, if comparative results are to be obtained.

Incubation appears to have raised the pH of the unlimed samples, due no doubt, to the increase in ammonia. Note that the North Colebrook wet sample that actually decreased in ammonia also decreased in pH. Lime increased the nitrate content which, as nitric acid, very markedly reduced the pH of the original limed soil. The hydrogen ion concentration at the start was determined one-half day after the samples had been moistened and limed.

Correlations of Nitrification with Chemical Composition

A positive correlation between ammonia plus nitrates and pH after 3 months incubation is shown in Table 28. While individual samples vary greatly the averages are in agreement with the data presented by Hesselman (19), although he deals with the ammonia nitrogen separately from nitrate nitrogen.

The correlation of ammonia nitrogen and C - N ratio is given in Table 29. Here we see the average maximum occuring when the ratio varies between 20 and 30 to 1.

[1]Bull (20) observed that the general level of ammonia and nitrates after incubation was lower in the set in which the soil had been air dried than in a previous set not allowed to air dry. He did not, however, run both sets concurrently, as was done in this work.

Table 27. Nitrogen Transformation. Comparison of Previously Dried with Undried Material

Sample	Previous condition	Treatment	NH_3–N p.p.m.			NO_3–N p.p.m.			pH	
			At start	3 mo.	Gain	At start	3 mo.	Gain	At start	3 mo.
Waterville, N. H.	Dry	0	1135	1808	663	29	29	0	4.15	4.36
Upper H layer		Lime[1]					121, 684	92, 655	6.74	5.03
	Wet	0	385	890	505	4	6	2	3.80	4.30
		Lime					89	85	6.70	5.20
Same	Dry	0	140	500	360	3	4	1	3.39	3.90
Lower H layer		Lime					334	331	6.52	5.03
	Wet	0	137	420	283	3	0	–3	3.35	3.75
		Lime					834	831	6.14	5.20
N. Colebrook, Conn.	Dry	0	990	2170	1180	—	19	19	4.50	5.00
H layer		Lime					1480	1480	—	4.90
	Wet	0	813	600	–213	25	310	285	4.72	4.00
		Lime					1480	1455	—	5.00
Rotting log	Dry	0	515	630	115	0	55	55	—	3.30
No. 198	Wet	0	620	580	–40	54	2	–52	—	3.16

[1] 1g. $CaC0_3$.

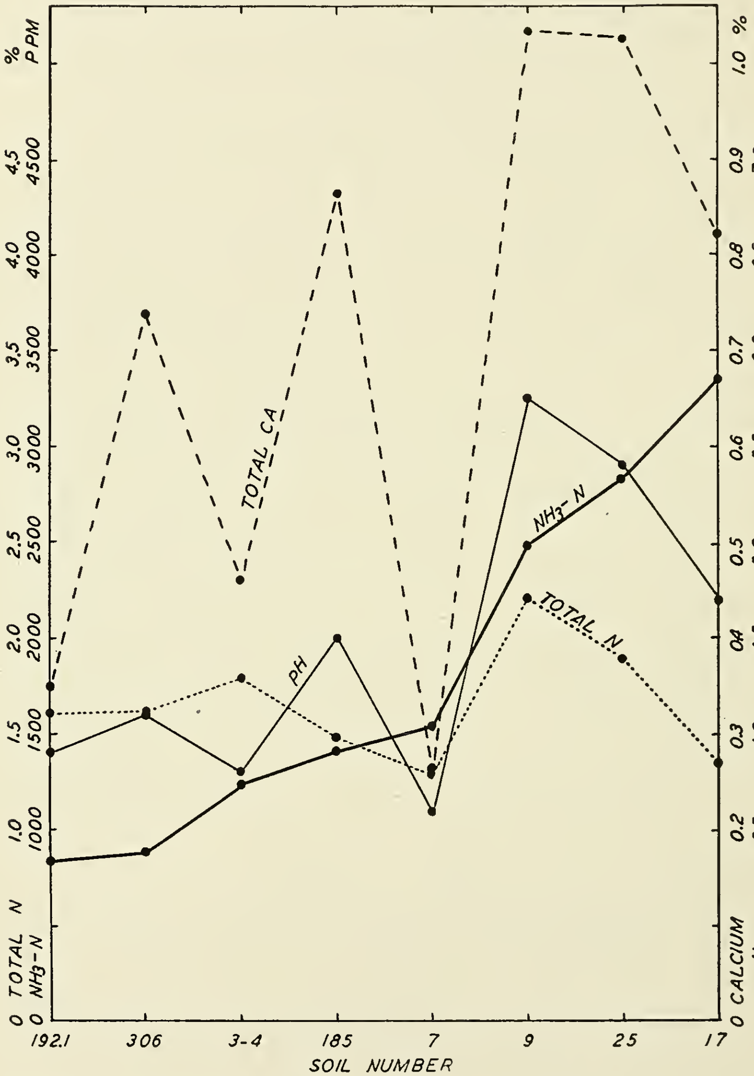

FIGURE 83. Relation of ammonia nitrogen content after a three-month incubation to other soil properties. Podzol soils, F layers only.

