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THE INFLUENCE OF SOIL PROFILE HORIZONS ON ROOT DISTRIBUTION OF WHITE PINE

(*PINUS STROBUS* L.)

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THE INFLUENCE OF SOIL PROFILE HORIZONS ON ROOTDISTRIBUTION OF WHITE PINE

(*PINUS STROBUS* L.)

INTRODUCTION

A WIDESPREAD interest in forest soils has developed in Americaduring the past decade. Forest ecologists now attribute greater importance to the soil factor in forest production than for.merly and are giving increasing attention to soil science. It is now accepted generally by soil scientists that the soil is an organized body, the integral parts of which may be regarded as definite entities. The parts of a soil body which are exposed in vertical cross section (profile) are called horizons. Broadly speaking, four major horizons may be recognized in most forest soils, namely, the organic matter horizon, the A horizon (zone of eluviation), the B horizon (zone of illuviation), and the C horizon (parent material). There is abundant evidence to support the view that the various soil horizons are characterized by physical, chemical, and biological differences of varying magnitude. Consequently, it is logical to assume that the individual horizons of a profile may be regarded as biological units or, at least, sub-units. In any event the mature soil body should not be regarded as homogeneous.

Little or no attention has been given to soil horizons in most of the previous investigations of root distribution. Frequently the vertical distribution of roots has be'en discussed with reference only to arbitrary depths below the ground surface. Special features such as "humus layers," hardpan, and the water table have received some consideration, but usually there has been a lack of recognition of the genetic soil horizons by root investigators. Soil scientists have been criticized occasionally, and rightly so, for failure to give sufficient recognition to root systems; but equally open to criticism are those root investigators who give little or no consideration to the soil features.

The soil is the medium in which plant roots obtain anchorage and satisfy their requirements for water and nutrients. In view of the fact that this medium is not homogeneous from the surface downward, but comprises horizons differing in important respects, it is reasonable to suggest that the behavior of roots in these horizons also may differ. It is highly desirable that we learn whether the soil scientist's concept of soil horizons is as useful in forest ecology as in pedology. If the vertical distribution of tree roots in the soil body is closely related to certain horizons it is important that this fact be recognized. Better information relative to the vertical distribution of roots will form a basis for more intelligent soil sampling and the interpretation of soil data in terms of tree behavior.

The purpose of this investigation was to determine the distribution of white pine roots in the different soil profile horizons and, if possible, to relate their distribution to certain soil characters. The relation of forest tree root distribution to soil features is exceedingly complex. Consequently, a large amount of investigative work, both in the field and greenhouse, will be necessary before the forest ecologist can gain a reasonably correct understanding of the subject. The present account is a preliminary report summarizing the results which have been obtained by the authors.

The investigation was conducted in the Yale Demonstration and Research Forest near Keene, New Hampshire. Stevens (1931) and Tourney (1932) described the location, climate, and vegetation of this forest so these factors are not discussed here. The field data were collected by the junior authors during the summers of 1934 and 1935. Individual reports covering each of the two summer's work were submitted by the junior authors as theses in the School of Forestry, Yale University.

REVIEW OF LITERATURE

FROM time to time various investigators have enumerated the soil factors considered most important in determining the behavior of roots. No attempt is made to present here more than a cross section of the various viewpoints. Goff (1887: 167), after considerable experience with agricultural plants, wrote as follows, ". . . a certain degree of warmth, moisture, and oxygen are indispensable to the development of roots, and . . . when these are present, the rapidity of growth and the number of branches are dependent upon the amount of available plant food. In that stratum of the soil in which the balance of these four conditions is on the whole most favorable to root growth, the roots develop fastest, and this is doubtless one law that governs their distribution." Engler (1903 : 307) emphasized the importance of heat and moisture for root development. Waterman (1919) regarded moisture, chemicals, oxygen, and density or penetrability of the soil as factors influencing root behavior. Schreiber (1926: 158) held both physical and chemical conditions of the soil to be influential and pointed outthe importance of moisture and nutrients. According to Wahlenberg (1929), investigations have shown that at least five soil factors-moisture, fertility, physical properties, aeration, and temperature-influence the behavior of roots. Stevens (1931 : 47) suggested that, apparently, four factors are of outstanding importance for root development-soil moisture, soil temperature, the composition of the soil atmosphere, and the physical nature of the soil.

The relation of forest tree root development to soil horizons has been investigated by a number of workers. Moller (1902) studied root development of pine seedlings grown in soil horizons from a 100 year old stand of Scotch pine near Eberswalde. The horizons recognized were: raw humus, 8 em.; humus, 4 em.; leached material *(Bleisand)*, 11 em.; and "yellow mineral. sand" with incipient *Ortstein* formation. He found that seedlings grown in raw humus showed the greatest amount of root branching; in the yellow sand root development was considerably less. Seedlings were grown in a box, the lower half of which was filled with humus, the upper half with yellow sand. Root development in the sand was poor but in the humus extensive branching was noted.

Hesselman (1910) noted in Norrland that pine on podzol soil had a very shallow root system. Most of the roots were in the A horizon *(Bleisand)*, which averaged about 7 to 8 em. in thickness and in the B horizon *(Rotsand)*, which was 8 to 15 em. He attributed the shallowness of roots to more favorable temperature and moisture relations in the upper horizons and not to aeration conditions.

Görz and Bennecke (1927) investigated the relation of pine root systems to soil profiles in the Grimnitz district in Germany. These authors indicate that most of the roots were in the upper soil horizons ; in the lower horizons poorer in nutrients root development was less.

Laitakari (1929) furnished careful descriptions of the soil profiles in which he studied the root system of Scotch pine. He concluded (p. 360) that ". . . the horizontal roots of pine do not, to any great extent, avoid the horizon $A_{1, 2}$." In this respect Laitakari's experience does not agree with that of Tamm who is cited (p. 360) as ". . . pointing to the fact that the roots of trees tend to avoid the washed light coloured soil layer, horizon $A_{1, 2}$." In no case did Laitakari find the average depth of the horizontal root system even close to the lower level of the brown layer (B horizon).

Swetloff (1931) investigated pine root systems at the Academy of Forest Technology in Leningrad. Soil horizons were recognized and an attempt made to establish the significance of the individual layers with respect to root development. The soils were podzolized sands and loamy sands developed on deposits of the Yoldien Sea and the Ancylus Sea. The greatest amount of root branching was noted in the organic layers (*Bodenstreu*); in some cases roots were observed extending upward from the podzol layer into the organic debris. A similar situation was noted by Kokkonen (1923) in his studies of moor soils and by Weaver and Kramer (1932) in the case of *Quercus macrocarpa*. Swetloff found that the organic layers contained proportionately more roots, particularly finer ones, than the other soil horizons. A tendency was noted for roots to spread out in the upper part of well developed podzol layers, but, as a rule, the podzol horizon contained, especially in its lower part, very few small roots. This condition stood in sharp contrast to that in the organic layers. In the illuvial horizon the number of roots was even smaller than in the A layer; the number of roots in the B_2 was less than in the B_1. The method employed by Swetloff consisted of first isolating a column of soil 50 em. square by trenching. Next the horizons were established and removed successively. The roots were then washed out, classified as to size, dried, and weighed.

Bornebusch (193I) investigated root systems of forest trees growing in the strongly podzolized soils of. the Jutland heath plain. Root development was particularly good in the raw humus and in the humus-rich upper part of the leached layer; in addition roots were abundant in the *Ortstein*. Turner (1936) working with shortleaf pine in Arkansas used essentially the same field methods asthose employed by the present authors. His investigation indicates that the greatest root development was in the A horizon. The number of roots per unit area of horizon appears relativeiy low. Turner's figures I, 2, and 3, sh9wing root distribution with reference to soil horizons represent, in each case, a composite of 15 samples. In spite of the fact that the occurrence of roots has thus, in effect, been magnified IS times the numbers per unit area are still considerably less than the present authors obtained in individual profiles of soil supporting white pine.

Coile (1937) discussed the distribution of forest tree rootsin the Piedmont soils of North Carolina. The field methods employed were similar to those used by the present authors. Coile found most of the fine roots near the sur-face in the A horizon; in the C horizons very few fine roots occurred. It was noted that root development Was poor in compact horizons of plastic clay.

It seems desirable to call brief attention to certain investigations which have been devoted to the relation of roots other than those of forest trees to soil horizons. Oskamp and Batjer.(1932) working in apple orchards in New York State made excavations 2 feet wide and 10 feet long at a distance of either 7 or 10 feet from the tree trunks. The excavations were placed at approximately right angles to the general spread of the root system and on the vertical wall nearest the tree trunk the root ends were charted. The excavation was extended to a depth sufficient to include 'all roots. These authors also obtained data on the weight of the roots in the soil removed during excavation. It was clearly shown that soil horizon characteristics had an important influence on root development. The absence, or infrequent occurrence, of roots in very compact layers is evident from a number of their charts. Root development appears to be greatest in the upper soil layers, that is, in the A and B horizons. Horizons which were poorly drained commonly showed'very poor .root development; in this respect soil color was regarded as a good diagnostic feature.

In 1933 Oskamp and Batjerreported on additional studies in which they employed essentially the same field methods as in 1932. This time, however, features such as mechanical composition, moisture equivalent, permeability, soil, moisture relations, base exchange, and acidity were investigated. These authors regarded internal drainage .conditions in a soil as favorable when the content of "total colloids" in the B_1 horizon was no greater than in the A_1 horizon. In cases where the B_1 horizon contained a .higher content of "total colloids," deficient internal drainage was indicated. Drainage conditions were regarded as highly important.

Subsequent work by Oskamp (1933, 1934, 1935a, 1935b, 1936), and by Batjer and Oskamp (1935) has served to further emphasize the importance of soil profile features in relation to root development. In general, profiles having brown horizons without sharp contrasts in color appeared more favorable than those with gray or strongly mottled layers.

Partridge and Veatch (1932), ,vorking in Michigan, also concluded that variations in soil profile character influenced root development of fruit trees. They found the largest number of roots in the A horizon and suggested that the character of the subsoil has a considerable influence on root distribution. In 1933 Veatch and Partridge stated that, "On the deep, dry, easily penetrable sands in which there is a dry C horizon and only a faint development of a clayey B horiion, there is a notable development of long lateral roots and a mass of fine roots in the surface (A) horizon but with relatively few in the lower horizon. . . ." These authors noted the occurrence of mats of fine roots in silt and clay pockets which may occur in sandy soils.

Sweet (1933) in New York State arrived at essentially the same conclusions as Oskamp and Batjer. His charts are particularly interesting since they show very clearly the marked influence which soil horizons have on root development.

A very large body of literature relating to the influence of various physical and chemical soil conditions on root development has appeared. Only contributions having a bearing on the present investigation will be considered. The importance of favorable soil moisture relations for root development has been pointed out by Büsgen (1901), Engler (1903), Weaver (1919), Aaltonen (1920), Kokkonen (1923), Hilf (1927), Laitakari (1929), Swetloff (1931), Sweet (1933), Turner (1936), and Coile (1937). Weaver (1919) investigated the roots of *Kuhnia glutinosa* Ell., a prairie plant, and found unusual branching in clay layers which occurred at depths of 8 to 12 feet below the ground surface. On November 5, 1917, the moisture content in a clay layer 8 feet down was 17.9 per cent whereas in the soil above and below it was 4.2 and 2.5 per cent, respectively. Hilf (1927) found that spruce roots penetrated less deeply in moist soils than in dry soils. Laitakari (1929: 340) observed that, ". . . the moisture also seems to induce a more than usually rich branching." He also points out that, "An excessive moisture, on the other hand, seems to be the cause of the development of long, branchless roots." Partridge and Veatch (1932) have noted in subsoils which are generally light textured that root development is better in areas or strata of heavier texture. It is suggested that more favorable moisture relations in the finer textured material is the explanation. Lenhart (1934) observed a greater length of roots in seedling longleaf pines growing in dry sand than in wet sand.

Oskamp and Batjer (1933) have pointed out that tree roots are usually shallow in soils which have a high water table. Kokkonen (1923) stated that pines commonly lacked a tap root in moor soils where the water table was high; when present under these conditions the tap root was dwarfed and bent sideways. His conclusion was that the position of the water table strongly influenced the vertical distribution of roots. McQuilkin (1935), on the other hand, has stated that, "Probably the most striking single feature of pitch pine roots observed in the course of this investigation is the fact that they develop extensively below the water table in saturated soils."

Swetloff (1931) suggested that the pronounced development of roots in the upper part of the soil body was, in part, a response to more favorable moisture relations in those layers. Partridge and Veatch (1932) observed that the greatest development of fruit tree roots was in the A horizon and suggested favorable moisture relations as a partial explanation. West (1934) investigated the root systems of certain agricultural plants in Australia. He found the greatest concentration of roots in the surface soil horizons and suggested that this location of the absorbing organs permitted plants to better utilize moisture reaching the soil as light summer precipitation.

The importance of soil aeration in relation to root development has been considered by numerous investigators. Cannon and Free (1917) discussed the ecological significance of this factor and remarked that, "Though many details are lacking it is known that the composition of the soil atmosphere is neither the same as, nor as constant as, the composition of the general atmosphere." Nutman (1934) concluded that soil aeration is of considerable importance in determining root distribution of the coffee tree. A number of writers, among whom may be mentioned Busgen and Munch (1929: 271), Watt (1931), Swetloff (1931), and Sprague (1933) have indicated that the concentration of roots in the surface soil horizohs appears to be associated with aeration conditions.

Soil temperature conditions were regarded by Swetloff (1931) asimportant in explaining the tendency of roots to be concentrated in the upper soil horizons. Adams (1934) has recently shown that root development of white pine seedlings is better in relatively warm soils than UNder conditions of lower temperature. He suggested that downward penetration of roots maybe inhibited by low temperature of the subsurface soil layers.

Soil texture in relation to root development has been considered by Haasis (1921), Groth (1927), Hilf (1927), Laitakari (1929), Burger (1931), Veatch and Partridge (1933), Sweet (1933), Anderson and Cheyney (1934), and Oskamp (193Sb, 1936). Haasis (192i) noted that rocks in the soil tended to inhibit root extension. Groth (1927) investigated root behavior of Douglas fir in Germany. In fine textured soil root development was less extensive but the roots were more branched than in soils of medium and coarse texture. Groth found Douglas fir developing a heart root system in coarse grained soils in which the fraction >0.1 mm. was 60 to 80 per cent; in fine textured soils in which 70 to 80 per cent of the particles were <0.1 mm. he found a shallow root system. Hilf(1927) stated that pine roots became more branched with increasing content of finer fractions in the soil. Laitakari (1929) found pine shallow rooted on sandy soils but on heavier textured soils there was a tendency for deeper horizontal root systems to develop. He noted that the presence of large numbers of stones in the soil proved a hindrance to development of long roots. Burger (1931) observed the behavior of oak roots growing in sand overlying loam. In the sand a tap root was produced with few branches but on entering the loam, branching was extensive. Sweet (1933) presented a soil profile-root distribution chart (figure 9) which illustrates strikingly the influence of texture and structure on root behavior. In the subsoil was a thin layer of reddish brown clay with light-brown compact fine sandy loam above and grayish-brown very compact fine sandy loam below. The clay supported a large number of roots but there were very few in the material above and below. Veatch and Partridge (1933) pointed out the occurrence of mats of fine roots in silty and clayey pockets in the lower horizons of sandy soils. Anderson and Cheyney (1934) investigated root development of *Pinus resinosa, Picea glauca,* and *Abies fraseri* seedlings. They reported a greater number of rootlets in the coarser soils. Oskamp (1935b) encountered seams of very fine sand in the C horizon of Berrien fine sandy loam soils in New York; in these seams was a remarkable concentration of roots.

Compactness of soil horizons has a bearing on root distribution because layers may be so hard as to offer great resistance to root penetration. Ramann (1888: 319) stated that the more compact the soil, the more shallow would be the root development. Weaver (1919:44) observed that "... hard soil profoundly affects the amount of branching, laterals practically always being more numerous in a less compact substratum." Busgen and Munch (1929:270) expressed the opinion that, "The wealth of branching and the whole appearance of the root system are governed in a striking manner by the nature of the soil into which the root penetrates. In loose sand or humus or in water the roots always develop much more plentifully than in heavy, compact soil. Mechanical obstacles seem to affect this more than do conditions of nutrition." von der Wense (1929) has discussed the unfavorable physical conditions, notably compactness of the soil, found in areas formerly in agricultural use. Albert (1907) and others have also considered this condition. von der Wense advanced the view that different soils respond differently. As a result of former agricultural use heavy textured soils may become very compact; on the other hand, agricultural use of light textured soil may render it more readily permeable. Sweet (1933) pointed out a number of cases in which root distribution was obviously influenced by the compact nature of soil horizons. Partridge and Veatch (1932) stated that if a compact subsoil varies in density roots are more abundant in the less compact places. Oskamp (1935a) frequently observed the inhibiting effect of compact soil layers on root distribution.

Soil color is a feature which apparently has some relation to root distribution in the various horizons. Oskamp and Batjer (1932, 1933) and Sweet (1933) have pointed out the broader relations between soil color of horizons and root distribution of fruit trees. Root distribution was better in profiles having a brown color than in profiles exhibiting gray or strongly mottled layers. Root development in gray horizons commonly is poor or lacking. Brown colors indicate good oxidation whereas gray and mottled layers usually indicate poor oxidation. Cheyney (1932) investigated the root system of a jack pine tree in Minnesota and at a point 6 feet below the ground surface encountered ". . . a thicker layer of fine, white, beach sand, apparent evidence of an old lake bottom." He notes that the roots did not enter this layer.