In Figure 83 the F layers from podzol soils are arranged in order of increasing amounts of ammonia formed upon incubation, and comparison is made with pH and with the total nitrogen and total calcium content of these soils. The correlation is closer in the case of pH and calcium than it is with nitrogen. Observe that pH, Ca and N are very much higher in No. 9 than in No. 7. The latter is from an almost pure spruce stand, while sample 9 came from a clear cut spruce-hardwoods plot. The difference in C - N ratio (No. 7 = 41.5; No. 9 = 22.2) is sufficient to account for the superior ammonification in No. 9. Comparing samples 9, 17 and

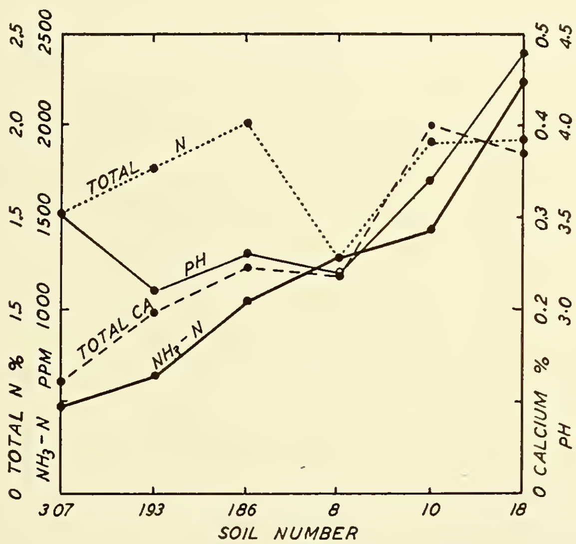

FIGURE 84. Relation of ammonia content after a three-month incubation to other soil properties. Podzol soils, H layers only.

25, which correspond to plots 1, 2, and 3 of the Cherry Mountain series, we note that plot 2 is poorly drained and the stand contains a much larger proportion of conifers than plot 3. This would account for the more acid reaction and the lower Ca content.

In the case of the H layers of podzol types (Figure 84) excellent agreement is found between NH_3-N, calcium, and pH. Total N does not correlate nearly so closely.

The ammonia formed in mild humus (twin mull) samples is correlated fairly well with total nitrogen content and also calcium as far as it goes (Figure 85). It may be mentioned here that the exchangeable calcium of sample No. 126 is considerably in excess of any of the other samples concerned in this group. Apparently reaction is of less consequence in this case.

All of the factors involved agree excellently with the ammonia nitrogen of the H layers of the mild humus type (Figure 86).

Correlations with Phosphorus and Potassium

The ammonia content of two groups of samples was compared with total phosphorus, soluble phosphorus, and replaceable potassium. The correlations were practically nil, hence no data are given.

TABLE 28. CORRELATION OF NH_3–N + NO_3–N AND pH

Organic layers

pH	3–3.5	3.5–4.0	4.0–4.5	4.5–5.0	5.0–5.5	5.5–6.0
	465	563	10	0	622	728
	633	736	677	25	1025	2819
	892	1129	823	43	1141	
	1032	1232	845	1025	1331	
	1279	1307	897	1215	2920	
		1439	940	1403		
		1543	1005	1845		
		1680	1073	2172		
			1148	2272		
			1217	2520		
			1545	2715		
			1886	3359		
			2057			
			2082			
			2215			
			2235			
			3862			
Ave.	**860**	**1204**	**1442**	**1550**	**1408**	**1773**

Mineral layers

pH	3–3.5	3.5–4.0	4.0–4.5	4.5–5.0	5.0–5.5	5.5–6.0
			56	62	157	133
			72	86	157	266
			142	101		
				116		
				160		
				182		
				272		
				374		
	Average		**90**	**169**	**157**	**200**

TABLE 29. RELATION OF NH_3-N TO C-N RATIO

Organic layers

C:N	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90
		573	244	188	0	0	0	0	26
			563	280	75	0	8	12	892
			992	465	845	10	10		
			1032	583	1025	15	71		
			1073	633	1148	15			
			1200	736	1543	25			
			1215	823		43			
			1232	897					
			1439	940					
			1545	1017					
			1845	1120					
			1875	1279					
			2075	1295					
			2235	1403					
			2272	1656					
			2486	1675					
			2625	2045					
			2828	2172					
			3675	2189					
				3359					
Ave.			1708	1238	773	15	22	6	459

Organic Matter Decomposition

The kind and amount of duff on the forest floor are dependent among other things upon the rate and completeness of decomposition. The best method of making comparisons in this respect is by taking the samples to the laboratory and measuring the rate of decomposition under uniform conditions. Perhaps the most satisfactory measurement is the amount of carbon dioxide evolved in a given time.

Results Over a 46 Day Period

The samples were prepared as described for the nitrogen transformation experiments and put into 12 ounce wide mouth bottles connected with some suitable device (to be described) for measuring the CO_2.

For the first test, carried out in the winter of 1928-29, the amount of soil used was governed by its carbon content, the object being to have the same amount of organic carbon in each sample, using 10 grams of soil containing 40 per cent C as a basis. In other words each sample as used contained a total of 4 g. of carbon. The bottles were equipped with a two-hole stopper in the one of which was inserted a soda-lime tube. In the other hole was placed a glass tube bent at right angles, the horizontal end of which was connected to the bulb end of a Meyer absorption tube. A battery of 12 such sets was connected to a water pump. Aeration at a slow rate was carried on for one hour each day. The CO_2 was absorbed

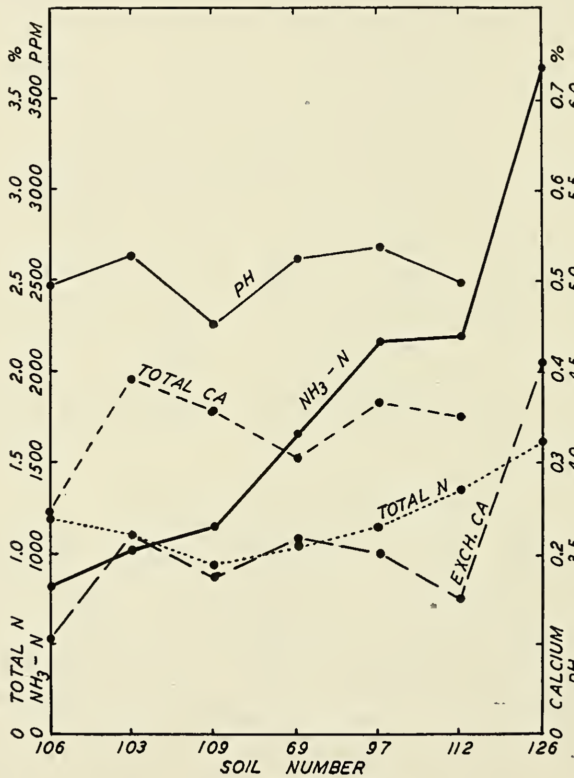

FIGURE 85. Relation of ammonia nitrogen content after a three-month incubation to other soil properties. Humus type profile, F layers only.

by standard KOH, the carbonates precipitated with $BaCl_2$ and the whole titrated with HCl. The data are given in Table 30.