Groth (1927) gave consideration to the influence of soil acidity on root development of Douglas fir but his data were inconclusive. Sprague (1933) examined soil pH values in an attempt to explain the gradual reduction of grass roots with increasing depth. He concluded that this reduction could not be explained on the basis of soil acidity. Nutman (1934: 291) stated that root distribution of the coffee tree was more uniform and deeper in nearly neutral soils than in those having a pH of less than 5.8-6.0.

A considerable number of investigators have discussed the influence of nitrogen on rootdevelopment. Miiller-Thurgau (1899) found root branching greater in solutions containing nitrogen than in solutions lacking this element. Matthes (1911) reported sowing lupine in a young spruce stand. After 4 years the spruce roots growing in the soil occupied by the lupine showed far better branching than in soil not supporting lupine. Weaver, Jean, and Crist (1922) grew crop plants in soil fertilized at various depths with $NaNO_3$ which was held in place with wax seals. Root branching in the fertilized levels was pronounced. Using similar technique Crist and Weaver (1924) found that roots of barley branched more profusely when they came in contact with soil zones fertilized with $NaNO_3$. These same authors applied monocalcium phosphate but the phosphorus did not increase root development as did nitrogen.

Various workers have obseryed that roots branch more profusely in soil rich in nutrients than in soil which is poor. Nobbe (1875) held that the roots of trees (pine, spruce, and fir) were concentrated at points where the greatest amounts of nutrients were available. Schwarz (1892) stated that the lower the content of nutrient salts in sandy soil the more extensive will be the root system of Scotch pine. As the nutrient salt content is increased root length is decreased. Biisgen (1901) pointed out the tendency of roots to branch in places where nutrients are available to them. Laitakari (1929:

340) observed that roots of pine ". . . grew straight and without branching over high points of rock covered by moss and even over stones. On the contrary, a special branching was found, for instance, on the site of old stumps; in decayed stems, too, groups of roots may be found." Biisgen and Münch (1929) believed that, ". . . better nutrition may also promote luxuriance in the development of the roots if at the same time mechanical hindrances, as in rich clay soil, are not present. Better nutrition in a particular part of the root area exerts a favorable influence on the production of side rootlets and, in soils minerally very poor, side roots already started may die off again." West (1934) suggested that the concentration of roots so commonly noted in the surface soil results frommbre nutrients being available in that zone.

Many investigators have pointed out the tendency for absorbing roots to develop in the organic layers of forest soils. Waterman. (1919) remarked that willows". . . show in marked degree the ability to form a small bunch of closely branched rootlets in small dark patches in the sand." He also noted that willows show marked root development in the vicinity of decaying organic matter. Moore (1922) found many feeding roots of white pine in the organic layers. Hesselman (1927) pointed out the fact that in organic layers of favorable type and condition tree root development was good. Hilf(1927) stated that the humus layers were important from the standpoint of root development in both beech and spruce. Root branching in these layers was particularly noticeable. Heyward and Barnette (1934) working in the longleaf pine region stated, "On the unburned areas a great many tiny feeding roots of the pines were found just beneath the A_0 horizon. These roots frequently had worked their way well into the duff layer. Na such concentration of feeding roots was apparent in the surface layer of soil on burned areas, where no protecting layer of litter was present, except that which had accumulated during the current year." Burger (1931: 99) noted a tendency for the roots of young spruce trees to produce fine branches in humus.

FIELD AND LABORATORY WORK

IN selecting stations for the present investigation, both soil conditions and character of the forest cover were considered. Soil variations in the Yale Demonstration and Research Forest are numerous because of differences in the origin of the parent materials. Since it was not feasible to investigate all soils within the tract attention was concentrated on those most commonly supporting white pine. In order to further simplify the problem stations were located only in essentially even aged, pure white pine stands which were established by natural regeneration. Most of the stands were between 35 and 45 years old and fairly well stocked, having a crown density of .7 to .9. A total of 23 stations were established but because of the bulky character of the data only 17 were selected for discussion in this report.

After having decided on the general location of a station the spatial distribution of the trees in the stand was considered and a position on the ground selected which seemed fairly representative. A trench 11 to 12 feet long and 2 to 2½ feet wide was then opened. The depth of the excavations, with one exception, varied from 5 to 7 feet, depending on the character of the lower layers. The walls were kept as nearly vertical as possible and roots entering or leaving the trench were cut off rather than pulled out. When the desired depth had been attained one of the walls was cleaned up, using a large knife or a trowel, and the horizon boundaries marked. The wall was divided into one foot squares by means of horizontal and vertical cords and the horizon boundaries were then sketched on cross-section paper using a scale of either 1 or 2 inches to a foot. After sketching the horizons the root ends were charted, using symbols to denote the various size classes recognized. Only living roots of white pine were recorded. In order to avoid missing any roots it was necessary to carefully work over the vertical wall with a sharp pointed instrument.

At each station the humus layer type was identified following the nomenclature of Bornebusch and Heiberg (1936). The soil horizons recognized are described as follows:

L. The uppermost layer of organic debris composed of freshly fallen and only slightly decomposed material.

F. The more or less decomposed organic debris lying below L. The material retains its original form sufficiently to permit identification.

H. The amorphous organic matter underlying the F horizon and just above A. Decomposition has advanced to a stage in which identification of the original material is impossible.

A. The upper (eluvial) horizon of the mineral soil from which material has been removed by chemical and physical processes.

B. The illuvial horizon underlying A; the zone of enrichment or accumulation.

C. The relatively unweathered material underlying the B; in many, but not all, cases it represents the parent material from which horizons A and B were derived.

In some of the soil profiles it was necessary to recognize subhorizons, as for example, A_1, A_2 or B_1, B_2. The same horizons were not distinguished in all profiles since important differences were commonly met. Thus, in certain cases the H horizon could not be distinguished and although B_1 and B_2 horizons were recognized in some profiles no such subdivision could be justified in others. The horizons were commonly very irregular and in some cases discontinuous. This lack of horizon continuity, which may have resulted from disturbance of the soil body by windthrown trees, together with pronounced stratification in the C of some profiles, necessitated the use of special designations which will be referred to later in the profile descriptions.

After the roots were charted the soil profile was described. In describing structure and consistency the terms proposed by Shaw (1928) were generally followed. The color designations refer to the appearance of the soil material in the field. Textural class was estimated in the field and later checked after analysis of the samples in the laboratory. Samples of about two quarts were taken from each of the horizons or strata and after being air dried were stored for analysis. In a number of profiles it was possible to obtain paired samples of soil supporting roots and adjacent soil lacking roots.

At each station a stem map covering approximately one-tenth acre was prepared. The diameters of all trees were measured at breast height on each area mapped. Figure 1 is a stem map showing the distribution and diameter at breast height of trees in the vicinity of station 13. It illustrates the type of chart prepared. Ages at or near the ground level were obtained by means of increment borings. Lists of the mosses, lichens, and higher vegetation at each station were prepared but these data are not presented since they contribute little to the subject of this report. In practically all cases herbaceous and shrubby vegetation was very sparse. Figures 2 and 3 illustrate the general conditions of stand and ground cover.

Mechanical analyses of the samples were obtained by means of the hydrometer method of Bouyoucos (1934). Moisture equivalents were determined with a centrifuge following the practice of Veihmeyer, Oserkowsky, and Tester (1928). Nitrogen was determined by the Kjeldahl method and *pH* was obtained electrometrically, using a quinhydrone electrode. Base exchange properties were investigated following the methods of Pierre and Scarseth (1931).

ROOT DISTRIBUTION IN RELATION TO SOIL PROFILE FEATURES

Profile horizons:

IN comparing root distribution in the different horizons two bases have been adopted (I) the average number of roots exposed in vertical cross sections 10 feet in length, and (2) the average number per square foot of rock-free cross-sectional area. The average number of roots in each horizon cross section (10 feet in length) is regarded as a fairly good index of the importance of the horizons from the standpoint of tree development. On the other hand the average number of roots per square foot of cross-sectional area is a more useful value in comparisons of the relative favorableness of different horizons for root development. The basic data appear in Table I.

The average number of roots exposed in the vertical cross sections 10 feet long is indicated in Table II. It is apparent at once that most of the roots occur in the A and B horizons or in their subdivisions; the number of roots in the organic horizons and in the C layers is relatively small. Comparisons of the number of roots in the F and H horizons, the H and A, the A and A_1, A and A_2, the A and C, the B and C, and in the B_2 and C_1 were made and in all cases statistically significant differences were indicated.

The relatively small average number of roots in the organic horizons (162 ± 28)* is not surprising in view of the thinness of these layers. In the A horizon the average number of roots was 1448 ± 160 whereas the number in the A_1 was 688 ± 247, and in the A_2, 739 ± 101. These differences are in large measure the result of variations in the average cross-sectional area of the horizons. Thus, the average cross-sectional area, in square feet, was 5.16 ± 0.43 in the A horizons and in the A_1 and A_2 horizons the areas were 2.18 ± 0.64 and 4.86 ± 0.51 square feet, respectively. A similar situation exists with respect to the B horizons. The sharp reduction in average number of roots in the C_1 horizons as compared with the B_2 layers is interesting. It indicates that the former are less favorable for root development than the latter. Comparisons of the average number of roots in the A_1 and A_2 horizons, the A and B, the A_2 and B_1, and in the B_1 and B_2 failed to demonstrate significant differences. In all these cases the horizons are adjacent.

* The values following the ± signs are in all cases the standard errors of the means.

The average number of roots per square foot of rock-free cross-sectional horizon area is presented in Table II. The data indicate that the number of roots per unit area is greatest in the H layer and that the number in the mineral soil horizons decreases with increasing depth below the surface. Thus, the average number per square foot in the A horizons is 322 ± 23, in the B, 107 ± 12 and in the C, 11 ± 2. The same situation is found to exist if the A_1, A_2, B_1, B_2, and C_1 horizons are compared. In these layers the average number of roots per square foot is 314 ± 40, 162 ± 37, 163 ± 21, 84 ± 17, and 2S ± 8, respectively. It is worthy of note that the number of roots per unit area in the B_1 is practically the same as in the A_2. This is an interesting situation since one might expect a decrease of roots in the B_1 as compared with the A_2 because of the depth factor. It may be suggested that conditions for root development in the B_1 are sufficiently favorable to compensate for the increased depth at which the horizon occurs. Statistical comparison of the average number of roots per square foot in the F and H, the A_1 and A_2, the A and B, the A and C, the B and C, the B_1 and B_2, and in the B_2 and C_1 horizons revealed significant differences in all cases. In the A_2 and B_1 horizons the average number of roots per square foot was not significantly different.

It seems clear from the above comparisons that there are important differences with respect to the number of roots found in the various soil horizons. Thus the profile horizons have an ecological as well as pedological significance.

Mechanical composition:

The mechanical composition of a soil is an index to many of its physical properties. In view of the fact that the physical characteristics ate always important from the standpoint of plant development, and frequently may be limiting, it seemed desirable to make mechanical analyses of the samples. Data concerning the mechanical composition of the soil horizons in each profile are presented in Table III.

In horizons of very coarse textured material (containing 90 per cent or more sand) conditions appear unfavorable for root development. Veatch and Partridge (1933) working with fruit trees, observed that "On the deep, dry, easily penetrable sands in which there is a dry C horizon and only a faint development of a clayey B horizon, there is a notable development of long lateral roots and a mass of fine roots in the surface (A) horizon but with relatively few in the lower horizon . . . ." The roots of white pine seem to behave in a similar way. The horizons in profile 8 are very coarse textured and the roots are largely confined to the upper 14 inches of the soil body. In profile 11 the roots are equally shallow; underlying the A and B horizons is the C_1 layer 3½ to 4½ feet in thickness. This horizon contains only 1.5 per cent of silt and supports very few roots.

A total of 96 soil horizons or strata were examined in the course of the investigation. In 29 the content of silt and clay was less than 10 per cent and in all other horizons more than 10 per cent. Of the 29 horizons containing low amounts of fine material 26 supported few if any roots; in the three remaining horizons root development was fair to good. The three exceptions are the B_1 of profile 8, and the B-1 material in profile 13, and the B horizon in profile 20. In the latter a high water table may to some extent compensate for the coarse texture of the soil material.

The unfavorable influence of extremely coarse textured material on root development is seen repeatedly. For example, in profile 4 the B horizon contains 17.5 per cent of silt and clay and supports numerous roots; the C_1 layer with very few roots contains only 3.5 per cent silt and clay. In profile 11 most of the roots are confined to the upper 12 to 14 inches of the soil body. The B horizon, which shows good root development contains 17.0 per cent silt and clay, whereas the C_1 with only occasional roots contains 1.5 per cent. In profile 18, the B_2 contains 15.1 per cent silt and clay and the adjacent C_1 contains 5.0 per cent; roots are abundant in the B_2 but practically absent from the C_1. Numerous similar examples might be cited but these should be sufficient to illustrate the point.

The fact that soil texture plays an important rôle in determining root distribution in the soil profile is supported by other evidence. In the coarse textured C horizon of a number of profiles occur strata of relatively fine textured material. Very commonly roots are concentrated in these strata but are absent in the adjacent coarse material. This situation is best illustrated in profiles 4, 9, and 18. The stratum of fine sand with roots in the C_3 layer of profile 4 contains 21.0 per cent silt whereas the adjacent material lacking roots contains only 1.0 per cent. In profile 9 the fine sand stratum with roots contains 20.5 per cent silt and clay but the adjacent material lacking roots contains none. In profile 18, even at a depth of 4 to 5 feet below the surface roots are abundant in fine textured soil although absent in the coarser textured material. Bornebusch (1931) stated that spruce, ordinarily regarded as shallow rooted, develops some deeply penetrating roots and in coarse textured subsoils these seek out the finer textured layers where moisture and nutrient relations are more favorable.

From time to time local concentrations of roots were observed in horizons of generally poor root development. The influence of texture was further investigated in 13 paired samples obtained from situations of this nature. The mean "total colloid" content of the samples of soil containing roots was 7.0 $\pm$ 1.4 per cent and the value for the corresponding samples of soil lacking roots was 3.2 $\pm$ 1.0 per cent. The difference is statistically significant.

It should not be assumed that conditions for root development are favorable in all fine textured horizons or strata. Features such as compactness of the soil material and position of the water table have an important bearing on the possibility of root development. Roots are practically lacking in the C_2 horizon of profile 3. This layer contains 26.0 per cent of silt and clay but is so extremely compact as to prevent or greatly inhibit root penetration. An excellent example of the unfavorable conditions presented by compact material is illustrated in the C_2 of profile 10. This layer contains 21.0 per cent silt and clay. Essentially the same relations obtain in the C_3 layer of profile 11, the C_2 of profile 12, the C_2 of profile 16, and the C_1 and C_2 of profile 17. In all these cases the very compact nature of the soil material presents a serious obstacle to root development.

From the standpoint of texture alone conditions for root development appear most favorable in loamy sands, sandy loams, and loams. The best root distribution observed in the course of this investigation was in profile 7, which varies in texture from a sandy loam in the A and B to a loam in the C_1 and C_2 horizons. As indicated in Figure 6 roots are abundant to a depth of 4 feet below the surface. In the profiles examined the content of fine material was usually greatest in the A and B horizons. This condition explains in part the concentration of roots in the upper soil layers.

Aloisture equivalent:

In sandy soils such as those under consideration, the water relations are of considerable ecological importance. Consequently moisture equivalent values are of interest because they furnish an indication of the capacity of a soil to hold water. Moisture equivalent data for the horizons in each profile appear in Table III. As might be expected the moisture equivalent generally decreases with increasing depth belo,v the ground surface. This situation results from the higher content of organic and inorganic colloidal material in the A and B horizons than in the C.

Of the 96 soil horizons or strata investigated only 29 had moisture equivalent values of 4.0 per cent, or less. In 26 of the 29 horizons, root development was either poor or lacking. The three exceptions are the C_1 of profile 12, the B-1 of profile 13 and the B of profile 20; in these the moisture equivalent ranged from 2.2 to 3.4 per cent. Thus it appears that a low moisture equivalent generally indicates conditions unfavorable for root development.

It does not follow, however, that root development was good in all horizons, with a moisture equivalent above 4.0 per cent. As was pointed out in the discussion of mechanical composition, features such as extreme compactness of material and relatively high position of the water table may inhibit root development in layers otherwise favorable. The C_2 horizon in profile 3, the C_g horizon in profile 11, and the C_2 horizon in profiles 16 and 17 all have moisture equivalents above 4.0 per cent but lack roots because of extreme compactness. It should constantly be kept in mind that development of roots in any particular horizon is dependent upon a oomplex of factors and that unfavorableness with respect to one may nullify or at least mitigate the effect of favorable conditions. Goff (1887: 167) recognized this situation when he wrote, "In that stratum of the soil in which the balance . . . of conditions is on the whole most favorable to root growth, the roots develop fastest, and this is doubtless one law that governs their distribution."

In a number of profiles the boundary between material which supported roots and material which lacked roots was very sharp. Thirteen paired samples were obtained and moisture equivalents determined. The mean value for the soils containing roots was 8.24 $\pm$ 0.98 per cent and for those lacking roots 3.10 $\pm$ 0.59 per cent. The difference indicated is statistically significant. In every case the moisture equivalent of the soil supporting roots was higher than that of the soil lacking roots. Providing other features such as extreme compactness are not limiting, root development in the lower horizons appears to increase as the moisture equivalent increases. This statement refers to the sandy soils under consideration and may not apply to heavier textured profiles.