The F layers in all cases evolved considerably more CO_2 than did the H or A_1 layers. This is to be expected since the C - N ratio is wider in the F portion. In the H and the organic portion of the

A_1 the more readily decomposed portions have already been broken down, leaving the more resistant substances of which lignin is the best known.

The most rapid decomposition occurs during the first few days, with a gradual dropping off with the passage of time. Sample No. 38, however, not only has a higher initial evolution but maintains a higher rate throughout, dropping off but little. Were the experiment to continue for a longer period of time, all samples would

TABLE 30. ORGANIC MATTER DECOMPOSITION AS MEASURED BY EVOLUTION OF CARBON DIOXIDE. (SAMPLES NOT PREVIOUSLY DRIED) MGMS. OF CO_2 AVERAGE PER DAY

Days	Profile No. 14 Devil's Hop Yard Raw humus		Profile No. 24 Devil's Hop Yard Mull		Profile No. 6 Bigelow Podzol	
	Soil No. 32 F	Soil No. 33 H	Soil No. 38 F	Soil No. 39 A_1	Soil No. 44 F	Soil No. 45 H
2	28.3	10.8	38.3	11.9	28.9	11.1
4	24.2	8.3	33.6	9.1	25.5	9.4
7	24.8	8.6	35.4	8.8	24.0	9.1
11	17.5	5.9	25.3	6.5	17.3	6.5
14	18.1	6.8	29.9	8.1	18.3	7.5
20	16.3	6.2	27.3	6.9	14.5	6.3
25	17.0	7.7	31.9	7.2	14.4	6.1
32	16.7	9.5	32.2	7.4	15.3	6.1
39	15.9	12.5	31.9	6.9	17.2	6.2
46	13.2	10.7	24.3	5.3	15.7	5.3
Accum. total	805.9	410.7	1381.4	332.4	799.8	306.4
W. F. wt. soil gm.	8.98	10.13	13.64	50.9	9.79	10.34
Ave. per gm. soil	89.7	40.5	100.6	6.5	84.9	29.5
Percent. CO_2 evolved	5.5	2.77	9.42	2.27	5.48	2.08

drop off to a much lower level. Observe that the amount of CO_2 evolved in percentage of the total amount originally present, varies considerably in the F layers, but is more constant in the H and A_1 horizons.

Seven Day Experiments

It was observed that the results obtained at the end of one week were comparable to the total for the full 46 day period as far as the relation of one soil to another was concerned. The next two experiments were therefore limited to 7 days each. The samples consisted primarily of litter only, although several F layers were included.

Preparation was carried out as already described. Titration was made every day excepting the sixth. The results are shown in Tables 31 and 32.

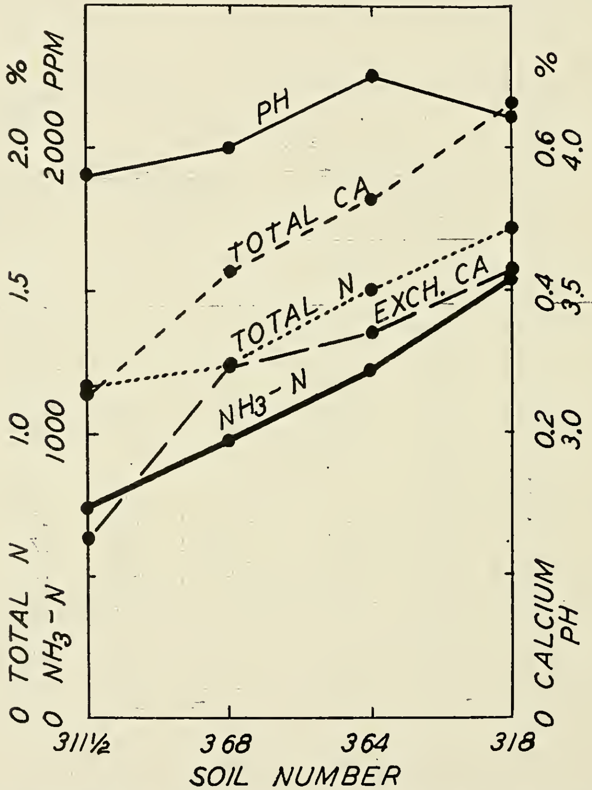

FIGURE 86. Relation of ammonia nitrogen content after a three-month incubation to other soil properties. Humus type profile, H layers only.

The greatest evolution occurred the second or third day. Observe that the initial evolution and also the total evolution is greater than it was in the first experiment. This is due to the fact that the samples in the second and third experiments were previously air dried. It is easily demonstrated that drying greatly stimulates the decomposition that occurs following moistening.

Other Experiments

In February, 1931, a number of samples were incubated at 28° and the CO_2 measured on the fourth, fifth, seventh, and tenth days. Through an error the bottles were first plugged with cotton, which resulted in such complete diffusion that practically no CO_2 accumulated. After the third day the bottles were kept stoppered except during the hour of incubation.

Table 31. Organic Matter Decomposition as Measured by Evolution of Carbon Dioxide. (Samples Previously Air Dried.) Mgms. of CO_2, Average per Period

Profile No.	9 Podzol	11 R. H.	11 R. H.	22a Mull	26 Mull	28 Mull
Soil No.	180	305	306[1]	176	178	309
Days						
1	59	41	79	48	53	39
2	124	131	102	123	105	110
3	124	196	88	122	94	112
4	97	177	73	100	70	89
5	75	143	64	76	55	62
7	62	113	64	66	45	46
Accumulated Total	540	806	470	535	418	457

[1]F layer; all others litter.