Total nitrogen:

Several investigators have pointed out the favorable influence of nitrogen on root development. The consensus of opinion appears to be that roots develop more branches in media containing fairly large amounts of nitrogen than in media containing lower amounts. Data relating to the total nitrogen content of the soils investigated are presented in Table IV.

Nitrogen content in the A, B, and C horizons generally decreases rather rapidly with increasing depth below the soil surface and at the same time the number of roots decreases. In 13 cases it was possible to obtain paired samples of soil containing roots and closely adjacent soil lacking roots. In all these instances the samples supporting roots contained more nitrogen than samples lacking roots. The mean total nitrogen content of the samples containing roots was 0.18 $\pm$ 0.005 per cent whereas in the soil lacking roots it was 0.006 $\pm$ 0.001 per cent. The difference is statistically significant.

The higher content of riitrogen in soil material supporting roots is to a large extent an effect of the presence of dead roots and their decomposition produets but at the same time also maybe regarded as favoring the presence of living roots. In soil material of uniformly low nitrogen content but of variable texture one would expect a concentration of roots at points where moisture relations were most favorable. In the course of time as these roots died they would contribute organic matter to the soil, thus further increasing the favorableness of the medium for root development.

Base exchange properties:

Base exchange relations in soil are receiving increasing attention from soil scientists and plant ecologists. In the present investigation it seemed desirable to examine certain of the phenomena with a view of ascertaining their relation to root distribution in soil profiles. Data relating to base exchange features are presented in Table V.

Total exchange capacity, exchangeable hydrogen and exchangeable bases are, as a rule, highest in the organic layers and decrease rather sharply with increasing depth in the mineral horizons. It was possible to obtain paired samples of soH containing roots and closely adjacent soil lacking roots; in most cases the soil material supporting roots showed a higher content of exchangeable bases than the adjacent material lacking roots. The mean total exchange capacity of soil supporting roots, was 3.35 $\pm$ 0.43 m.e.,* whereas the value for soil lacking roots was 1.71 $\pm$ 0.29 m.e. The difference between these values is statistically significant. With respect to exchangeable hydrogen the values were 1.95 $\pm$ 0.40 m.e. and 1.02 $\pm$ 0.22 m.e., respectively. This difference is ndt significant. The mean content of exchangeable bases in soil supporting roots was 1.39 $\pm$ 0.25 m.e. and in soil lacking roots 0.67 $\pm$ 0.26 m.e. These values are not significantly different.

* Milligram equivalents per 100 grams of soil.

In the profiles investigated it appears that roots develop more abundantly in soil material having a relatively high base exchange capacity than in material having a lower capacity. The results relating to exchangeable hydrogen and exchangeable bases are not conclusive.

Hydrogen ion concentration:

The hydrogen ion concentration of the soil is generally regarded as an ecological factor which merits consideration. In the present investigation this feature was examined in the hope that a better understanding of root development would result. The data are presented in Table VI.

Hydrogen ion concentration varied from pH 3.8 to 6.4. In the organic layers the pH ranged from 3.8 to 5.0 whereas in the mineral soil horizons it varied from 4.5 to 6.4. Examination of the data has led to the conclusion that root distribution in these profiles is not appreciably influenced by the relatively small variation in hydrogen ion concentration.

SOIL PROFILE DESCRIPTIONS AND COMMENTS

In most of the area covered the bedrock was a fairly coarse grained biotite granite. All of the tract and the surrounding region was glaciated. The soils developed from deposits of glacial till, glaciofluvial materials, and stratified materials laid down in temporary lakes. In general the soils developed on glacial till contain higher proportions of the fine fractions than those developed on assorted materials. Internal drainage of soils derived from assorted materials is, in general, good to excessive but may be slow in those derived from glacial till because of compact subsoil.

Marbut (1935) included all of southern New Hampshire in his region of gray-brown podzolic soils. In the Yale Forest in general, and the areas under consideration in particular, the soils are predominantly of this group. It is doubtful whether brown soils, in the sense of Ramann, occur in this forest; well developed podzols are of uncommon occurrence at present and seem confined to moist or wet situations. Although the evidence at hand is not perfect there is reason to believe that prior to removal of the virgin timber some of the well drained light sandy soils in the forest were podzols.

The soil series most commonly encountered in the investigation here reported were the Gloucester, Hinsdale, and Merrimac. Following are descriptions of the various stations and the soil profiles. In each case comments on the principal features of root distribution are appended.

Station 3:

This station is located in the Buckminster lot on nearly level ground having moderately good drainage. The parent soil material is glacial till. Forest cover consists of a pure stand of white pine which is approximately even aged at 45 years and has a crown density of about .6. There are 249 trees per acre and the average d.b.h.* is 9.7 inches. The evidence strongly indicates that this area was once cleared of forest growth and used for agricultural production. It seems probable, but is by no means certain, that the present stand represents the first the land has supported since it was abandoned for agricultural use.

The horizon features and root distribution are illustrated in Figure 4. Following is a description of the soil profile:

L horizon. Thickness, ¼ to ½ inch; composed almost entirely of white pine debris.

F horizon. Thickness, ½ to ¾ inch; a slight tendency toward matting is evident. White fungal mycelia are occasionally noted. The humus layer type is classified as a granular mor.

A_1 horizon. Thickness, 1½ to 3 inches, average 2; texture-sandy loam; color—dark brown, mottled with light brown; structure-laminated in the upper inch, in lower part granular; consistency-in upper part firm, in lower part friable. No earthworms were noted.

A_2 horizon. Thickness, 3 to 6½ inches, average 5; texture-sandy loam; color-brown, mottled with dark brown and occasional spots of gray (podzol); structure-granular; consistency-friable. Much charcoal noted; it appeared clear that this soil was at one time a podzol and had been cultivated. Tamm (1920: 296) has noted that in Norrland typical forest podzols have been cultivated for agricultural production. In these one may find streaks or lumps of leached material *(Bleicherde)* or B material *(Orterde)* indicating their former condition.

B_1 horizon. Thickness, 5.5 to 12 inches, average 9; texture-sandy loam; color-dark rusty brown; structure-granular; consistency-friable. Occasional fragments of charcoal were noted; horizon is poorly demarcated. Near the center of the transect is a glacial boulder having a height of about 14 inches and a breadth of about 26. It is of interest to note that the B_1 horizon dips downward in the vicinity of this rock. This same feature in more pronounced form may be seen in profile 19, illustrated in Figure 18.

B_2 horizon. Thickness, 4 to 9 inches, average 6; texture-sandy loam;

* Diameter at breast height, 4.5 feet above ground.

color-light rusty brown; structure-granular; consistency-friable. Some charcoal noted; horizon is poorly demarcated from B_1; rocks present.

C_1 horizon. Thickness, 4 to 10 inches, average 6; texture-sandy loam; color-light brownish gray, mottled with brown; structure-tendency toward granular; consistency-friable. This horizon is fairly well demarcated; rocks present.

C_2 horizon. Thickness to a depth of 5 feet below surface-average 30 inches; texture-sandy loam; color-gray with occasional streaks of rust brown; structure-massive; consistency-firm to hard. Occasional horizontal rusty streaks are evident; rocks are present. Excavation in this horizon was accomplished with great difficulty because of its extremely compact nature.

The average number of roots per square foot of rock-free area in each horizon was as follows: F-54, A_1-198, A_2-107, B_1—57, B_2–38, C_1-12, and C_2–6. The decrease in number of roots per square foot with increasing depth below the surface is fairly uniform. One per cent of the total number of roots encountered occur in the F horizon, 54 per cent in the A, 30 per cent in the B and 15 per cent in the C. Most of the roots charted were less than 0.05 inch in diameter. The occurrence of roots larger than 0.05 inch in the various horizons is indicated in Table I and will not be repeated here. It may be said, however, that the relative distribution of the larger roots in general parallels that of the smaller ones.

Noteworthy features other than the concentration of roots in the A and B horizons are the influence of the large rock on profile development and the very few roots in the C horizons. In profile 19, Figure 18, is an even more striking example of the influence of rocks on horizon development.

In the profile description it was noted that the C_2 horizon was gray in color and mottled, suggesting slow drainage. It was also pointed out that this horizon was extremely compact. These two features, poor drainage and a high degree of compactness would appear sufficient to explain the scarcity of roots. At other stations, notably in profile 1a, a similar absence of roots was noted in gray subsoil layers. This same feature has been mentioned by Sweet (1933) who investigated root distribution in apple orchards. In the profile under consideration no roots were observed below a depth of 3 feet, 4 inches. The few roots noted in the upper part of the C_2 horizon were for the most part localized in the occasional rusty streaks.

The mechanical analysis data and information on moisture equivalent values presented in Table III Indicate a rather gradual decrease in content of finer fractions with increasing depth until the C_2 horizon is reached.

As would be expected the total nitrogen content of the soil horizons decreases with increasing depth; these data appear in Table IV. In the case of nitrogen values and root distribution data such as those at hand it is difficult to determine whether one is dealing with a cause or an effect relationship. It is interesting to note the results obtained with two sets of paired samples taken in the C_2 horizon from the rusty streaks where roots were present and from the immediately adjacent soil lacking roots. The nitrogen content of the samples containing roots was 0.014 and 0.029 per cent, whereas the values for the samples lacking roots were 0.012 and 0.015 per cent.

Soil acidity, expressed in terms of pH, varies only slightly in the various horizons and is not regarded as an important factor influencing root distribution. The data are presented in Table VI.

Station 4:

This station is located in the Capron lot on a bench about 80 feet above, and one-quarter mile from, the Ashuelot River. Drainage is good to excessive. The soil body developed from strongly stratified glaciofluvial material. Forest cover consists of a pure stand of white pine which is approximately even aged at 34 years; crown density is about .7. There are 400 trees per acre and the average d.b.h. is 7 inches. This area was for a time in agricultural use.

The horizons and root distribution are illustrated in Figure 5. The profile is described as follows:

L horizon. Thickness, ½ to 1 inch; composed almost entirely of white pine debris.

F horizon. Thickness, ¼ to 1 inch; somewhat matted and in places interwoven with bright yellow fungal mycelia.

H horizon. Very thin to absent; color-black; in part crumb-like but occasionally matted and permeated with yellow fungal mycelia. The humus layer type at this station is classified as a form of granular mar.

A horizon. Thickness, 3 to 8 inches, average 5½; texture-loamy coarse sand; color—dark brownish gray, mottled with black and gray (podzol); structure-single grain, tending toward laminated in upper part; consistency-friable to loose. Obviously a cultivated soil. There is a considerable development of white fungal mycelia in this horizon; charcoal abundant; no earthworms observed.

B horizon. Thickness, 7 to 19 inches, average 13; texture-loamy coarse sand; color-dark brown; structure-tendency toward granular; consistency-loose to friable.

C_1 horizon. Thickness, 5 to 24 inches, average 16; texture-gravelly coarse sand; color-light yellowish gray; structure-single grain; consistency-loose.

C_2 horizon. Thickness, 14 to 22 inches, average 18; texture-gravelly coarse sand; color-gray; structure-single grain; consistency—loose.

C_3 horizon. Thickness to a depth of 7 feet below the ground surface-average 30 inches (thickness of fine sand layer-8 inches) ; texture-gravelly coarse sand (texture of fine sand layer—loamy fine sand) ; color—gray (in fine sand layer the lower part is rust colored) ; structure-single grained; consistency-loose (in fine sand layer-friable to firm).

The average number of roots per square foot of rock-free area in each horizon is as follows: F-117, A-175, B-38, C_1-2, C_2-1, and C_3-none (fine sand stratum-15). Three per cent of the total number of roots encountered occur in the F horizon, 59 per cent in the A, 28 per cent in the B, and 10 per cent in the C. The number of roots larger than 0.05 inch diameter was relatively small but their distribution with respect to horizons was similar to that of the roots $<$0.05 inch.

The concentration of roots in the A and B horizons is particularly noticeable. This is all the more striking in view of the fact that in general these two horizons occupy only the upper 18 inches of the soil body. In the horizon designated as C_3, which is a gray, coarse sand, occurs a stratum of loamy fine sand about 8 inches in thickness. Along the lower boundary of this layer of fine sand are numerous roots. Quite clearly this is a case where subsoil character has influenced root development.

The data on mechanical analyses (Table III) indicate a sharp decrease in content of finer fractions with increasing depth. A noticeable exception is found in the loamy fine sand stratum in the C_3 horizon. The coarse material in the C_3 contains only 1 per cent of silt and 1 per cent "total colloids"; in the loamy fine sand stratum there is 21 per cent silt and 3.5 per cent "total colloids." The moisture equivalent values indicate a similar trend. In the loamy fine sand stratum the moisture equivalent is 5.3 per cent and in the coarse C_3 material 1.8 per cent. It may be suggested that the localization of roots in the loamy fine sand layer results from more favorable moisture relations; of course other factors also may be influential. Concentration of the roots along the lower boundary of the layer is noteworthy; this same condition was noted in profile 18.

The content of nitrogen in the different horizons is indicated in Table

IV. In general the position is taken that the nitrogen content of the soil is the result of the presence of roots rather than the primary cause of their presence. However, it is difficult to dra\v sharp lines with reference to this relationship. Base exchange relations were investigated in samples of the coarse C_g material lacking roots and the loamy fine sand stratum containing roots. In the coarse material lacking roots the total exchange capacity was 1.50 m.e., in the fine material supporting roots, 4.40 m.e. With respect to exchangeable hydrogen the values were 0.43 and 2.00 m.e., respectively. The data appear in Table V. The hydrogen ion concentration in each horizon is indicated in Table VI. Soil acidity is not here regarded as an important factor in determining root distribution.

Station 7:

Located in the Capron lot about 300 feet from the Ashuelot River on a small terrace which is approximately 10 feet above the average river level during the summer. Drainage is slow and at times each year the entire soil body may be under the influence of water. In August, 1934, the water table was encountered at a depth of 5 feet 4 inches below the ground surface. In spite of the slow drainage and relatively high water table, moisture relations are regarded as excellent. The soil body has developed from post-glacial alluvium.

Forest cover consists of an excellent pure stand of white pine which is approximately even aged at 35 years. Crown density is about .9. There are 1158 trees per acre and the average d.b.h. is 5.3 inches. The evidence at hand indicates that formerly this area was in agricultural use.

Horizon features and root distribution are illustrated in Figure 6. Following is a description of the profile:

L horizon. Thickness, ½ to ¾ inch; composed almost wholly of white pine debris.

F horizon. Thickness, ¾ to 1¼ inches; in general loose but somewhat matted in spots and permeated by grayish fungal mycelia.

A_1 horizon. Thickness, I to 2 inches, average 1½; texture-fine sandy loam; color-dark brown; slightly mottled with light brown and black; structure-crumb; consistency—friable. Considerable charcoal is present. The humus layer type is classified as a coarse mull which is deteriorating. In spots the surface soil is compact and has a laminated structure. White fungal mycelia are abundant. Earthworms* such as *Allolobophora caligi-*

* Lumbricidae were identified by Dr. Grace E. Pickford, Research Assistant in the Bingham Oceanographic Laboratory in Yale University.

nosus (Savigny) f. *typicus, A. caliginosus* (Sav.) f. *typicus* trans. ad *trapezoides, A. caliginosus* f. *trapezoides* (Dugès), and *Dendrobaena octaedrus* (Savigny) are in places common but evidence points to a larger population in the recent past. In the extreme upper part of this horizon is a suggestion of incipient podzol development.

A_2 horizon. Thickness, 4 to 8 inches, average 6; texture—fine sandy loam; color—light yellowish brown, some mottling; structure—granular; consistency—friable to firm. Very occasional earthworms.

B_1 horizon. Thickness, 8 to 14 inches, average 10½; texture—fine sandy loam; color—brown, slightly mottled; structure—granular; consistency—firm. This horizon is poorly demarcated.

B_2 horizon. Thickness, 9 to 14 inches, average 12; texture—fine sandy loam; color—light yellowish brown; structure—granular; consistency—firm. Occasional bits of charcoal were noted; the horizon is poorly demarcated below.

C_1 horizon. Thickness, 10 to 15 inches, average 12; texture—loam; color—very light brown, some mottling; structure—granular; consistency—firm.

C_2 horizon. Thickness, 7 to 15 inches, average 11; texture—loam; color—olive brown; structure—granular; consistency—firm. Old root canals ½ inch in diameter were noted in this horizon.

C_3 horizon. Thickness to a depth of 6 feet below the ground surface, average 18 inches; texture—coarse sand; color—rusty brown; structure—single grain; consistency—loose but with some tendency toward cementation in narrow streaks. This horizon is frequently under the influence of the ground water.

The average number of roots per square foot of rock-free area in each horizon is as follows: F—215, A_1—328, A_2—151, B_1—80, B_2—47, C_1—17, C_2—10, C_3—none. One of the most remarkable features of this transect is the very gradual reduction in number of roots per square foot with increasing depth. Roots occur in quantity to a depth of about 4 feet; below 5 feet (in the C_3 horizon) practically none were found. Five per cent of the total number of roots encountered occur in the F horizon, 43 per cent in the A, 42 per cent in the B, and 10 per cent in the C.

Mechanical analysis of samples from the various horizons indicates that the content of fine material remains fairly uniform with increasing depth to the C_3 layer which is coarse sand. The excellent root distribution in this profile appears to reflect the uniformity of soil texture. The moisture equivalent (Table III) varies considerably, being highest in the C_2 (26.7 per cent) and A_1 (19.8 per cent) horizons. In the other horizons (excepting the

C_3) the moisture equivalent values do not fall below 10 per cent. Thus, a soil body of high moisture holding capacity is indicated. Absence of roots in the coarse sandy C_3 horizon is probably the result of water-logging during considerable periods of each year.