Table 32. Organic Matter Decomposition as Measured by Evolution of Carbon Dioxide. (Samples Previously Air Dried.) Mgms. of CO_2, Average per Period.

Profile No.	10 Mod. Podzol	16 Humus	17 Humus	27 Mull	29 Mull	30 Mull
Soil No.	379	317	367[1]	377	313	315
Days						
1	70	90	55	41	66	114
2	83	130	92	85	160	158
3	65	81	66	98	181	91
4	47	56	45	73	128	64
5	38	45	33	53	95	51
7	39	46	42	47	83	47
Accumulated Total	332	448	333	398	715	525

[1]F layer; all others litter.

In addition to the foregoing, CO_2 was measured after one month and three months on some samples set to incubate in a nitrogen transformation experiment previously described. At the periods stated a vial containing standard KOH was suspended in each bottle of soil for three days (with one interruption). The results of both of the above tests calculated on a relative basis are given in Table 33.

TABLE 33. CO_2 EVOLUTION, RELATIVE VALUES[1]

Profile No.	Soil No.	Horizon	Mgms. CO_2 4th Day	7th-10th Day	Total 4th-10th Days	1 Month	3 Months
13	S 358	F	100	100	100	100	100
	S 359	H	31	23	29	23	40
	S 360	A_2	15	14	17	8	4
22a	S 362	F	88	156	140	112	121
	S 363	A_1	—	—	—	11	7
31	419	Lit.	102	113	123	—	—
	420	F	—	178	160	128	98
	421	H	16	55	54	24	19
	422	A_2	—	—	—	18	13
12	426	Lit.	110	125	135	—	—
	427	F	127	142	150	116	91
	428	H	53	57	58	55	74
	429	A_2	—	—	—	9	0
11	305	Lit.	220	205	224	—	—
—	Lake Chamberlain	F	120	138	140	—	—

[1]Values based on organic carbon content of original samples.

TABLE 34. CO_2 EVOLUTION, RELATIVE VALUES ON TREATED SOILS

Profile No.	Soil No.	Horizon	Treatment	1 Month	3 Months
13	S 358	F	O	100	100
			L	78	77
			N	113	89
			NPK	108	85
			LNPK	84	71
	S 359	H	O	25	62
			N	23	54
			NPK	24	53
			LNPK	32	59
	S 360	A_2	O	3.3	8
			N	6.6	8
			NPK	5.9	8
			LNPK	17	8
22a	S 362	Lit.	O	112	121
			N	124	108
			NPK	126	104
			LNPK	119	123

Effect of Treatment

Carbon dioxide was measured after one month and three months on the samples treated with fertilizers and described under the section on nitrogen transformation, page 807. These results are presented as relative values in Table 34. No allowance has been made for the CO_2 coming from the lime ($CaCO_3$) itself. Apparently lime has not been particularly stimulating to decomposition when used either alone or in conjunction with a complete fertilizer. The beneficial effect of nitrogen at one month has disappeared at three months.

Natural Moist Condition versus Previous Drying

Finally, measurements were made on CO_2 evolution in the experiment designed to determine the effect of air drying on nitrogen transformation. Vials of KOH were suspended in the bottles of soil and titrations were made at the end of 1, 2, 7, and 14 days with the results given in Table 35. Here we see that the use of lime has increased very markedly the CO_2 evolved. Since these soils

TABLE 35. EFFECT OF PREVIOUS DRYING UPON THE EVOLUTION OF CARBON DIOXIDE

Location	Horizon	Previous condition	Treatment	Mgms. CO_2, average per day				
				Nov. 24 1st day	Nov. 25 2d day	Dec. 1 7th day	Dec. 3-8 9th-14th day	Total
Waterville, N. H.	H_1	Dry	O	62	53	18	4.3	154
			Lime[1]	203	90	30	6.4	355
		Wet	O	28	19	14	3.6	78
			Lime	155	51	29	6.4	267
	H_2	Dry	O	32	21	8	1.2	67
			Lime	176	48	13	2.4	249
		Wet	O	10	4	3	0.9	22
			Lime	204	30	11	2.8	258
N. Colebrook	H	Dry	O	73	54	20	3.8	166
			Lime	238	101	36	11.0	431
		Wet	O	13	10	9	2.3	44
			Lime	204	56	34	9.6	341

[1] 1 g. $CaCO_3$ which is equivalent to 440 Mgm. CO_2.

are quite acid the bulk of the increase must be due to a decomposition of the lime itself. In every case previous drying resulted in a very definite increase in rate of decomposition. This stimulation of the dry samples drops off rapidly, however, and by the end of two weeks has almost disappeared.

Correlations and Relationships

Efforts to find a correlation between decomposition and other properties are somewhat disappointing. Without further discussion it must be said that there is practically no correlation between CO_2 and total nitrogen; nor is there with the amount of nitrogen transformed. With pH, total calcium, and exchangeable calcium the correlation is contradictory, being direct in some cases and inverse in others. Some correlation was observed between CO_2 and carbon-nitrogen ratio, although it is far from perfect.

Reference to Table 31 shows that the litter from Meshomasic Mountain (No. 305) decomposed far in excess of any of the other samples in the experiment. It may or may not be significant that within this particular group of samples No. 305 was most acid in reaction, contained the lowest amount of total and exchangeable calcium, and the greatest amount of soluble nitrogen.

On the other hand, sample 313 gave off the largest amount of CO_2 of the group in which it was included, but this sample was second highest in total calcium and highest in exchangeable calcium. Therefore we are hardly justified in placing too much significance on the correlations mentioned in the case of No. 305.