Nitrogen content of the horizons is indicated in Table IV. One may note a parallel between the gradual decrease in number of roots and the gradual decrease in content of nitrogen. Hydrogen ion concentration values may be found in Table VI. There does not seem to be any apparent relation between root distribution and acidity of the horizons in this profile.

Station 8:

Located in the Capron lot on a nearly flat alluvial plain. Drainage is good to excessive. The soil profile developed on a coarse sandy, to gravelly, glaciofluvial deposit of considerable depth. The forest cover consists of a pure stand of slowly growing white pine having an age of 35 years; crown density is about .7. There are 1250 trees per acre and the average d.b.h. is 4.6 inches. It is clear that this area was formerly in agricultural use. The present stand appears to be the first generation since the land was abandoned.

The horizon features and root distribution are illustrated in Figure 7. Following is a description of the profile:

L horizon. Thickness, ¼ to ½ inch; entirely white pine debris.

F horizon. Thickness, ½ to ¾ inch; felty, permeated with bright yellow fungal mycelia.

H horizon. Thickness, ¼ to ½ inch; very felty, reddish brown, permeated with bright yellow fungal mycelia. This humus layer type is classified as a fiberous mor.

A horizon. Thickness, 2 to 5 inches, average 4; texture—loamy coarse sand; color—blackish gray, mottled with irregular areas of gray (podzol) and rusty brown (B_1); structure—granular; consistency—friable. This soil obviously has been cultivated. At one point was noted a lense-like mass of gray A_2 material which evidently represents a relict podzol horizon. At present in the upper ¼ to ½ inch is clear evidence of incipient podzol formation—the color is gray and the white sand grains stand out prominently. No earthworms or other macroscopic soil fauna were observed.

B_1 horizon. Thickness, 5 to 10 inches, average 8; texture—coarse sand; color—dark rusty brown; structure—single grain; consistency—loose.

B_2 horizon. Thickness, 8 to 15 inches, average 11; texture—gravelly coarse sand; color-rusty brown; structure-single grain; consistency-loose. Well demarcated from the C_1 horizon.

C_1 horizon. Thickness, 12 to 23 inches, average 18; texture-gravelly coarse sand; color-light brownish gray; structure-single grain; consistency-loose.

C_2 horizon. Thickness to a depth of 7 feet below the ground surface, average 40 inches; texture-eoarse sand; color-very light brownish gray; structure—single grain; consistency-loose. In this horizon are noted horizontal orange colored streaks about ¼ inch in thickness and 3 to 6 inches apart.

The average number of roots per square foot of rock-free area in each horizon is as follows: H-522, A-421, B1-151, B_2-16, C_1-2, and C_2-3. Nine per cent of the total number of roots encountered occur in the H horizon, 46 per cent in the A, 39 per cent in the B, and 6 per cent in the C. In this profile most of the roots are concentrated in the A and B_1 horizons which occupy the upper 14 inches of the soil body. A few roots occur in the lower horizons but they tend to be localized in areas of rusty brown soiL

Examination of the mechanical analysis and moisture equivalent data (Table III) at once suggests an explanation of the shallow rooting in this soil. The content of "total colloids" in the A and B_1 horizons is 8.0 and 3.5 per cent, respectively. In the layers below the values are so small as to be scarcely measurable. The moisture equivalent data indicate values of 14.1 per cent in the A, 13.4 in the B_1, 1.9 in the B_2, 0.9 in the C_1, and 0.8 in the C_2. This is a situation in which the B_2 and lower horizons have a practically negligible capacity for supplying moisture to the trees during periods of drought; the effective soil depth is represented by the A and B_1 horizons. Bornebusch (1931) described a similar situation in the heath plains of Jutland. He figured a profile in which fairly fine textured sand overlay coarse sand; the roots of spruce developed only in the fine textured surface material. Both the C_1 and C_2 horizons are grayish in color and show some mottling. As was mentioned earlier, root development has usually been found poor or lacking in gray subsoil. In this case, however, it is difficult to believe that poor aeration is responsible. The gray color is partly explained by the fact that the soil body is young and that weathering processes have not proceeded very far as yet.

Total nitrogen values appear in Table IV. As noted in other profiles there seems to be a parallel between root development and content of nitrogen in the various horizons. Base exchange relations in the horizons were determined and the values are presented in Table V. It is evident that in this case the horizons having the highest total exchange capacity also have the largest number of roots. Hydrogen ion concentration data may be found in Table VI. They bear no apparent relationship to root distribution.

Station 9:

This station is located about 30 feet from station 4. Forest conditions at the two stations are similar with the exception that the number of trees per acre at station 9 is 460 as compared with 400 at station 4.

A detailed description of the profile at station 9 is not presented since it is essentially the same as the profile at station 4. However, it should be noted that in profile 9 the B and C_1 horizons are not as thick as in profile 4. On the other hand, the C_2 horizon in profile 9 is much thicker than in profile 4 and is very gravelly in the lower part; in fact, it seemed desirable to indicate this textural change by a broken line in Figure 8. In the C_3 horizon is a stratum of loamy fine sand somewhat thinner but otherwise similar to that described in profile 4.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-247, A-309, B—126, C_1-20, C_2 sand-2, C_2 gravel-12, and C_3-none (loamy fine sand-92). The number of roots is considerably greater than in profile 4 and may be partly explained by the somewhat greater density of the stand. Just as in profile 4 most of the roots are localized in the surface 18 inches. A considerable development of roots is noted in the gravelly lower part of the C_2 horizon and in the loamy fine sand layer in the C_3. Four per cent of the total number of roots encountered occur in the F horizon, 51 per cent in the A, 23 per cent in the B and 22 per cent in the C. Although roots larger than 0.05 inch in diameter were fewer in number than those of smaller size their distribution in the various horizons was similar.

Mechanical analysis data (Table III) indicates a pronounced textural change in going from the A and B horizons to the C_1. The gravelly lower part of the C_2 contains a slightly higher proportion of the fine material than does the sandy upper part. However, this slight difference in texture does not appear adequate to explain the better development of roots in the gravel. The loamy fine sand stratum in the C_a contains a much larger content of fine fractions than does the material immediately above and below; here the difference in texture appears to be the explanation for the localization of roots. The considerable development of roots in the loamy fine sand stratum is of particular interest when it is recalled that this layer is located at a depth of 6 feet below the ground surface and that most of the roots are in the surface 18 inches.

From the standpoint of the moisture equivalent data (Table III) the A and B horizons having values of 15.4 and 11.9 per cent are most favorable for root development. The sandy material in the C_a, which is practically lacking in roots, has a moisture equivalent of 1.4 per cent but the loamy fine sand stratum in this horizon has a value of 7.6 per cent. Moisture relations in the fine sand stratum must be relatively favorable and are believed to explain the concentration of roots. The percentage of total nitrogen in the various horizons is indicated in Table IV. As in other profiles the horizons containing roots have higher percentages of nitrogen than those lacking roots. The hydrogen ion concentration in the different horizons is indicated in Table VI. It does not appear possible to explain root distribution in this profile on the basis of soil acidity.

Station 10:

Located in the Worcester lot on a gentle north facing slope, about 100 feet below the crest of a ridge. Drainage conditions are good. The soil profile has developed from glacial till containing considerable rock. The forest cover is a pure stand of white pine 30 years old having a crown density of .7 to .8. There are 1110 trees per acre and the average d.b.h. is 5 inches. It is believed that this area was formerly in agricultural use.

Horizon features and root distribution are illustrated in Figure 9. Following is a description of the profile:

L horizon. Thickness, ¼ to ½ inch; nearly pure white pine debris.

F horizon. Thickness, ¼ to ¾ inch; slightly matted and interwoven with whitish fungal mycelia. ,

H horizon. Thickness, ⅛ to ¼ inch; fine crumb structure; lying on and scarcely intermixed with the mineral soil. Classified as a granular mor which is tending toward a mull type. Rodent tunnels are noted under the organic debris.

A horizon. Thickness, 3 to 6 inches, average 4½; texture-sandy loam; color-light yellowish brown, mottled with gray and dark brown; structure—crumb to fine granular; consistency-friable. This horizon is clearly demarcated. In the upper part were noted numerous specimens of *Dendrobaena octaedrus* (Savigny). In places the upper two inches of the A horizon show a laminated structure which is thought to be a condition persisting from the time when the area was in agricultural use. The mottling earlier referred to evidently resulted from cultivation which mixed surface organic debris and A and B material. Charcoal fragments are frequently noted. There is a considerable development of whitish fungal mycelia in this horizon.

B horizon. Thickness, 7 to 12 inches, average 10; texture-loam; color-rusty brown; structure-granular; consistency-firm to friable.

C_1 horizon. Thickness, 3 to 14 inches, average 9; texture-gravelly loamy sand; color-light brownish yellow; structure-single grain; consistency-friable to loose. An irregular tongue of this horizon penetrates deeply into the C_2, attaining a maximum depth of about 5½ feet below the surface.

C_2 horizon. Thickness to a depth of 6 feet below the surface, average about 42 inches; texture-gravelly sandy loam; color-light gray to grayish white; structure-cloddy; consistency-firm to hard. The very light color and compact nature of this horizon are outstanding features. Large boulders 1 to 3 feet in diameter are encountered.

The average number of roots per square foot of rock-free area in each horizon is as follows: H-190, A-276, B-100, C_1-33, and C_2—1. Three per cent of the total number of roots encountered occur in the H horizon, 44 per cent in the A, 37 per cent in the B, and 16 per cent in the C. The roots are concentrated in the upper 2 feet of the soil body in the A, B, and C_1 horizons. An outstanding feature of the profile is the irregular extension of the C_1 horizon deep into the C_2. In this extension of the C_1 scattered roots occur whereas in the adjacent C_2 material they are absent.

The mechanical analysis and moisture equivalent data (Table III) suggest an explanation of the root distribution. The content of fine material in the A and B horizons is considerably higher than in the C horizons. There is a particularly sharp break in the moisture equivalent values going from the A horizon with a value of 19.0 per cent and the B with 12.6 to the C_1 with a value of 5.6. Samples were obtained at a depth of about 4 feet from the extension of the C_1 horizon containing roots and the adjacent C_2 material without roots. As may be noted in Table III the C_1 material has slightly more fine material than the C_2. Too much importance should not be placed on such small differences but at least they are consistent with what might be expected. The absence of roots in the light gray C_2 layer is in harmony with the findings at other stations. The material in this horizon has the appearance of fresh rock flour; it is very compact and must represent a considerable obstacle to free root development.

The total nitrogen content of the various horizons is indicated in Table IV. Samples taken from the extension of the C_1 with roots and the adjacent C_2 without roots showed nitrogen values of 0.017 and 0.005 per cent, respectively. Base exchange relations were investigated and the results presented in Table V. Relatively high values are indicated for total exchange capacity and for exchangeable hydrogen in the A and B horizons but much lower values are recorded for the C_1 and C_2. Samples from the C_1 extension containing roots had a total exchange capacity of 1.55 m.e., whereas the value for the adjacent C_2 material without roots was 0.40 m.e. The hydrogen ion concentration data are presented in Table VI.

Station 11:

Located on a gentle slope in the Whitcomb lot; drainage conditions are good. The profile developed on glaciofluvial material derived from acidic rocks. The forest stand consists of pure white pine 35 years old; crown density is .7-.8. There are 342 trees per acre and the average d.b.h. is 9.3 inches. Evidently this is the first stand after the land was abandoned for agricultural use.

The horizon features and root distribution are illustrated in Figure 10. Following is a description of the soil profile:

L horizon. Thickness, ¼ to ½ inch; composed almost wholly of white pine debris.

F horizon. Thickness, ¼ to ¾ inch; somewhat matted and interwoven with yellow fungal mycelia. In places there is a trace of an H layer. This humus layer type is regarded as a form of granular more

A horizon. Thickness, 3 to 5 inches, average 4; texture-loamy coarse sand; color-grayish brown; structure-granular; consistency-friable. This horizon is clearly demarcated. A slight mottling with both lighter and darker material is noted. Nearby was found a well defined podzol layer about 2 inches thick buried 5 inches below the ground surface. A tendency toward laminated structure in the surface 1 to 2 inches suggests that the soil had become compacted prior to development of the present forest stand. There is clear evidence of incipient podzol development in the surface soil; white sand grains stand out very clearly.

B horizon. Thickness, 4 to 15 inches, average 7; texture-gravelly loamy coarse sand; color-rusty brown; structure-granular; consistency—friable.

C_1 horizon. Thickness, 31 to 50 inches, average 4S; texture-gravelly coarse sand; color-light gray; structure-single grain; consistency-loose.

C_2 horizon. Thickness, 6 to 18 inches, average 10; texture-gravelly coarse sand; color-light gray; structure-single grain; consistency-loose.

C_g horizon. Thickness to a depth of 7 feet below the surface, average 17 inches; texture-sandy loam; color-gray; very compact.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-164, A-256, B-87, C_1-4, C_2-5, and C_g-

none. Five per cent of the total number of roots encountered occur in the F horizon, 49 per cent in the A, 34 per cent in the B, and 12 per cent in the C. The roots in this profile are concentrated in the A and B horizons which occupy the upper 12 to 14 inches of the soil body. A few roots occur in the C horizons but they are definitely localized.

The mechanical analysis data presented in Table III indicate a relatively high content of fine material in the A and B horizons and a sharp decrease in the C layers. Moisture equivalent data are particularly interesting and suggest the reason for the concentration of roots in the A and B horizons. Evidently the C horizons in this soil body contain relatively low amounts of colloidal matter and possess little capacity-to hold water. It may be recalled that the C_2 and C_a horizons are gray in color and in common with the situation found in other profiles support few roots. Total nitrogen content of the horizons is indicated in Table IV. Soil acidity values are indicated in Table VI.

Station 12:

Located in the Carey lot on nearly level ground having good drainage; a total depth of 8½ feet was attained but the water table was not encountered. The soil profile has developed on glaciofluvial material showing considerable stratification. Forest cover consists of a pure, nearly even-aged stand of white pine 40 years old. Crown density is estimated to be .9. There are 591 trees per acre and the average d.b.h. is about 7 inches. Evidently the present stand is the first to develop since the land was abandoned for agricultural use.

The horizon features and root distribution are illustrated in Figure 11. Following is a description of the profile:

L horizon. Thickness, ⅛ to ¾ inch, composed entirely of white pine debris.

F horizon. Thickness, ½ to ¾ inch, lying loosely on the mineral soil. Many rodent tunnels are in evidence. The humus layer type is regarded as transitional from coarse mull to granular mor.

A horizon. Thickness, 4 to 8 inches, average 5½; texture-loamy sand; color-dark grayish brown, mottled with rusty brown in lower part; structure-granular; consistency-soft to friable. This horizon shows clear evidence of cultivation since there are irregular inclusions of B material in the lower half. In the upper ½ to 1½ inches organic debris is well mixed with the mineral soil. There is considerable evidence that earthworm activity was greater in the recent past and that the population has decreased. Occasional specimens of the following species are now encountered: *Allolobophora caliginosus* (Savigny), *A. caliginosus* (Sav.) f. *typicus,* and *A. caliginosus* (Sav.) f. *typicus* trans. ad *trapezoides.* In places the structure is breaking down and whitish fungal mycelia are becoming prominent.

B horizon. Thickness 8 to 23 inches, average 14; texture-loamy coarse sand; color-light rusty brown; structure-tendency toward granular; consistency-friable. Occasional old root canals and rodent tunnels are found partially filled with organic debris. The lower boundary is not clear.

C_1 horizon. Average thickness of horizon as a whole, 32 inches; broken up by irregular bodies of material as indicated in Figure 11. The bodies designated as C_1-1 are fine sandy loam and those referred to as C_1-2 are coarse sand.

The C_1 material and the two variations are described separately.

C_1: texture-loamy medium sand; color-grayish yellow; structure-single grain; consistency-soft.

C_1-1: texture-fine sandy loam; color-dark gray, mottled with streaks or lenses of light gray; structure-granular; consistency-hard.

C_1-2: texture--coarse sand; color-light gray; structure-single grain; consistency-loose. Occasional lenses or lumps of finer, dark gray material are noted.

C_2 horizon. Average thickness, 14 inches; texture-coarse sandy loam; color-gray; structure-massive; consistency-hard. The stratum designated as C_{2x} is a very compact sandy clay of grayish color. Underlying the C_2 horizon is a layer of coarse sand designated as C_3.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-238, A-286, B-126, C_1-43 (C_1-1, 53; C_1-2, none), C_2-none (C_{2x}, 5), and C_3-none. Four per cent of the total number of roots encountered occur in the F horizon, 34 per cent in the A, 37 per cent in the B, and 25 per cent in the C.

Root distribution is excellent in the A and B horizons which occupy the upper two feet of the soil body. It may be noted that a rather sharp reduction in number of roots is encountered in going from the B into the C_1. In the latter horizon the absence of roots in the coarse sand (C_1-2) and their scattered occurrence in the loamy medium sand (C_1) and fine sandy loam (C_1-1) is noteworthy. Very few roots were found in the gray C_2 and C_3 horizons. These layers are compact and may offer considerable resistance to root penetration. In this profile, then, the roots tend to be concentrated in the upper two feet of the soil body with scattered occurrence to a depth of about 4 feet.

The mechanical analysis data (Table III) suggest an explanation for the absence of roots in the coarse sand (C_1-2) and their presence in the loamy medium sand (C_1) and fine sandy loam (C_1-1). The content of material.smaller than sand size in the C_1-2 is S.8 per cent, whereas in the C_1 it is 18.1 and in the C_1-1, 37.7 per cent. The moisture equivalent (Table III) of the coarse sand is 1.9 per cent whereas it is 8.5 in the fine sandy loam and 3.4 in the loamy medium sand. The C_2 horizon contains a considerably higher proportion of fine material than do any others and from the standpoint of moisture relations alone might be expected to favor root development. However, the depth at which this layer occurs together with its compactness seems sufficient to account for the absence of roots.

The total nitrogen content of the various horizons is ·presented in Table IV. It may be pointed out that the content of nitrogen in the body designated as C_1-2 which is lacking in roots is less than in the C_1 and C_1-1 where roots occur. Base exchange phenomena were investigated and the data are reported in Table V. In general there appears to be a relationship between the total exchange capacity of the soil horizons and root occurrence. However, just as in the case of the nitrogen yalues, it is not entirely clear whether the relationship is one of cause or effect. Soil acidity values are presented in Table VI. It is doubtful whether hydrogen ion concentration exerts any important influence on the root distribution in this profile.

Station 13:

Located in the Carey lot on nearly level ground having good drainage; a total depth of 7½ feet was attained but the water table was not reached. The soil body has developed on stratified glaciofluvial material; about 100 feet to the west is a low esker. Forest cover consists of a pure stand of white pine 41 years old; crown density is about .8. There are 497 trees per acre and the average d.b.h. is 7.3 inches. The area was formerly cultivated and the present stand is believed to be the first complete cover since the land was abandoned for agricultural use.

Horizon features and root distribution are illustrated in Figure 12. A description of the profile follows:

L horizon. Thickness, ¼ to ½ inch, nearly pure white pine debris.

F horizon. Thickness, ¼ to ¾ inch; somewhat matted in places and permeated with yellow fungal mycelia. The humus layer type is regarded as transitional from mull to granular more

A horizon. Thickness, 4 to 8 inches, average 6; texture-loamy sand;

color-light brown, mottled in the lower part with rusty brown; structure-fine granular; consistency-friable. Considerable charcoal is noted in this horizon; lower boundary sharp; evidently cultivated. The surface inch shows evidence of earthworm work and occasional specimens of *Allolobophora caliginosus* (Sav.) f. *trapezoides* (Ant. Duges) were noted. It appears that conditions formerly were more favorable than at present. Evidence of incipient podzol formation is seen. In spots yellow fungal mycelia are observed permeating the soil.

B horizon. Average thickness of horizon as a whole, 24 inches. This horizon is broken up by irregular bodies of material which appeared worthy of recognition as B-1, B-2, and B-3. This was done as may be seen in Figure 12.

B-1: texture-coarse sand; color-yellowish gray; structure-single grain; consistency-loose. Bits of charcoal and old root canals were noted.

B-2: texture-loamy coarse sand; color-rusty brown to light brown; structure-single grain; consistency-friable. Large pieces of charcoal were noted.

B-3: texture-loamy sand; color-eoffee brown, some mottling with light brown; structure-granular; consistency-friable. Charcoal is fairly abundant.

It is believed that the irregularities noted may have resulted from disturbance of the soil body by uprooting of windthrown trees.

C_1 horizon. Thickness, 12 to 27 inches, average 22; texture-gravelly coarse sand; color-light grayish brown; structure-single grain; consistency-firm. There are occasional rusty streaks in this horizon owing to oxidation of iron containing minerals (as biotite) which have been concentrated in thin streaks. Many boulders are encountered.

C_2 horizon. Thickness, 12 to 32 inches, average 24; texture-gravelly coarse sand; color-light grayish brown; consistency-firm.

C_a horizon. Average thickness to a depth of 6 feet below the ground surface, 10 inches; texture--eoarse sand. Very few rocks were noted.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-636, A-497, B-I-II5, B-2-135, B-3-17I, C_1-122, C_2-g, Ca-none. Five per cent of the total number of roots encountered occur in the F horizon, 40 per cent in the A, 42 per cent in the B, and 13 per cent in the C. The greatest concentration of roots is in the F and A horizons with gradual reduction in numbers down to the C_1 horizon. In the C_2 and C_a horizons there are practically no roots.

The mechanical analysis data presented in Table III indicate that the C_2 horizon contains less fine material than any of the other layers. This is reflected by the low moisture equivalent which indicates poor water holding capacity. It seems likely that this explains in part the lack of roots.

The total nitrogen content of the various horizons is indicated in Table IV. As in the transects earlier described one notes a broad relationship between nitrogen content of the various horizons and the number of roots. In the C_1 horizon which supports numerous roots the nitrogen content is 0.018 per cent whereas in the C_2 which is lacking in roots the value is 0.003 per cent.

In Table V are presented data relating to the base exchange phenomena in this profile. The most noteworthy features are the high total exchange capacity in the A and C_1 horizons. In the C_1 layer the content of exchangeable bases is relatively high with the result that the percentage base saturation is also high (55.25 per cent). To what extent the high base exchange status of the C_1 horizon influences root distribution can only be conjectured. Soil acidity values for this profile may be found in Table VI. Variations in the hydrogen ion concentration of the mineral soil horizons are too small to warrant one attaching importance to this factor.

Station 14:

Located in the Carey lot on nearly level ground in a very shallow basin-like depression. Drainage is slow; the water table stood at a point 4½ feet below the surface in the early part of July, 1934, but by the end of the month had dropped below a depth of 5 feet. The soil profile developed on stratified glaciofluvial material. The forest consists of a pure stand of white pine, even-aged at about 45 years; crown density was estimated at .8 to .9. There are 633 trees per acre and the average d.b.h. is 8 inches. Formerly the land was in cultivation and the present stand appears to be the first which has come in since abandonment.

The horizon features and root distribution are illustrated in Figure 13. Following is a description of the profile:

L horizon. Thickness, ¼ to ½ inch; nearly pure pine debris.

F horizon. Thickness, ½ to 1 inch; slightly matted and permeated with fungal mycelia.

H horizon. Thickness, ¼ to ½ inch; color-black; structure-granular. This humus layer type is regarded as a granular more

A horizon. Thickness, 4½ to 8 inches, average 6; texture-loamy sand; color-dark reddish brown, mottled with rusty brown (B_1) in the lower part and with black (organic matter and charcoal) and gray (podzol) in the upper part; structure-granular; consistency-friable. The upper 2 inches are rather compact and the structure tends to be laminated. There is evidence of former earthworm activity but no specimens were seen. A considerable development of fungal mycelia was noted and there is evidence of incipient podzol formation.

B_1 horizon. Thickness, 3 to 12 inches, average 6; texture-loamy medium sand; color-rusty brown; structure-granular; consistency-firm to friable. Irregularly mottled with small blackish spots resulting from decay of roots or concentration of organic colloids. Occasional bits of charcoal were noted.

B_2 horizon. Thickness, 2 to 10 inches, average 5½; texture-loamy medium sand; color-light rusty brown, faintly mottled with orange; structure-single grain, with tendency toward granular; consistency-firm.

C_1 horizon. Thickness, 11 to 24 inches, average 15; texture-gravelly coarse sand with small irregular bodies of silt and silty clay; color-light yellowish brown, mottled with light gray and rusty brown; structure-single grain; consistency-loose. The finer textured material is granular and firm. This horizon evidently is under the influence of water during a part of each year.

C_2 horizon. Thickness to a depth of 5 feet below the surface, average 32 inches; texture-loam; color-olive, strongly mottled with brown and orange; structure-massive; consistency-firm to hard. Old root canals are evident in this horizon, which is water-logged for considerable periods each year.

The average number of roots per square foot in each horizon is as follows: F-78, H-475, A-390, B_1-153, B_2-47, C_1-9, and C_2-2. Nine per cent of the total number of roots encountered occur in the F and H horizons, 57 per cent in the A, 29 per cent in the B, and 5 per cent in the C. The roots are concentrated in the H, A and B_1 horizons with much smaller numbers in the B_2 and practically none in the C layers. Most of the roots occur in the upper 18 inches and below a depth of 24 inches are practically lacking. The lack of roots in the C_1 and C_2 horizons may partly be the result of the high water table with attendent poor aeration. In addition it may be pointed out that the C_1 is very coarse textured and the C_2 is compact.

The mechanical analysis (Table III) indicates a somewhat higher content of fine material in the A than in either the B_1 or B_2 horizons. The C_1 horizon contains very little silt and clay but the C_2 is finer textured than any of the other horizons. Moisture equivalent values (Table III) for the A and B_1 horizons are appreciably higher than the values for the B_2 and C_1 layers. Poor development of roots in the B_2 and C_1 may be associated with their low capacity to hold moisture. Absence of roots in the C_2 may be explained on the basis of excessive moisture, poor aeration, and compactness rather than in terms of deficient moisture.

Total nitrogen values for the horizons are presented in Table IV. The nitrogen content decreases rather regularly with increasing depth until the C_2 horizon is reached. In this layer the nitrogen content is higher than in either the B_2 or Ct. Data relating to base exchange phenomena appear in Table V. The relationships between root distribution and the base exchange features are obscure. It may be noted that the C_2 horizon has a higher total exchange capacity than any other mineral soil horizon. Absence of roots in this layer seems associated with poor aeration and compactness rather than with lack of nutrients. Hydrogen ion concentration values are assembled in Table VI. The variations noted in this factor are small and cannot account for the distribution of roots.

Station 15:

Located in the Swamp lot on level ground having good drainage; a total depth of 9 feet was attained at this station but the water table was not reached. The parent soil material is of glaciofluvial origin. Forest cover consists of a pure stand of white pine about 35 years old having a crown density of about .9. There are 1396 trees per acre and the average d.b.h. is about 5 inches. This area was formerly in cultivation but it is not clear how long ago it was abandoned.

The horizon relations and root distribution are illustrated'in Figure 14. Following is a description of the profile:

L horizon. Thickness, ¼ to ½ inch; composed entirely of white pine debris.

F horizon. Thickness, ½ to 1 inch; slightly matted and in spots permeated with fungal mycelia.

H horizon. Thickness, up to ½ inch; color-brownish black; very finely granular. The humus layer type is regarded as a granular more

A horizon. Thickness, 7 to 13 inches, average 9½; texture-loamy sand; color-grayish brown, mottled with gray and rusty brown; structure-granular; consistency-friable. This horizon is clearly demarcated; occasional tongues, thought to represent old root canals, are observed extending into the B horizon. Near the lower boundary of this layer are irregular lumps of light gray material (podzol) containing charcoal which are believed to be associated with cultivation. In the upper ⅛ to ¼ inch there is clear evidence of incipient podzol formation; whitish fungal mycelia are abundant.

B horizon. Thickness, 4 to 12 inches, average 8; texture-coarse sand; color-brown; structure-granular; consistency-friable. Charcoal is encountered in the upper part.

C_1 horizon. Thickness, 3 to 11 inches, average 5; texture-gravelly coarse sand; color-light yellowish brown; structure-single grain; consistency-loose. This horizon is much coarser textured than those above. Occasional tongues are noted penetrating into the C_2 horizon; these tongues evidently represent old root canals.

C_2 horizon. The total thickness of this horizon, including a stratum of fine sand (designated as C_{2z} in Figure 14) is about 50 inches; texture-gravelly coarse sand; color-gray; structure-single grain; consistency-loose.

C_{2z}: thickness-2 to IS inches, average 7; texture-fine sand; color-light gray; structure-granular; consistency-friable.

C_a horizon. Thickness to a depth of 7 feet below the surface, average 9 inches; texture-gravelly coarse sand; color-light gray; structure-single grain; consistency-loose.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-46, H-384, A-28I, B-111, C_1-42, C_2-9, C_{2z}-3, and C_a-5. Four per cent of the total number of roots encountered occur in the F and H horizons, 60 per cent in the A, 20 per cent in the B and 16 per cent in the C. Root development in the A and B horizons is excellent with a decrease in numbers in the C horizons, particularly in the gray C_2 and Ca' Most of the roots are in the surface 18 inches. It is interesting to note the two tongues of the C_1 horizon which extend into the C_2. In both of these tongues root development is better than in the adjacent C_2 material.

The A and B horizons contain considerably more fine material (Table III) than the C horizons. In the gravelly coarse sand C_2 horizon is a stratum of fine sand which has been designated C_{2z}. There appears to be no tendency for roots to develop in this layer. The few roots which occur in the C_2 and C_3 layers are localized. The moisture equivalent values (Table III) clearly indicate a pronounced decrease of water holding capacity in the C horizons. In the A and B horizons the values are 14.6 and 14.4 per cent, respectively; in the C horizons the highest value is 3.2 in the C_1. This difference in moisture relations may explain the scanty development of roots in the C layers. Special samples were collected from the tongues of C_1 and from the immediately adjacent C_2 material. The moisture equivalent of the C_1 material which supports roots is 2.7 per cent and in the C_2 material which lacks roots, 1.8 per cent. It is true that this difference is small and were it an isolated case would merit no attention. However, this same relation was found repeatedly in the course of the investigation.

The nitrogen values (Table IV) indicate a marke.d decrease in content of nitrogen in going from the B horizon into the C_1. The special samples mentioned above were analyzed for nitrogen with the result that nearly twice as much was found in the C_1 material containing roots (0.018 per cent) than in the C_2 lacking roots (0.011 per cent). Base exchange features were not investigated in all horizons of this profile. However, the special samples previously mentioned were examined. The total exchange capacity (Table V) in the C_1 tongue containing roots was 1.65 m.e., in the adjacent C_2 material lacking roots, 0.80 m.e. As in the case of the moisture equivalent and nitrogen values the absolute value of this difference is small. Nevertheless, it is believed to haye some significance since the same relationship was found in other profiles. There was no difference in the degree of base saturation of the samples. The variations in soil acidity (Table VI) are small and seem incapable of influencing root behavior in this profile.

Station I6:

Located in the Lafontaine lot on the slope of a hill which rises above the adjacent sandy flat. Drainage is good but not excessive. Because of the texture of the soil and the seepage of water from the higher ground, moisture relations are excellent. The parent soil material is glacial till. The forest cover consists of a pure stand of white pine which is essentially even-aged at 47 years; crown density is .8. There are approximately 342 trees per acre and the average d.b.h. is 10 inches. This area has been cleared but there is no evidence that it was ever cultivated. It seems possible, however, that it may have been used as pasture but this could not be definitely established.

Horizon features and root distribution are illustrated in Figure IS. A description of the profile follows:

L horizon. Thickness, ¼ to ¾ inch; for the most part composed of white pine debris but with some hardwood leaves.

F horizon. Thickness, ½ to 1 inch; lying loosely on the mineral soil. In the F and Ai horizons there is considerable myriapod activity. Large casts formed by these animals are very abundant, some of them being ½ inch thick, 1 inch wide, and 4 inches, or more, long.

A_1 horizon. Thickness, 2 to 6½ inches, average 5; texture-sandy loam; color-dark brown; structure-erumb; consistency-friable. The humus layer type is regarded as a coarse mull. This layer is in excellent condition; the lower boundary is irregular.

A_2 horizon. Thickness, 1 to 9 inches, average 4½; texture-sandy loam; color-light grayish yellow, mottled with brown; structure-erumb; consistency-friable. Considerable organic debris and A_1 material have been worked into this layer by the soil fauna. There is no evidence in either the A_1 or A_2 that the soil was ever cultivated.

B_1 horizon. Thickness, 2 to 11 inches, average 5; texture-sandy loam; color-light rusty brown; structure-fine granular; consistency-friable. This horizon is very irregular and contains occasional stones; some charcoal was observed.

B_2 horizon. Thickness, 2 to 8 inches, average 4; texture-sandy loam; color-light yellow; structure-fine granular; consistency-friable.

C_1 horizon. Thickness, 4 to 17 inches, average 8; texture-sandy loam; color-olive gray; structure-granular; consistency-firm.

C_2 horizon. Thickness to a depth of 5 feet, average 32 inches; texture-sandy loam; color-olive; structure—massive; consistency-very hard. Excavation in this horizon was accomplished with great difficulty.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-6, A_1-376, A_2-268, B_1-209, B_2-151, C_1-96, and C_2-15. Fifty-four per cent of the total number of roots encountered occur in the A horizons, 25 per cent in the B, and 21 per cent in the C. The most striking feature of root distribution at this station was the pronounced development in the A horizon and the fairly good development in the B and C_1. To a depth of slightly more than 2 feet the soil body is very well permeated with roots. Another feature, very noticeable in the field, was the concentration of roots along the contact of the C_1 and C_2. In the C_2 relatively few roots appear and they tend to be confined in the upper part; below a depth of 3 feet there are practically none. In view of the extremely compact nature of this horizon the scanty development of roots was not at all surprising.

Examination of the mechanical analysis data (Table III) reveals a soil profile which is relatively heavy textured throughout. The lack of roots in the C_2 appears to be more a matter of compactness than texture. In the C_2 at a depth of about 2½ feet may be noted a concentration of roots in a horizontal plane. Samples collected from this zone were compared with samples collected immediately above and below where roots are absent. As may be observed in Table III the mechanical analyses of these samples are practically identical. The concentration of roots here is evidently not a matter of soil texture. The moisture equivalent of the sample containing roots was slightly higher than that of the adjacent soil devoid of roots. The moisture equivalent value for the Ai was highest (19.7 per cent) ; a gradual decrease was noted with increasing depth to the C_2 layer with a value of 9.0 per cent.