In this connection we must turn to the work of Melin (31) who found a parallelism between total nitrogen content and ratio of decomposition *within* a given species (working with leaves from various species) but "as regards leaves from different species, there was no direct correlation between total N content and the rate of the first decomposition."

Joffe (24) believes that the speed of decomposition and quantity of organic matter are closely associated with the process of podzolization and the resultant effect upon the soil profile.

We know from observation in the field that duff from mull types breaks down more rapidly than does that from any of the other types. (Shortly after this manuscript had gone to press, there appeared a paper by L. G. Romell, "Mull and Duff as Biotic Equilibria" (Soil Science 34: 161-188, 1932), in which he upheld Muller's view that the decomposition of organic matter in duff and mull types differed in kind but not in rate. The present author made no measurements of CO_2 of the soil in situ and cannot, therefore, offer any evidence to substantiate or disclaim Romell's thesis. In the light of his paper, however, the above sentence in the text might be altered to read, "We know from observation in the field that duff (litter) on mull types *disappears as a surface covering* more quickly and completely than does that from any of the other types.") In the laboratory studies some indication of this was apparent but there was an insufficient number of samples to demonstrate such results with absolute certainty.

DISTRIBUTION OF TREE SPECIES AND LESSER VEGETATION BY PROFILE TYPES

In this work no attempt at a detailed frequency distribution study of the vegetation was attempted. However, in Tables 36 and 37 the vegetation is listed by profile types. It is seen that some

TABLE 36. DISTRIBUTION OF TREE SPECIES

Species	Podzol		All humus types	Mull
	N. H.	Conn.		
Ash, white	—	—	—	5
Aspen	—	—	1	—
Aspen, large tooth	—	—	1	—
Basswood	—	—	—	2
Beech	2	1	2	3
Blue beech	—	—	—	1
Birch, black	—	2	2	2
Birch, gray	—	1	2	—
Birch, paper	1	1	—	—
Birch, yellow	5	1	—	1
Butternut	—	—	1	—
Cherry, wild black	—	—	1	—
Cherry, fire	1	—	—	—
Chestnut	—	1	—	—
Dogwood, tall	—	—	1	1
Fir, balsam	2	—	—	—
Hickory, pignut	—	—	—	2
Hickory, bitternut	—	—	—	3
Hickory, shagbark	—	1	—	3
Hickory, mockernut	—	—	1	—
Hemlock	1	2	3	1
Hop hornbeam, American	—	—	—	3
Maple, mountain	1	—	—	—
Maple, red	4	2	2	—
Maple, sugar	1	1	1	7
Maple, striped	1	—	—	1
Oak, black	—	2	3	6
Oak, chestnut	—	3	—	1
Oak, red	—	2	1	6
Oak, scarlet	—	2	3	2
Oak, white	—	2	3	7
Pine, red	—	—	2	2
Pine, white	—	1	2	—
Sassafras	—	—	—	1
Spruce, red	3	—	—	1
Tulip-tree	—	—	—	1
Witch-hazel	—	—	1	—

TABLE 37. DISTRIBUTION OF SHRUBS AND OTHER VEGETATION

Species	Podzol		All humus types	Mull
	N. H.	Conn.		
Adder's tongue	—	—	—	1
Arrow-wood	—	—	1	4
Aster	2	—	—	3
Bittersweet	—	—	—	1
Blueberry, low bush	—	2	2	3
Blueberry, high bush	—	—	1	1
Chokeberry	—	—	1	—
Clintonia	3	—	—	1
Dewberry	—	—	—	1
Dogwood	—	—	—	4
Elder, red-berried	1	—	—	—
Fern, brake	—	1	1	3
Fern, Christmas	—	—	—	1
Fern, grape	—	—	—	1
Golden rod	—	—	—	1
Goldthread	1	—	—	—
Grasses	—	—	1	4
Greenbrier	—	—	—	1
Ground pine	—	—	2	—
Hazelnut	—	1	1	—
Herbs	—	—	—	3
Hobblebush	4	—	—	1
Huckleberry	—	—	2	2
Indian cucumber	1	—	—	—
Laurel, mountain	—	1	2	—
Male-berry	—	—	1	—
Mayflower, Canada	2	—	1	1
Moss	2	—	2	1
Moss, shining club	1	—	—	—
Partridgeberry	—	1	1	3
Plantain, rattlesnake	—	—	1	—
Pogonia, whorl	—	1	—	—
Raspberry	1	—	—	—
Sarsaparilla	—	—	1	—
Shadbush	—	1	2	—
Sheep sorrel	—	—	1	—
Smilax	—	—	1	—
Star flower	—	1	—	—
Sweet pepperbush	—	—	1	—
Trillium, painted	2	—	—	1
Twisted stalk	—	—	—	1
Viburnum, toothed	—	—	—	1
Violet	—	—	—	1
Wintergreen	—	1	—	1
Wintergreen, spotted	—	—	—	1
Woodbine	—	—	—	1
Woodfern, spring	3	—	—	1
Wood sorrel	4	—	—	—

of the trees such as hemlock, red maple and beech are to be found in all locations. The oaks, hickories, and ash are not present in the strongly podzolized region, but are quite abundant in Southern New England. Of the oaks, the scarlet and chestnut are quite apt to be associated with the raw humus and moderately podzolized groups, while the white, red, and black oaks are associated with the mull types.

In the case of the shrubs and other lesser vegetation the data are not sufficiently complete to permit the drawing of any definite conclusions. Hobblebush and wood sorrel appear to be more abundant in the northern region, while arrow-wood and dogwood seem to be confined to the mull groups in Connecticut.