Nitrogen relations in this profile (Table IV) appear excellent. The special C_2 sample containing roots contained slightly more nitrogen (0.022 per cent) than the corresponding sample lacking roots (0.017 per cent). Base exchange data are presented in Table V. With increasing depth below the surface there is a rather constant decrease in total exchange capacity. In the special C_2 sample with roots the total exchange capacity as well as the content of exchangeable bases was slightly higher than in the corresponding sample without roots. Soil acidity values appear in Table VI. Evidently this factor cannot be held responsible' for the distribution of roots here noted.

Station 17:

Located in the Fisher-Robinson lot on ground sloping gently to the west. Drainage is slow but moisture relations are regarded as favorable. In the latter part of July, 1935, the water table stood at a point 4 to 4½ feet below the surface but during August it dropped considerably. The parent material of the soil is glacial till. Forest cover consists of a stand of white pine about 66 years old; crown density is .8. There are 166 white pine trees per acre and the average d.b.b. is about 11.5 inches. There is no evidence that this area was ever cultivated.

The horizon features and root distribution are illustrated in Figure 16. Following is a description of the soil profile:

L horizon. Thickness, ½ to 1 inch; composed of white pine debris and hardwood leaves.

F horizon. Thickness, 1 to 2 inches; matted, rather tough, interwoven with roots and fungal mycelia.

H horizon. Thickness, ¼ to ½ inch, fairly distinct from the mineral soil. The humus layer type is classified as a coarse mull which is tending toward a granular more

A horizon. Thickness, 5 to 14 inches, average 7; texture-sandy loam; color-dark brown; structure-coarse crumb; consistency-friable. This layer was in excellent condition but no earthworms were observed nor was there evidence of recent work. Occasional rounded boulders were noted; clearly demarcated from the B_1.

B_1 horizon. Thickness, 3 to 12 inches, average 9; texture-sandy loam; color-rusty brown, mottled with orange and light brown; structure-fine granular; consistency-friable. In spots there was some discoloration by A material. Evidently seepage water works down the slope.

B_2 horizon. Thickness, 1 to 6½ inches, average 3; texture-sandy loam; color-light brown, mottled with orange; structure-fine granular; consistency-friable.

C_1 horizon. Thickness, 2 to 9 inches, average 5½; texture-sandy loam; color-brownish gray, mottled with brown; structure-fine granular; consistency-firm. During periods each year this horizon is poorly drained; occasional rocks were noted.

C_2 horizon. Thickness to a depth of 5 feet below the surface, average 32 inches; texture-sandy loam; color-slate gray; structure-laminated; consistency-hard to firm. In the upper part there is considerable mottling with orange. This horizon is very compact and is poorly drained during considerable periods each year. Some rocks were encountered.

The average number of roots per square foot of rock-free area in each horizon is as follows: F-182, H-512, A-373, B_1- 236, B_2- 154, C_1- 27, and C_2–1. Eight per cent of the total number of roots encountered occur in the F and H horizons, 45 per Cent in the A, 44 per cent in the B, and 3 per cent in the C. Root distribution is excellent in the A and B horizons which occupy the upper 2 feet of the soil body. In the C_1 a sharp reduction in root numbers is noted and in the C_2 horizon below a depth of about 2½ feet roots are absent.

The mechanical analysis data (Table III) relating to this profile do not suggest an explanation for the lack of roots in the C_1 and C_2. It is true that the clay content of both these layers is higher than in the upper horizons but the difference is not great. The A and B_1 horizons have higher moisture equivalent values than the B_2, C_1 and C_2. However, absence of roots in the lower part of this profile certainly cannot be the result of lack of moisture. Rather, excessive moisture, together with the resistance offered to penetration by roots, seem to be the causal factors. Nitrogen values are presented in Table IV. As in the other profiles examined there is a pronounced decrease in total nitrogen content with increasing depth. Total exchange capacity (Table V) decreases with increasing depth as has been noted in other profiles. The highest base saturation is found in the C_2 but here the total exchange capacity is very low, only 0.9 of a milligram equivalent. Soil acidity values in Table VI do not suggest an explanation for the lack of roots in the C_1 and C_2. It is true that the pH in both these layers is higher than in any of the upper horizons but the difference is not great.

Station 18:

Located in the Blake lot on level ground having good drainage. The soil has developed from lacustrine material which is highly stratified. Forest cover consists of a pure stand of white pine about 37 years old; crown density is estimated to be .9. There are 373 trees per acre and the average d.b.h. is about 8.S inches. This area was formerly in agricultural use and the present stand developed under a cover of gray birch which was removed ten or more years ago.

Horizon features and root distribution are illustrated in Figure 17. Following is a description of the profile:

L horizon. Thickness, ½ to 1 inch; composed of nearly pure white pine debris.

F horizon. Thickness, ½ to 1 inch; slightly matted and permeated with whitish fungal mycelia.

H horizon. Thickness, ¼ to ½ inch. In places black and crumb-like but more generally representing a transition from the F layer. Whitish fungal mycelia are common. The humus layer type is considered to be a granular more

A horizon. Thickness, 4½ to 9 inches, average 7; texture-sandy loam; color-dark brown; structure-tendency toward crumb; consistency-friable. In the upper part is noted evidence of incipient podzolization and a laminated structure and in the lower part a slight mottling with rusty brown. Some whitish fungal mycelia were observed. No earthworms were noted nor is there any evidence of recent work.

B_1 horizon. Thickness, 4 to 12 inches, average 6; texture-coarse sandy loam; color-light rust brown; structure-fine granular; consistency-friable. Poorly demarcated from B_2.

B_2 horizon. Thickness, 3 to 24 inches, average 12; texture-loamy coarse sand; color-light brown; structure-single grain; consistency-loose.

C_1 horizon. Thickness, extremely variable as may be noted in Figure 17 but the average is about 17 inches; texture-gravelly coarse sand; color-light brownish gray; structure-single grain;'consistency-loose. The stratum designated as C_{1x} is about 6 inches thick; texture-fine sandy loam; color-light olive; structure-fine granular; consistency-friable to finn.

C_2 horizon. In this horizon were numerous strata which have been designated by numerals.

C_2-1: Thickness, about 8 inches; texture-eoarse sand; color-light brownish gray; structure-single grain, consistency-loose. Considerable cross-bedding is noted in this layer.

C_2-2: Thickness, about 6 inches; texture-fine sandy loam; color-light brownish gray; structure-laminated; consistency-friable. In places this layer is streaked with rusty brown. In the lower part is a notable concentration of roots.

C_2-3: Thickness extremely variable; texture-eoarse sand; color-brownish gray, iron stained along upper and lower contacts; structure-single grain; consistency-loose.

C_2-4: Thickness, 4 to 6 inches; texture-loam; color-light brownish gray streaked with rusty brown and orange; structure-laminated (varved); consistency-friable.

C_2-5: Thickness, 6 to 8 inches; texture-medium sand; color-gray, finely streaked with rust; structure-single grain; consistency-loose.

The average number of roots per square foot of rock-free area in each horizon is as follows: H-38S, A-276, B_1—173, B_2-70, C_1-3, C_{1x}-69, C_2-I-none, C_2-2-73, C2-3-1, C_2-4-4, and C2-5-none. Four per cent of the total number of roots encountered occur in the H horizon, 39 per cent in the A, 41 per cent in the B, and 16 per cent in the C. The outstanding features in this profile are the concentration of roots in the H, A, B_1 and B_2 horizons and in the layers designated as C_{1X} and C_2-2. A sharp reduction in number of roots is noted in the C_1 compared with the B_2. The development of roots in the fine textured strata in the C is an interesting illustration of the influence of moisture relations on root distribution.

The mechanical analysis data (Table III) seem to furnish a key to the distributional features noted. There is very little clay in any of the layers but the percentage of silt and fine sand undergoes wide fluctuations. The A, B_1 and B_2 horizons all contain fair proportions of fine material and are classed as loams or loamy sands. These horizons, occupying the upper two feet of the soil body, contain a large proportion of the roots. The C_1 layer, almost devoid of roots, is a gravelly coarse sand containing only 5 per cent of particles smaller than sand size. The layer immediately below (C_{1X}) contains 38.4 per cent of particles smaller than sand size and supports good root development. The layer C_2-2 is likewise much finer textured than the layers immediately above or below. Here again, particularly along the lower boundary, root development is good. The layers designated as C_2-4 are likewise finer textured than the members adjacent but here only occasional roots are found. Lack of more extensive development is not surprising in view of the fact that the layers occur at a depth of 5 to 6½ feet below the surface.

Moisture equivalent values (Table III) indicate about the same relations as do the mechanical analysis data. Of the layers which contain fair numbers of roots the lowest moisture equivalent value is 4.8 for the upper part of the layer C_2-2. The highest value for the horizons lacking roots is 5.8 per cent. Root distribution here is evidently not controlled by deficient aeration, or compactness of horizons but by soil moisture conditions.

Examination of the nitrogen analyses in Table IV is instructive. Horizons in which root development is reasonably good invariably have a higher content of nitrogen than do adjacent layers lacking roots. Base exchange phenomena were not investigated in all horizons of this profile. However, certain layers were examined and the data are presented in Table V. The C_1 layer lacking roots has a total exchange capacity of 1.00 m.e. whereas in the C_{1x} layer with roots the value is 3.10. It appears that the C horizons containing roots have slightly higher base exchange capacities than adjacent layers without roots. Soil acidity (Table VI) is not a limiting factor with respect to root distribution in this profile.

Station I9:

Located in the Goodwin lot on gently sloping ground. Drainage conditions are good. This station has developed from very rocky glacial till material overlying a stratified deposit. The forest consists of a pure stand of white pine 41 years old; crown density is about .7. There are 902 trees per acre and the average d.b.h. is about 5 inches. There is no evidence at hand to indicate that this area was ever cultivated.

Horizon features and root distribution are illustrated in Figure 18. Following is a description of the profile:

L horizon. Thickness, ¼ to 1 inch. Nearly pure white pine debris.

F horizon. Thickness, ¼ to ¾ inch. In most places this layer is only slightly matted but in spots it is tough and interwoven with yellow fungal mycelia.

H horizon. Thickness, ⅛ to ½ inch; in part black, granular. In spots interwoven with fungal mycelia. This humus layer type is classified as a granular mar. No earthworms were observed nor was there any evidence of recent activity of these organisms.

A horizon. Average thickness, 4 inches; texture-coarse sandy loam;

color-dark brown; structure-tendency toward granular; consistency-loose to friable. The upper 1/8 inch in places is distinctly gray because of incipient podzol formation. Some charcoal is found. This horizon is irregular but clearly demarcated from the B_1.

B_1 horizon. Average thickness, 8 to 10 inches; texture-coarse sandy loam; color-rusty brown; structure-fine granular; consistency-friable. This horizon is poorly demarcated from the B_2. A large rock having a width of nearly 3 feet and a height of about 2 feet occurs in this layer.

B_2 horizon. Thickness, 3 to 29 inches, average 17; texture-loamy coarse sand; color-light brown; structure-fine granular; consistency-firm. Considerable rock is encountered in this layer which is well demarcated from the C. At either side of the large rock the B_2 horizon dips downward. It seems probable that this downward extension results from concentration of water around the sides of the rock.

C horizon. This layer extends from the very irregular lower boundary of the B_2 horizon to a depth of at least 6 feet. At a depth of about 4½ feet is a layer of medium sand designated as ex. The C material is a very gravelly coarse sand containing much rock; color-gray; structure-single grain; consistency-loose. In'this layer are occasional lenses or streaks of finer material.

The stratum designated as C_x is about 8 inches thick; texture-medium sand with streaks of finer material, rock and coarse gravel lacking; color-light gray, streaked with olive; structure-single grained; consistency-loose.

The average number of roots per square foot of rock-free horizon area is as follows: F-130, H-394, A-363, B_1-226, B_2-117, C-1, ex-none. Six per cent of the total number of roots encountered occur in the F and H horizons, 22 per cent in the A, 71 per cent in the B, and 1 per cent in the C. In this profile the roots are very strictly confined to the F, H, A, B_1, and B_2 horizons. Aside from the notable downward extensions of the B_2 most of the roots are in the upper two feet of soil. This is a case of pronounced control of root development by soil horizons.

Mechanical analysis data (Table III) indicate that the horizons supporting roots are texturally finer than the C in which roots are almost lacking. Thus, 51 per cent of the C material is larger than 2 mm. diameter and of the fraction less than 2 mm. in size nearly 87 per cent is classed as sand. The moisture equivalent values reflect the textural relations just mentioned. In the A the moisture equivalent was 14.6, in the B_1 11.6, in the B_2 8.7, and in the C 2.5 per cent. This suggests that deficient moisture in the C may be the chief reason for the lack of roots. In this connection it may be mentioned that special samples were taken from the narrow tongue of B_2 extending into the C on. the right side of the large rock and from the immediately adjacent C material. The former sample, which supported roots, had a moisture equivalent of 4.7 per cent, whereas the value for the latter sample, lacking roots, was 2.3 per cent.

The nitrogen content (Table IV) of the C is very much less than in the A and B horizons where the roots are concentrated. Data relating to base exchange phenomena appear in Table V. It may be noted that there is a relatively sharp reduction of total base exchange capacity in the C (0.56 m.e.) compared with the B_2 (3.12 m.e). The highest amount of exchangeable bases are found in the A, B_1 and B_2 layers. The differences in soil acidity are small, varying in the mineral soil from pH 5.3 in the A to 5.6 in the B_2 and C; the values, expressed in terms of pH, appear in Table VI:

Station 20:

Located in the Goodwin lot in a depression on a very gentle slope. Drainage is poor; evidently the soil is water-logged for considerable periods each year. In August, 1935, the water table stood at a point about 5 feet below the surface; it is doubtful if it drops much lower during the average year. The forest consists of a nearly pure stand of white pine 45 years old having a crown density of about .9. There are 674 trees per acre and the average d.b.h. is 6.4 inches. There is no evidence that this area was ever cultivated.

The profile features and root distribution are illustrated in Figure 19. Following is a description of the profile:

L horizon. Thickness, ¼ to ¾ inch; composed of white pine debris with some hardwood leaves.

F horizon. Thickness, ½ to 1 inch; in general loose but matted in spots.

H horizon. Thickness, ⅛ to ¼ inch; amorphorus, black, very finely granular. This humus layer type is regarded as a granular more

A_1 horizon. Thickness, 1 to 3½ inches, average 2; texture-loamy medium sand; color-brownish gray; structure-laminated to single grain; consistency-firm.

A_2 horizon. Thickness, 4 to 12 inches, average 7; texture-medium sand; color-light gray to nearly white; structure-single grain; consistency-firm.

B horizon. Thickness, extremely variable from about 7 to 42 inches, average 30; texture-medium sand; color-light gray to light brownish gray, strongly mottled with rusty brown; structure-single grained for most part;

consistency—friable. The rusty brown material occurs as small lenses and stringers which are firm to hard. This is clearly a case of incipient hardpan formation.

C horizon. This layer is encountered at variable depths below the surface. At one end of the trench it reaches within 21 inches of the surface but at the other end it is not encountered at the ground water level approximately 5 feet down. Texture—coarse sand; color—rusty brown to orange with horizontal streaks of grayish brown and reddish brown giving the appearance of stratification; one also notes wavy, nearly vertical, reddish and in some cases black streaks; structure—coarse granular with a tendency to platy; consistency—hard, almost cemented.

The average number of roots per square foot of rock-free horizon area is as follows: F—117, H—394, A_1—356, A_2—121, B—28, and C—2. Eleven per cent of the total number of roots encountered occur in the F and H horizons, 56 per cent in the A, 32 per cent in the B, and 1 per cent in the C. A remarkable feature of this profile is the extreme irregularity of the B horizon. This irregularity seems to be associated with poor drainage. In spite of the seemingly unfavorable features of the B layer root development is surprisingly deep. In the C layer, which is exceedingly compact as well as poorly drained, there are very few roots.

As indicated in Table III the A_1 and A_2 horizons contain more fine material than the other layers. However, the decrease in number of roots in the B horizon does not seem to be as much a matter of soil texture as a matter of excessive moisture. The incipient hardpan development in the B does not, as yet, offer an appreciable obstacle to root development. In the C, as in the B, excessive moisture content, together with the extreme compactness of the material, must represent an unfavorable condition.

The moisture equivalent data (Table III) have limited value in explaining root distribution in this profile. Several special samples were taken in the B and C layers from points where roots were present and immediately adjacent where they were absent. Along the right end of the transect a narrow tongue of B material extends into the C. Samples from this narrow tongue, which contains roots, showed a moisture equivalent of 6.3 per cent, whereas adjacent C material showed a value of 3.2 per cent. In the C material, directly below the above mentioned tongue of B, are numerous roots occurring in a narrow vertical streak. A sample of this C material containing roots had a moisture equivalent of 4.8 per cent whereas the adjacent C without roots had a value of 2.1 per cent.

The nitrogen content of the various horizons is presented in Table IV.

Nitrogen was determined in samples from the tongue of B mentioned above and found to be 0.036 per cent; in the adjacent C material the value was 0.010 per cent. The C material containing roots contained 0.069 per cent nitrogen whereas the adjacent material lacking roots contained 0.012 per cent. Base exchange features of this profile were examined only in the special samples mentioned earlier. As may be noted in Table V the total exchange capacity in both cases was higher in the samples containing roots than in the corresponding samples from adjacent points lacking roots. Data on the hydrogen ion concentration (Table VI) does not seem to throw any light on the root distribution features noted.

Station 21:

Located in the Morse lot on a narrow bench near the base of a fairly steep slope. Drainage is excellent. The soil profile has developed on glacial till containing many large boulders. The forest consists of pure white pine about 32 years old; crown density is .7. There are 508 trees per acre and the average d.b.h. is about 6 inches. There is no evidence that this ground was ever cultivated.