DISCUSSION

Properties of Podzol and Mull Soils

Our investigations have indicated that podzolized soils of New England are characterized by a moderately thick F layer that weighs about 22,000 pounds per acre inch, and a thick humus, usually raw, felty or greasy in texture, that weighs about 50,000 pound per acre inch. Frequently the A_1 horizon is either entirely lacking or is present only as a very thin layer. A_2, the leached layer, being mostly silica, has a volume weight of from 1.1 to 1.4, while that of B_1 is always less, usually 0.8 or 0.9. In B_2 there is an increase that continues into the C_1, being about 1.5 in the latter. These differences are more closely associated with the organic matter than they are with colloidal content, although silt plus clay is generally somewhat low in A_2 and rather high in B_1. Clay alone exhibits on the whole even less variation in this respect than does silt plus clay.

Similar studies on the mull types reveal a thickness and weight of the F not dissimilar to what was found in the podzols, but the H layer is lacking. The volume weight is lowest in A_1 (about 0.8) and increases regularly with depth, being in the C horizon practically identical to the corresponding horizon of podzol.

Silt plus clay and clay alone tend to be higher in the B_1 than in the horizons either above or below B_1. Volume weight is closely associated with carbon content, as was true in the podzols.

Color. The color of New England soils is influenced very considerably by the parent rock material, particularly in the red sandstone region where all of the soils are red or purplish red. Podzolization, of course, modifies the colors of the A and B horizons, resulting in a gray A_2 and usually a very dark reddish brown (coffee brown) B_1. B_2 may be of the same color as B_1 or it may be more yellowish than B_1. In the red sandstone region the whole profile, even though podzolized, may possess a purplish hue.

Chemical relations. Chemically the podzol profile differs from the mull type in possessing a greater acidity in all but the C horizons, a definite leached layer high in silica and low in iron, aluminum, organic matter, nitrogen, and calcium content and very low in buffer capacity; and a B horizon relatively low in silica and high in the other constituents. In the mulls, this accumulation in the B is not present or, in any event, only to a very slight degree.

The properties of the humus types lie intermediate between those of the podzol and the mull types.

Biological relations. Nitrogen transformation in the duff of forest soils is dependent upon the properties of the material itself rather than upon the type of profile with which it was associated. Variations within a type are as great or greater than differences between types, other conditions being equal. In other words the type of profile is in indirect rather than direct control of the biological processes.

Decomposition of the duff from the mull types appeared to be more rapid than that from the humus and podzol types. Evidence of this is greater and more convincing in the forest than it is in the laboratory. Dissimilarity in environmental conditions exert an influence in the field that is not obtained in the laboratory under uniform conditions. Light, temperature, wind movement, nature of the underlying soil, activity of earthworms, and other macroscopic organisms are apt to be sufficiently different to exert an effect not obtained in an artificial environment. Therefore one is not justified in applying to the field, without caution, results on decomposition obtained in the laboratory.

Profile Development

In a pedological sense, all of the soils of New England are relatively young. Zones of eluviation and illuviation are not well defined in the majority of agricultural soils and forested soils of the mull type. This is shown not only in the data in the latter part of Tables 3 and 7 but also in the study of seven profiles from Connecticut mixed hardwood stands given in Bulletin 330 of this Station (20, p. 687). Studies at the Harvard Forest in Massachusetts (15) lead to similar conclusions.

Under certain conditions, notably where older hemlock or white pine are growing and where other factors are suitable, this soil forming process is accentuated and greatly hastened, which results in a mature soil or one approaching that condition. The relative coarseness of the soil aids this process through rapid leaching. Here we find some concentration of silt and clay in the B horizon, but the principal movement is confined to the iron, aluminum, organic matter and calcium. So long as the present stand of timber exists or is replaced by a similar stand, the soil profile will retain its mature characteristics. A radical change in forest type or treatment or a full clearing of the land and devoting it to agricultural uses would alter the soil profile and very probably cause a tendency towards the mull type.

Toumey states (46) that: "Each stage in succession is accompanied by a corresponding change in the environmental complex but primarily in the soil. *It is this change in the soil that makes possible the next stage in succession* . . . . So long as succession takes place change in the soil takes place. So long as change in the soil takes place there must be corresponding change in the vegetation. . . . There is no climax in vegetation except when the soil weathering processes are complete and the soil is fully developed. There is no succession except when the soil weathering processes are in progress and the soil not fully developed."

This appears to be sound reasoning, yet does it not credit to the vegetation a degree of sensitivity to soil properties greater than that which actually exists? A change in vegetation probably always brings about a change in soil—certainly it does in some cases—but does it necessarily follow that a change in vegetation is dependent upon a change in the soil (exclusive of fire and the activities of man)?

Tamm (44) states that according to the Russian point of view if a steppe vegetation gave way to a forest type of vegetation, the soil would gradually but very slowly change. The new soil type would retain some of the characteristics of its former character for a long time. He says, ". . . . the conversion which takes place in the soil after the change of the vegetation goes much slower than the change of the forest vegetation itself."

It may be well to include Coffey's (9) statement on the subject. "There is no doubt that a change in native vegetation is usually indicative of a change in soils, but there are striking exceptions. In many instances where there is a marked difference in the natural timber growth it is possible to find differences in the soils to explain it, but in other instances markedly different soils will show the same character of timber growth. . . . A fundamental essential of scientific classification is that it must be based upon inherent and invariable properties of the materials classified. Classifying soils according to native vegetation is therefore going at the matter backwards; it is putting the effect before the cause. It is better to determine the cause of the change in vegetative covering, and, if found to be due to a variation in the soil, base the classification upon this; otherwise the destruction of the vegetation will destroy the foundation of the system."

The system of soil classification followed is in harmony with the foregoing quotation. We describe the properties of the various soils as they are found irrespective of the vegetation, but our chief aim is to attempt a correlation of soil properties and environmental factors associated with various forest types.

With respect to cultivation of a former podzol forest soil, Tamm (43) states that in the north country one frequently sees clumps and streaks of bleached soil and orterde in a cultivated field, indicating the marked resistance it is offering to the loss of its original characteristics. A similar thing has been observed in New Hampshire, and in at least two localities in Connecticut.

Period of Time Required to Podzolize a Soil

Observations in Sweden by Tamm (43) indicate that in a young soil under Scotch pine one to two cm. of leached soil are formed in about 100 years. Podzolization develops at a much slower rate in moss heath with thin raw humus than in forests rich in raw humus and moss. Observations by Griffith, Hartwell and Shaw (15) led them to believe that a leached horizon appeared under white pine after about 60 years, and at 80 years the upper margin of the B_2 had risen from a 9 inch depth to about 1 inch. Upon cutting the white pine and allowing hardwood to come in, the level of the B_2 gradually lowers again. One must bear in mind that these measurements were made simultaneously on stands of various ages occurring on soils presumed to be uniform originally. The changes just described unquestionably do occur, and, in this country at least, the method used by these investigators is the only one at our disposal at the present time.

The foregoing studies together with our own observations lead us to conclude, therefore, that where podzolization occurs in Connecticut it is a slow process and has not been formed by one generation of trees.

Altitude

Although the altitude in this State varies from sea level to 2355 feet the variation is not sufficiently great to be a main controlling factor. In the higher altitude one is more apt to find podzolization, but other factors such as forest species and soil have a greater influence than altitude has.

On the other hand, in New Hampshire latitude and altitude directly and indirectly are the most contributory factors in effecting podzolization.

Relation of Forest Type and Soil Properties

Studies similar to those of Cajander (8) if carried out in New England would not yield the fruitful results that he obtained in Finland and Central Europe. In New England we have many more species with which to deal and the forests are in most cases much more heterogeneous in composition. Associations of tree and ground cover are not nearly so well defined. The factors involved that bring about this heterogeneity may be assigned partly to climate and partly to the activities of man through his repeated cutting of the timber, in many cases before it had been allowed to reach a profitable size for lumber.

Nevertheless we do find some correlations. Raw humus, and humus approaching such a condition, is generally more apt to be found on poor droughty soils such as the Gloucester series, and particularly on the hill tops and knolls.

Podzols in Connecticut are more likely to be found under hemlock. Even in hemlock-hardwood mixtures, the podzol may be confined to a local area immediately below the hemlock tree. In fact podzol in this State occurs in most cases only in very localized areas, confined to one or two trees, or mere patches beneath a few individual trees. It is always restricted to the immediate forest or woodlot. Perhaps the most uniform distribution and largest area in Connecticut is the large burn at the Eastford—Pomfret location (profile No. 9), although even here it varies considerably in thickness.

Mull is much more common than is podzol as would be expected from a consideration of climate and forest species which occur here. Under certain conditions the mull is more fully developed than in others. It is quite evident that the controlling factors are soil and topography, the latter greatly influencing the moisture relations and hence the stand. A good mull is found under a thrifty hardwood stand, and the stand is there because of the favorable soil. On poor soils only the more hardy species such as pitch pine, scarlet oak, and chestnut oak survive. Under these conditions, due both to species and soil, a raw humus develops.

As one goes north podzol becomes more common until in the White Mountain region podzol is the rule. There mull is to be found only in woodlots or other favorable localities where moisture conditions are favorable and the soil quite fertile.

SUMMARY

The data presented in this bulletin were obtained in a study of soils in the forests of Connecticut and New Hampshire. Connecticut lies in the transition zone between the gray brown soils to the south and west and the definitely podzolized soils to the north. New Hampshire is located at the southern portion of the latter group.

The forests from which these soils were taken included pure hardwoods, hemlock-hardwoods, pine plantations, spruce hardwoods and nearly pure spruce.

For this study profiles were grouped into the following types: Podzol, Raw Humus, Humus, Mild Humus, and Mull.

The weight of the F layer varied from 9200 to 28,000 pounds per acre inch, and averaged 19,800 pounds, while the H layers varied from 35,800 to 107,700 pounds and averaged 53,100 pounds per acre inch. There was very little difference in the weight per *acre inch* between Connecticut and New Hampshire profiles, altho the *total* amount was greater in the latter.

A soil density of 1.0 or less (water = 1.0) was found in the case of the A_1 horizon of the mulls and B_1 horizon of the podzol profiles. Below B_1 the density always increased with depth. All orstein samples possessed a high volume weight.

Volume weight was correlated more closely with organic matter content than with clay content or any other physical property studied. The deposition of organic matter in the B horizon of podzol soils causes quite a marked reduction in the total weight per acre of the soil to a depth of 24 inches.

All of the soils are quite acid, with the H layer, where present, being the most acid portion of the profile. The upper horizons of the podzol and raw humus types are definitely more acid than the corresponding horizons of the mild humus and mull types.

Differences between the podzol and non-podzolized profiles are most strikingly shown in the distribution of iron, aluminum, nitrogen and organic carbon in the two types.

Based upon the analyses, the podzol types in New England are of the iron-humus type with no distinct separation of the iron from the humus. This is in distinction from the podzols of the Scandinavian countries which are usually either iron or humus podzols or the iron-humus type in which most of the iron is in a layer separate from the humus.

Forest soils are characterized by a wide C - N ratio.

Calcium is not concentrated in the B horizons as is the iron, but is more or less diffused throughout the whole lower profile. New England soils appear to be more deficient in lime than are the soils of Sweden reported by Tamm.

Although the *percentage* composition of calcium in the duff is high, on an acre basis it is quite insignificant in amount when compared with that in the lower mineral horizons.

The proportion of calcium in the exchangeable form is high (30-75 per cent) in the duff layers, and low (less than 5 per cent) in the B and C. On the whole the proportion is much less in forest soils than it is in good agricultural soils.

Magnesium equals or exceeds the calcium in amount present.

Exchangeable hydrogen is highest in the H and B_1 layers of the podzols, and is closely associated with the organic matter content.