The profile features and root distribution are illustrated in Figure 20. Following is a description of the profile:

L horizon. Thickness, ¼ to ½ inch; composed almost entirely of white pine debris.

F horizon. Thickness, ½ to 1½ inches; lying loosely on the A layer.

A horizon. Thickness, 2½ to 5 inches, average 4; texture—sandy loam; color—dark brown to grayish black in spots; structure—coarse to fine crumb; consistency—friable. Past work of earthworms is clearly evident but there is no sign of recent activity and none of the organisms could be found in the trench or immediate vicinity. The humus layer type is classified as a coarse mull.

B_1 horizon. Thickness, 4 to 8 inches, average 6; texture—sandy loam; color—light rusty brown; structure—tendency to fine granular; consistency—friable to loose. A slight mottling with grayish brown in the upper part appears as a result of past earthworm work. This layer is rather poorly demarcated from the B_2. Occasional rocks are encountered.

B_2 horizon. Thickness, 7 to 24 inches, average 18; texture—loamy coarse sand; color—yellowish brown; structure—slight tendency to granular; consistency—friable. This layer is well demarcated from the C. Many boulders are encountered.

C horizon. This layer was encountered at a depth of 2 to 2½ feet below the surface; because of the number and size of the boulders it was impossible to attain a depth greater than 3 feet. Texture—gravelly coarse sand; color—light yellowish brown; structure—single grain; consistency—loose.

The average number of roots per square foot of rock-free horizon surface is as follows: F—106, A—289, B_1—186, B_2—121, and C—29. Two per cent of the total number of roots encountered occur in the F horizon, 26 per cent in the A, 70 per cent in the B, and 2 per cent in the C. Root distribution in the upper 2½ feet of this soil is excellent. However, below this depth, in the C horizon, roots are scarce.

The mechanical analysis data and moisture equivalent values (Table III) suggest a reason for the concentration of roots in the A and B horizons and their scarcity in the C. The percentage of silt and clay in the A and B layers varies from about 22 to 33 per cent but in the C it is about 10 per cent. The moisture equivalent values indicate a variation in the A and B layers from 11.8 to 21.7 per cent; in the C the moisture equivalent is 6.3 per cent. The layers in this profile in no case are so compact as to render penetration difficult; neither are they water-logged and poorly aerated. There can be little doubt, however, that moisture relations in the C layer must be relatively unfavorable because of the coarse texture of the material.

The nitrogen content (Table IV) of the A is relatively high (0.290 per cent) and is approximated only by the value for the A_1 of station 16, the A of station 17, and the A of station 11. The content of nitrogen in the C is less than half that of the B_2. The total base exchange capacity (Table V) of the A horizon of this profile is 18.63 m.e. This is the highest value recorded in this investigation for any A layer. With increasing depth the exchange capacity decreases and in the C it is 3.26 m.e. which is approximately one-half the value for the B_2. The hydrogen ion concentration (Table VI) in the mineral soil horizons is remarkably constant and affords no explanation for the marked reduction of roots in the C.

SUMMARY AND CONCLUSIONS

THE relation of soil profile horizons to root distribution of white pine was investigated in the Yale Demonstration and Research Forest near Keene, New Hampshire, during 1934 and 1935. The work was carried out in essentially even-aged pure stands of white pine established by natural regeneration and growing in soils belonging to the gray-brown podzolic group. In most cases the stands were between 35 and 45 years old. Twenty-three profiles were examined but only 17 are discussed in the present publication; the cross-sectional area in the 17 profiles amounted to 1005 square feet.

In most profiles the largest number of roots occurred in the A and B horizons, or in their subdivisions. However, the average number of roots per square foot in the H layers was 407 ± 37, which was higher than in any other horizon. The number of roots per square foot of cross-sectional area in the mineral soil horizons decreased with increasing depth below the surface. The mean number of roots per square foot of cross-sectional surface in the various horizons was as follows: F—137 ± 37, H—407 ± 37, A_1—314 ± 40, A_2—162 ± 37, B_1—163 ± 21, B_2—84 ± 17, and C_1—25 ± 8. Viewed from a broader standpoint, the numbers per square foot in the A, B, and C horizons were 322 ± 23, 107 ± 12, and 11 ± 2, respectively. Thus it is indicated that root distribution differs in the various soil horizons and that the greatest development occurs in the upper soil layers.

Mechanical composition of the soil horizons influenced root distribution. Root development was usually poor or lacking in soil material containing 90 per cent or more sand. That texture plays an important rôle in determining root distribution was further evidenced by the concentration of roots in fine textured strata which occurred in coarse sandy subsoils. Likewise a pronounced difference in content of the fine soil material in adjacent horizons was frequently accompanied by an equally pronounced difference in number of roots, fewer roots occurring in the horizons of coarser texture. From the standpoint of texture alone, conditions for root development appear most favorable in loamy sands, sandy loams, and loams, and least favorable in coarse sands; clays were not encountered in this investigation.

Physical conditions, other than texture of the soil, also are important in determining root distribution. In the investigation here reported it was noted that root development in very compact layers usually was poor or lacking. Horizons having a gray or mottled appearance likewise seem to be relatively less favorable than brown-colored horizons.

In the profiles investigated the moisture equivalent usually decreased with increasing depth below the ground surface. This condition may be explained by the concentration of organic matter in the upper layers and the immaturity of the soils. In general, root development was poor or lacking in horizons having a moisture equivalent of 4.0 per cent, or less.

The total nitrogen content was highest in the organic layers and decreased in the mineral soil with increasing depth below the surface. Root development appeared better in horizons with a relatively high content of nitrogen than in horizons poorer in this element.

The total exchange capacity was highest in the organic layers and decreased in the mineral soil horizons with increasing depth. The data indicate that root development was better in horizons having relatively high exchange capacity than in horizons of lower exchange capacity.

Hydrogen ion concentration of the soil material was examined but no consistent relation between this factor and root distribution could be established.

The concentration of white pine roots in the upper soil horizons appears to result from a combination of factors among which may be mentioned (1) greater content of fine material less than 0.05 mm. diameter, (2) generally better physical conditions, particularly structure and consistency, (3) higher moisture equivalent values, (4) higher content of organic matter, (5) higher content of total nitrogen, and (6) higher total exchange capacity and higher content of exchangeable bases. Other factors also are believed to be important and worthy of investigation; among these may be mentioned soil temperature, soil aeration, and soil moisture.

The A and B horizons together with the organic layers merit most careful consideration by the forest ecologist since they support the greatest number of tree roots. The productivity of the soil body is closely associated with the character of these horizons. From a practical point of view the upper soil layers are of especial importance since they embody most of the changes which result from plant succession or from cultural operations. It seems clear that soil profile horizons have ecological as well as pedological significance.

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FIGURE 4

Horizon features and root distribution in profile 3. Each interval between the graduations along the sides and bottom of the chart represents one foot. Horizons are lettered and rocks are cross hatched. The following symbols indicate root size.

Diameter of root	*Symbol*
up to 0.05 inch	·
>0.05 to 0.1 inch	o
>0.1 to 0.2 inch	⊕
>0.2 to 0.5 inch	θ
>0.5 to 1.0 inch	×

In the charts of profiles 3, 4, 7, 8, 9, 10, and 11 roots having a diameter larger than 1.0 inch are designated by the symbol ∗. In charts of the remaining profiles the periphery of roots larger than 1.0 inch diameter is drawn to scale.

Note the influence of the large rock in the center on horizon development. The C_2 layer is gray with occasional streaks of rust brown and is very compact. In this horizon roots are practically confined to the rust brown streaks.

APPENDIX

TABLE I. NUMBER AND SIZE OF ROOTS IN THE SOIL PROFILE HORIZONS

(Based on vertical cross-sections 10 feet in length.)

Pro-file	Horizon	Number of roots by size classes						Total number roots	Number of roots per square foot of rock-free area		
		0–.05"	.05–.1"	.1–.2"	.2–.5"	.5–1.0"	>1.0"		0–.05"	>.05"	Total
3	L	..	..	..	..	..	..	..	..	..	..
	F	20	1	1	..	..	..	22	49	5	54
	A_1	315	23	14	2	1	..	355	176	22	198
	A_2	419	32	16	5	1	1	474	95	12	107
	B_1	256	20	10	4	1	1	292	50	7	57
	B_2	149	10	6	..	3	2	170	33	5	38
	C_1	47	4	1	..	..	..	52	11	1	12
	C_2	171	5	2	..	..	..	178	6	..	6
4	L	..	..	..	..	..	..	..	..	..	..
	F	49	..	..	..	..	..	49	117	..	117
	A	805	53	34	4	..	..	896	157	18	175
	B	364	40	26	3	1	..	434	32	6	38
	C_1	32	1	..	..	..	..	33	2	..	2
	C_2	20	..	..	..	..	..	20	1	..	1
	C_3	..	..	..	..	..	..	..	..	..	..
	C_3 (fine sand)	97	4	5	..	..	..	106	14	1	15
7	L	..	..	..	..	..	..	..	..	..	..
	F	127	10	..	1	..	..	138	198	17	215
	A_1	392	48	10	1	1	..	452	284	44	328
	A_2	682	51	26	5	..	..	764	135	16	151
	B_1	572	92	28	7	2	..	701	65	15	80
	B_2	419	43	8	1	2	..	473	42	5	47
	C_1	178	2	..	..	..	..	180	17	..	17

TABLE I (CONTINUED)

Profile	Horizon	Number of roots by size classes: 0–.05″	.05–.1″	.1–.2″	.2–.5″	.5–1.0″	>1.0″	Total number roots	Number of roots per square foot of rock-free area: 0–.05″	>.05″	Total
	C_2	91	1	..	..	..	..	92	10	..	10
	C_3	2	..	..	..	..	..	2	..	..	..
8	L	..	..	..	..	..	..	..	..	..	..
	F	..	..	..	..	..	..	..	..	..	..
	H	260	1	..	..	..	..	261	520	2	522
	A	1,240	52	29	2	..	..	1,323	394	27	421
	B_1	887	57	30	3	6	1	984	136	15	151
	B_2	137	6	1	..	..	1	145	15	1	16
	C_1	33	1	1	..	..	..	35	2	..	2
	C_2	119	3	2	..	1	..	125	3	..	3
9	L	..	..	..	..	..	..	..	..	..	..
	F	98	1	..	..	..	..	99	245	2	247
	A	1,308	96	28	7	..	..	1,439	281	28	309
	B	576	48	19	5	2	..	650	112	14	126
	C_1	165	9	..	..	..	..	174	19	1	20
	C_2 (sand)	28	1	..	..	..	..	29	2	..	2
	C_2 (gravel)	192	5	1	..	..	..	198	12	..	12
	C_3	2	1	..	1	..	..	4	..	..	..
	C_3 (fine sand)	198	8	1	..	..	..	207	88	4	92
10	L	..	..	..	..	..	..	..	..	..	..
	F	..	..	..	..	..	..	..	..	..	..
	H	72	2	..	..	..	..	74	185	5	190
	A	920	53	20	5	3	2	1,003	253	23	276
	B	765	38	38	2	1	..	844	91	9	100

TABLE I (CONTINUED)

Profile	Horizon	Number of roots by size classes 0–.05″	.05–.1″	.1–.2″	.2–.5″	.5–1.0″	>1.0″	Total number roots	Number of roots per square foot of rock-free area 0–.05″	>.05″	Total
	C_1	304	12	12	..	..	..	328	31	2	33
	C_2	45	..	2	..	..	..	47	1	..	1
11	L	..	..	..	..	..	..	..	..	..	..
	F	77	2	..	..	..	..	79	160	4	164
	A	663	77	40	6	2	..	788	215	41	256
	B	494	27	16	..	..	..	537	80	7	87
	C_1	144	1	1	..	..	..	146	4	..	4
	C_2	40	1	3	..	..	..	44	5	..	5
	C_3	..	..	..	..	..	..	..	..	..	..
12	L	..	..	..	..	..	..	..	..	..	..
	F	167	..	..	..	..	..	167	235	..	235
	A	1,215	79	23	10	2	1	1,330	261	25	286
	B	1,352	88	25	14	1	..	1,480	115	11	126
	C_1	652	55	6	5	1	..	719	39	4	43
	C_1–1	208	9	..	..	..	..	217	51	2	53
	C_1–2	..	..	..	..	..	..	..	..	..	..
	C_2	2	..	..	..	..	..	2	..	..	..
	C_{2x}	31	6	..	..	..	..	37	4	1	5
	C_3	..	..	..	..	..	..	..	..	..	..
13	L	6	..	..	..	..	..	6	10	..	10
	F	298	1	..	..	..	..	299	634	2	636
	A	2,294	121	27	10	..	..	2,452	465	32	497
	B–1	1,102	53	10	8	4	..	1,177	108	7	115
	B–2	1,097	31	12	6	1	..	1,147	129	6	135

TABLE I (CONTINUED)

Profile	Horizon	Number of roots by size classes: 0–.05"	.05–.1"	.1–.2"	.2–.5"	.5–1.0"	>1.0"	Total number roots	Number of roots per square foot of rock-free area: 0–.05"	>.05"	Total
	B–3	264	11	5	1	..	..	281	161	10	171
	C1	648	11	8	4	..	..	671	118	4	122
	C2	143	3	1	..	..	..	147	9	..	9
	C3	..	..	..	..	..	..	..	..	..	..
14	L	..	..	..	..	..	..	..	..	..	..
	F	82	1	..	..	..	..	83	77	1	78
	H	220	8	..	..	..	..	228	458	17	475
	A	1,803	131	25	12	2	..	1,973	356	34	390
	B1	724	53	17	8	1	..	803	138	15	153
	B2	214	9	..	1	..	..	224	45	2	47
	C1	122	5	..	..	..	..	127	9	..	9
	C2	37	..	..	..	..	..	37	2	..	2
15	L	..	..	..	..	..	..	..	..	..	..
	F	37	..	..	..	..	..	37	46	..	46
	H	116	3	..	..	..	..	119	374	10	384
	A	1,971	215	51	16	1	..	2,254	246	35	281
	B	677	68	17	5	..	..	767	98	13	111
	C1	180	7	4	..	..	..	191	40	2	42
	C2	325	16	..	..	..	..	341	9	..	9
	C_{2_z}	21	2	1	..	..	..	24	3	..	3
	C3	20	7	4	2	..	..	33	3	2	5
16	L	..	..	..	..	..	..	..	..	..	..
	F	6	..	..	..	..	..	6	6	..	6
	A1	1,305	92	19	5	1	..	1,422	345	31	376

TABLE I (CONTINUED)

Pro-file	Horizon	Number of roots by size classes: 0-.05"	.05-.1"	.1-.2"	.2-.5"	.5-1.0"	>1.0"	Total number roots	Number of roots per square foot of rock-free area: 0-.05"	>.05"	Total
	A2	842	90	23	11			967	233	35	268
	H1	664	62	31	5			762	182	27	209
	B2	301	26	17				344	132	19	151
	C1	507	15	9				535	91	5	96
	C2	383	11	2				397	14	1	15
17	L										
	F	211	12	2				226	170	12	182
	H	170	6	3				179	486	26	512
	A	1,904	167	55	15	4	2	2,147	331	42	373
	B1	1,487	139	34	17	2		1,679	209	27	236
	B2	395	20	1				416	146	8	154
	C1	115	6					121	26		27
	C2	19						19			1
18	L										
	F										
	H	130						131	382	3	385
	A	1,298	90	30	9			1,428	251	25	276
	B1	722	54	15	14	2		807	155	18	173
	B2	646	31	8	2			687	66	4	70
	C1	46						46	3		3
	$C1_x$	278	3	4				286	67	2	69
	C_{2-1}	2						2			
	C_{2-2}	226	4					231	71	2	73
	C_{2-3}	7						7	1		1

TABLE I (CONTINUED)

Profile	Horizon	Number of roots by size classes 0–.05"	.05–.1"	.1–.2"	.2–.5"	.5–1.0"	>1.0"	Total number roots	Number of roots per square foot of rock-free area 0–.05"	>.05"	Total
	C_{2-4}	21	..	..	..	..	..	21	4	..	4
	C_{2-5}	..	..	..	..	..	..	..	..	..	..
19	L	..	..	..	..	..	..	..	..	..	..
	F	114	3	..	..	..	..	117	127	3	130
	H	114	10	2	..	..	..	126	356	38	394
	A	787	92	18	7	1	2	907	315	48	363
	B_1	1,191	85	31	9	5	1	1,322	204	22	226
	B_2	1,478	82	16	7	..	..	1,583	109	8	117
	C	30	..	..	..	..	..	30	1	..	1
	C_x	..	..	..	..	..	..	..	..	..	..
20	L	..	..	..	..	..	..	..	..	..	..
	F	105	12	1	..	..	..	118	104	13	117
	H	114	17	2	..	1	..	134	335	59	394
	A_1	461	36	12	11	3	..	523	314	42	356
	A_2	640	71	23	14	1	1	750	103	18	121
	B	670	52	13	2	1	..	738	26	2	28
	C	22	..	..	..	..	..	22	2	..	2
21	L	..	..	..	..	..	..	..	..	..	..
	F	52	1	..	..	..	..	53	104	2	106
	A	772	82	26	4	1	3	888	251	38	289
	B_1	784	69	33	8	1	1	896	163	23	186
	B_2	1,311	107	25	9	1	2	1,455	109	12	121
	C	70	2	..	..	..	..	72	28	1	29