Soluble phosphorus and exchangeable potassium are very largely confined to the organic portions of the profile.

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 was greater in the F layer than in the H or A_1 horizons as a rule. Inoculation had but little effect, which indicated that if any stimulating or inhibiting substances exist in the inoculating material they are not extracted with water.

Where treatments were used some benefit was observed. In no case did all of the added bloodmeal nitrify. Samples possessing a very wide C-N ratio required a large amount of nitrogen to permit the accumulation of ammonia or nitrates.

A positive correlation exists between nitrogen transformation and pH, C-N ratio, calcium and in some cases total nitrogen.

As would be expected the more completely the organic portion of the forest soil profile is decomposed the less CO_2 is evolved. Evolution is most rapid during the first few days; after this period it rapidly falls off to a low level, which persists for a long period.

Air drying a soil before incubation had no effect on nitrogen transformation except to increase slightly ammonia formation. Such treatment is, however, stimulating to the initial evolution of CO_2.

Practically no correlation was found between the rapidity of decomposition and chemical properties of the soil.

Some correlation between tree species and type of soil profile is apparent, but only to a limited degree. In the case of the lesser vegetation such a relation is even less evident.

The type of profile that develops in the forests of Southern New England appears to be controlled to a large extent by the soil and related environmental factors and only indirectly by the vegetation growing thereon. Podzolization is a slow process and is not brought about within one generation of trees.

Podzolization in the forest soils of the mountainous sections of New Hampshire is the rule rather than the exception and results from a combination of factors, the greatest being climate and soil. Assuming that it would be possible to produce and maintain a good mull condition and still retain the forest type now present, would or would not the tree growth be favored? Presumably it would. Such a question at the present time is largely an academic one.

PLANT SPECIES MENTIONED[1]

Trees

Common Name	Scientific Name
Ash, white	*Fraxinus americana*
Aspen	*Populus tremuloides*
Aspen, large toothed	*Populus grandidentata*
Basswood	*Tilia americana*
Beech	*Fagus grandifolia*
Beech, blue	*Carpinus caroliniana*
Birch, black	*Betula lenta*
Birch, gray	*Betula populifolia*
Birch, paper	*Betula alba papyrifera*
Birch, yellow	*Betula lutea*
Butternut	*Juglans cinerea*
Cherry, wild black	*Prunus serotina*
Cherry, fire	*Prunus pennsylvanica*
Chestnut	*Castanea dentata*
Dogwood, tall	*Cornus florida*
Fir, balsam	*Abies balsamea*
Hickory, pignut	*Carya glabra*
Hickory, bitternut	*Carya cordiformis*
Hickory, shagbark	*Carya ovata*
Hickory, mockernut	*Carya alba*
Hemlock	*Tsuga canadensis*
Hop hornbeam, American	*Ostrya virginiana*
Maple, mountain	*Acer spicatum*
Maple, red	*Acer rubrum*
Maple, sugar	*Acer saccharum*
Maple, striped	*Acer pennsylvanicum*
Oak, black	*Quercus velutina*
Oak, chestnut	*Quercus prinus*
Oak, red	*Quercus rubra*
Oak, scarlet	*Quercus coccinea*
Oak, white	*Quercus alba*
Pine, pitch	*Pinus rigida*
Pine, red	*Pinus resinosa*
Pine, white	*Pinus strobus*
Sassafras	*Sassafras variifolium*
Spruce, red	*Picea rubra*
Tulip-tree	*Liriodendron tulipifera*
Witch-hazel	*Hamamelis virginiana*

Shrubs and Other Lesser Vegetation

Adders tongue	*Erythronium americanum*
Arrow-wood	*Viburnum acerifolium*
Aster	*Aster sp.*
Bittersweet	*Celastrus scandens*
Blueberry, low bush	*Vaccinium vacillans or pennsylvanicum*
Blueberry, high bush	*Vaccinium corymbosum*
Chokeberry	*Pyrus arbutifolia*
Clintonia	*Clintonia borealis*
Dewberry	*Rubus hispidus*
Dogwood	*Cornus sp.*

[1]Checked according to Gray's Manual, Seventh Edition.

Common Name	Scientific Name
Elder, red-berried	*Sambuscus racemosa*
Fern, brake	*Pteris aquilina*
Fern, Christmas	*Polyslichum acrostichoides*
Fern, grape	*Botrychium sp.*
Goldenrod	*Solidago sp.*
Goldthread	*Coptis trifolia*
Grasses	*Gramineae*
Greenbrier	*Smilax rotundifolia*
Ground pine	*Lycopodium complanatum*
Hazelnut	*Corylus sp.*
Hobblebush	*Viburnum alnifolium*
Huckleberry	*Gaylussacia baccata*
Indian cucumber	*Medeola virginiana*
Laurel, mountain	*Kalmia latifolia*
Male-berry	*Lyonia ligustrina*
Mayflower, Canada	*Maianthemum canadense*
Moss, club	*Lycopodium sp.*
Partridgeberry	*Mitchella repens*
Plantain, rattlesnake	*Epipactis sp.*
Pogonia, whorl	*Pogonia verticellata*
Raspberry	*Rubus idaeus*
Sarsaparilla	*Aralia nudicaulis*
Shadbush	*Amelanchier canadensis*
Sheep sorrel	*Rumus acetosella*
Smilax	*Smilax sp.*
Star flower	*Trentalis americana*
Sweet pepperbush	*Clethra alnifolia*
Trillium, painted	*Trillium undulatum*
Twisted stalk	*Streptopus sp.*
Viburnum, toothed	*Viburnum dentatum*
Violet	*Viola incognita*
Wintergreen	*Gaultheria procumbens*
Wintergreen, spotted	*Chimaphila maculata*
Woodbine	*Psedera quinquefolia*
Woodfern, spring	*Aspidium spinulosum*
Wood sorrel	*Oxalis acetosella*

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