TABLE II. AVERAGE NUMBER OF ROOTS IN THE SOIL PROFILE HORIZONS

Horizon	*Average number of roots in a cross section 10 feet long*	*Average number of roots per square foot of cross section*
L		
F	88 ± 20	137 ± 37
H	156 ± 22	407 ± 37
A	1448 ± 160	322 ± 23
A_1	688 ± 247	314 ± 40
A_2	739 ± 101	162 ± 37
B	1282 ± 187	107 ± 12
B_1	916 ± 131	163 ± 21
B_2	611 ± 181	84 ± 17
C	373 ± 77	11 ± 2
C_f	165 ± 45	25 ± 8

TABLE III. MECHANICAL ANALYSES AND MOISTURE EQUIVALENT VALUES

Profile	Horizon	Gravel > 2 mm. per cent	Composition of fraction < 2 mm. Sand per cent	Silt per cent	Clay per cent	"Total colloids" per cent	Moisture equivalent per cent
3	A1	5	72.5	22.5	5.0	11.5	21.6
	A2	22	73.5	23.5	3.0	9.0	15.8
	B1	10	72.0	26.0	2.0	3.5	14.7
	B2	12	72.5	27.0	0.5	1.5	10.3
	C1	23	70.5	25.0	4.5	7.5	9.7
	C2	17	74.0	20.0	6.0	11.0	7.9
4	A	11	80.0	15.5	4.5	8.5	22.7
	B	25	82.5	17.0	0.5	3.0	14.7
	C1	23	96.5	3.5	..	1.5	3.1
	C2	66	99.5	0.5	..	..	2.4
	C3	43	99.0	1.0	..	1.0	1.8
	C3 (fine sand)	..	79.0	21.0	..	3.5	5.3
7	A1	1	66.0	26.0	8.0	12.5	19.8
	A2	1	68.0	26.5	5.5	7.5	15.4
	B1	1	71.5	25.5	3.0	5.5	12.1
	B2	1	71.5	25.0	3.5	6.5	10.7
	C1	..	57.5	39.0	3.5	6.5	11.7
	C2	1	49.0	37.5	13.5	21.5	26.7
	C3	13	100.0	..	..	..	2.4
8	A	10	86.0	9.5	4.5	8.0	14.1
	B1	15	93.5	5.0	1.5	3.5	13.4
	B2	32	99.5	0.5	..	0.5	1.9
	C1	4	100.0	..	..	..	0.9
	C2	3	99.5	0.5	..	..	0.8
9	A	15	81.0	16.0	3.0	7.0	15.4
	B	35	85.5	14.5	..	..	11.9
	C1	42	97.0	2.5	0.5	1.0	4.0
	C2 (sand)	17	99.5	0.5	..	..	2.1
	C2 (gravel)	71	97.5	2.5	..	0.5	2.8
	C3	24	100.0	..	..	..	1.4
	C3 (fine sand)	13	79.5	19.5	1.0	4.5	7.6
10	A	5	71.0	24.0	5.0	8.5	19.0
	B	10	68.0	30.0	2.0	2.0	12.6
	C1	20	80.0	19.5	0.5	1.0	5.6
	C2	17	79.0	20.0	1.0	2.0	3.1
	C1 (special)*	15	84.0	15.0	1.0	4.5	5.5
	C2 (special)*	14	84.0	14.5	1.5	2.0	4.2
11	A	23	76.5	19.0	4.5	8.5	22.1
	B	51	83.0	15.0	2.0	5.5	13.1

TABLE III (CONTINUED)

Profile	Horizon	Gravel > 2 mm. per cent	Composition of fraction < 2 mm. Sand per cent	Silt per cent	Clay per cent	"Total colloids" per cent	Moisture equivalent per cent
	C1	38	98.5	1.5	..	..	2.0
	C2	23	98.0	1.0	1.0	1.0	1.5
	C3	..	79.0	20.0	1.0	3.0	5.1
12	A	..	82.2	13.6	4.2	4.7	12.9
	B	1	77.1	21.1	1.8	2.8	7.4
	C1	1	81.9	15.3	2.8	3.6	3.4
	C1–1	..	62.3	34.1	3.6	7.1	8.5
	C1–2	1	94.2	3.0	2.8	3.1	1.9
	C2	2	65.2	22.1	12.7	16.7	14.9
13	A	2	83.0	12.1	4.9	6.4	9.8
	B–1	1	90.2	8.0	1.8	2.3	2.5
	B–2	2	82.3	16.4	1.3	2.0	9.5
	B–3	1	83.1	11.1	5.8	7.4	9.4
	C1	5	72.1	14.0	13.9	17.3	13.9
	C2	71	97.0	1.7	1.3	2.0	2.1
14	A	1	81.7	13.9	4.4	7.1	13.5
	B1	1	78.1	21.4	0.5	1.1	10.8
	B2	1	82.3	16.2	1.5	2.1	4.6
	C1	12	91.5	6.5	2.0	3.0	3.2
	C2	2	50.4	30.1	19.5	27.8	19.6
15	A	20	79.3	15.2	5.4	9.0	14.6
	B	24	81.2	18.0	0.8	1.3	14.4
	C1	20	93.9	4.6	1.5	2.5	3.2
	C2	36	97.5	1.0	1.5	2.0	1.7
	$C2_z$	9	97.5	1.0	1.5	2.0	1.4
	C1 (special)†	33	96.0	2.5	1.5	1.5	2.7
	C2 (special)†	23	96.5	1.5	2.0	2.5	1.8
16	A1	8	63.7	28.1	8.2	13.8	19.7
	A2	11	65.3	27.6	7.1	12.4	17.3
	B1	30	68.8	25.1	6.1	8.3	13.9
	B2	32	69.4	28.6	2.0	3.2	11.5
	C1	29	66.2	25.7	8.1	14.6	11.9
	C2	21	70.8	20.6	8.6	15.1	9.0
	C2 (special–1)‡	34	69.8	21.1	9.1	15.1	11.3
	C2 (special–2)‡	30	69.7	21.2	9.1	15.1	9.7
17	A	11	63.6	30.8	5.6	9.2	19.4
	B1	15	71.9	24.0	4.1	7.2	13.3
	B2	24	75.2	20.4	4.4	7.9	8.9
	C1	19	75.5	17.9	6.6	11.9	7.3
	C2	19	73.9	17.8	8.3	13.0	7.2

TABLE III (CONTINUED)

Pro-file	Horizon	Gravel > 2 mm. per cent	Composition of fraction < 2 mm. Sand per cent	Silt per cent	Clay per cent	"Total colloids" per cent	Moisture equivalent per cent
18	A	8	77.6	17.5	4.9	8.1	14.1
	B1	11	75.7	23.5	0.8	1.0	9.6
	B2	15	84.9	13.3	1.8	2.5	7.1
	C1	25	95.0	4.0	1.0	2.0	2.3
	$C1_x$	..	61.6	33.9	4.5	9.3	11.1
	C2–1	3	95.0	3.0	2.0	2.5	1.5
	C2–2 (upper part)	..	73.7	23.8	2.5	4.2	4.8
	C2–2 (lower part)	1	51.6	43.0	5.4	10.1	12.7
	C2–3	6	95.3	3.2	1.5	2.2	1.5
	C2–4	..	63.4	33.6	3.0	5.0	5.8
	C2–5	..	94.6	4.0	1.4	2.4	1.8
19	A	7	77.5	17.4	5.1	8.7	14.6
	B1	15	77.6	19.3	3.1	4.1	11.6
	B2	18	79.9	17.1	3.0	4.5	8.7
	C	51	86.9	11.6	1.5	3.0	2.5
	C_x	3	94.0	4.0	2.0	2.5	2.1
	B2 (special) §	49	91.0	7.5	1.5	2.5	4.7
	C (special) §	49	92.0	6.0	2.0	2.5	2.3
20	A1	..	78.7	17.2	4.0	6.6	9.8
	A2	..	88.0	9.0	3.0	5.0	4.4
	B	..	95.5	3.0	1.5	2.0	2.2
	C	25	96.5	2.0	1.5	2.0	2.1
	B (special) ‖	..	91.9	5.1	3.0	3.5	6.3
	C (special–1) ‖	1	92.4	5.6	2.0	2.5	3.2
	C (special–2) ‖	35	94.0	4.8	1.2	2.2	4.8
21	A	6	72.5	22.7	4.8	8.6	21.7
	B1	19	66.5	27.9	5.6	9.4	17.3
	B2	47	77.7	18.2	4.1	5.8	11.8
	C	67	90.7	5.8	3.5	5.2	6.3

* The C1 special sample was taken from the irregular extension containing roots at a depth of 4 feet; the C2 special sample was taken from the immediately adjacent material lacking roots.

† The C1 special sample was taken from the tongues which penetrate into the C2 at either end of the profile; the C2 special sample came from the adjacent material lacking roots.

‡ The C2 special–1 sample was taken from a streak containing roots; the C2 special–2 sample was taken from adjacent material lacking roots.

§ The B2 special sample came from the tongue near the center of the profile; the C special sample came from the adjacent material lacking roots.

‖ The B special sample was taken from the narrow tongue containing roots at the left end of the transect; the C special–1 sample was taken from the adjacent material lacking roots; the C special–2 sample was taken from the material containing roots directly below the tongue of B.

TABLE IV. TOTAL NITROGEN VALUES

(*Per cent*)

Horizon	Profile number																
	3	*4*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*
L	0.959	0.828	0.991	0.949	0.699	0.929	0.662	0.718	0.931	0.883	0.889	0.984	1.500	0.982	1.426	0.989	0.898
F	1.559	0.650	1.434	1.416	1.297	1.534	1.836	1.513	1.492	1.312	1.417	1.474	1.660	1.641	1.671	1.681	1.523
H	..	..	..	1.607	..	1.462	..	..	..	1.305	0.842	..	1.429	1.262	1.568	1.939	..
A	..	0.176	..	0.118	0.121	0.169	0.276	0.138	0.078	0.095	0.135	..	0.242	0.117	0.141	..	0.290
A_1	0.127	..	0.152	..	..	..	..	..	..	..	..	0.205	..	..	..	0.116	..
A_2	0.077	..	0.079	..	..	..	..	..	..	..	..	0.161	..	..	..	0.027	..
B	..	0.069	..	..	0.050	0.049	0.089	0.038	..	..	0.081	..	..	..	..	0.023	..
B–1	..	..	..	..	..	..	..	..	0.006	..	..	..	..	..	..	..	..
B–2	..	..	..	..	..	..	..	..	0.032	..	..	..	..	..	..	..	..
B–3	..	..	..	..	..	..	..	..	0.025	..	..	..	..	..	..	..	..
B_1	0.049	..	0.071	0.077	..	..	..	..	..	0.031	..	0.085	0.089	0.062	0.064	..	0.127
B_2	0.021	..	0.044	0.012	..	..	..	..	..	0.012	..	0.043	0.038	0.026	0.014	..	0.058
C	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.002	0.012	0.021
C_x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.002	..	..
C_1	0.013	0.004	0.044	0.000	0.006	0.008	0.009	0.003	0.018	0.002	0.021	0.030	0.018	0.013	..	..	..
C_{1x}	..	..	..	..	..	..	..	..	..	..	..	..	..	0.016	..	..	..
C_1–1	..	..	..	..	..	..	..	0.010	..	..	..	..	..	..	..	..	..
C_1–2	..	..	..	..	..	..	..	0.000	..	..	..	..	..	..	..	..	..
C_2	0.000	0.003	0.044	0.008	..	0.005	0.006	0.015	0.003	0.016	0.009	0.019	0.011	..	..	..	..
C_{2z}	..	..	..	..	..	..	..	..	..	..	0.008	..	..	..	..	..	..
C_2s*	..	..	..	..	0.000	..	..	..	..	..	..	..	..	..	..	..	..
C_2g*	..	..	..	..	0.001	..	..	..	..	..	..	..	..	..	..	..	..
C_2–1	..	..	..	..	..	..	..	..	..	..	..	..	..	0.004	..	..	..
C_2–2	..	..	..	..	..	..	..	..	..	..	..	..	..	0.008	..	..	..
C_2–3	..	..	..	..	..	..	..	..	..	..	..	..	..	0.003	..	..	..
C_2–4	..	..	..	..	..	..	..	..	..	..	..	..	..	0.026	..	..	..
C_2–5	..	..	..	..	..	..	..	..	..	..	..	..	..	0.000	..	..	..
C_3	..	0.000	0.011	..	0.000	..	0.011	..	..	..	0.006	..	..	..	..	..	..
C_3fs*	..	0.001	..	..	0.005	..	..	..	..	..	..	..	..	..	..	..	..

* s = sand; g = gravel; fs = fine sand.

TABLE V. BASE EXCHANGE VALUES

Profile	*Horizon*	*Total exchange capacity, m.e.*	*Exchangeable hydrogen, m.e.*	*Exchangeable bases, m.e.*	*Base saturation per cent*
4	C3	1.30	0.57	0.73	56.15
	C3 (fine sand)	1.85	0.57	1.28	69.19
8	L	48.5	45.8	2.7	5.57
	F	72.5	67.0	5.5	7.59
	H	90.0	88.1	1.9	2.11
	A	9.65	5.65	4.00	41.45
	B1	8.20	5.29	2.91	35.49
	B2	1.00	0.95	0.5	5.00
	C1	0.65	0.60	0.5	7.69
	C2	0.20	0.18	0.2	10.00
9	C3	1.50	0.43	1.07	71.33
	C3 (fine sand)	4.40	2.99	1.41	32.04
10	L	43.0	42.0	1.0	2.33
	F	55.5	54.6	0.9	1.62
	H	56.0	52.9	3.1	5.54
	A	12.2	10.6	1.6	13.11
	B	4.6	3.9	0.7	15.22
	C1	1.6	1.5	0.1	6.25
	C2	0.20		0.20	100.00
	C1 (special)	1.55	0.99	0.56	36.13
	C2 (special)	0.40		0.40	100.00
12	L	49.29	43.42	5.87	11.91
	F	71.09	53.11	17.98	25.29
	A	8.45	7.33	1.12	13.24
	B	3.34	2.92	0.42	12.57
	C1	1.00	0.51	0.49	49.00
	C1–1	1.93	1.09	0.84	43.52
	C1–2	0.49	0.18	0.31	63.26
	C2	3.20	1.19	2.01	62.81
13	L	55.09	51.26	3.83	6.95
	F	72.46	62.06	10.40	14.35
	A	5.65	5.04	0.61	10.80
	B–1	1.31	1.08	0.23	17.56
	B–2	3.73	2.54	1.19	31.90
	B–3	1.00	0.81	0.19	19.00
	C1	5.43	2.43	3.00	55.25
	C2	1.35	1.09	0.26	19.26

TABLE V (CONTINUED)

Profile	Horizon	*Total exchange capacity, m.e.*	*Exchangeable hydrogen, m.e.*	*Exchangeable bases, m.e.*	*Base saturation per cent*
14	L	50.19	45.81	4.38	8.73
	F	81.56	62.54	19.02	23.32
	H	74.05	72.86	1.19	1.61
	A	6.51	5.30	1.21	18.59
	B_1	3.42	2.92	0.50	14.62
	B_2	1.61	1.23	0.38	23.60
	C_1	1.11	1.09	0.02	18.02
	C_2	7.90	4.36	3.54	44.81
15	C_1 (special)*	1.65	0.57	1.08	65.45
	C_2 (special)*	0.80	0.28	0.28	65.00
16	L	56.32	50.82	5.50	9.77
	F	71.36	61.34	10.02	14.04
	A_1	13.58	9.71	3.87	28.50
	A_2	8.65	7.38	1.27	14.68
	B_1	4.87	4.78	0.09	1.85
	B_2	4.05	3.31	0.74	18.27
	C_1	3.67	2.92	0.75	20.44
	C_2	4.87	2.92	1.95	40.04
	C_2 (special–1)†	5.26	3.94	1.32	25.09
	C_2 (special–2)†	3.00	2.18	0.82	27.33
17	L	67.93	57.93	10.00	14.72
	F	100.00	96.83	3.17	3.17
	H	105.41	104.37	1.04	0.99
	A	16.51	14.05	2.46	14.90
	B_1	7.51	7.35	0.16	2.13
	B_2	3.62	3.27	0.35	9.67
	C_1	1.26	1.09	0.17	13.49
	C_2	0.90	0.51	0.39	43.33
18	C_1	1.00	0.86	0.14	14.00
	C_{1x}	3.10	0.23	2.87	92.58
	C_2–2 (upper part)	3.55	2.14	1.41	39.72
	C_2–2 (lower part)	3.80	1.57	2.23	58.68
	C_2–3	2.60	0.77	1.83	70.38
19	L	61.48	59.44	2.04	3.32
	F	87.60	77.68	9.92	11.32
	H	79.78	73.20	6.58	8.25
	A	10.36	7.88	2.48	23.94
	B_1	5.60	4.66	0.94	16.79

TABLE V (CONTINUED)

Profile	*Horizon*	*Total exchange capacity, m.e.*	*Exchangeable hydrogen, m.e.*	*Exchangeable bases, m.e.*	*Base saturation per cent*
	B2	3.12	1.42	1.70	54.48
	C	0.56	0.49	0.07	12.50
	C_x	0.81	0.70	0.11	13.58
	B2 (special)‡	1.31	1.07	0.24	18.32
	C (special)‡	0.91	0.48	0.43	47.25
20	B (special)§	5.50	4.84	0.66	12.00
	C (special–1)§	3.95	3.56	0.39	9.87
	C (special–2)§	2.65	2.14	0.51	19.24
21	L	56.59	54.23	2.36	4.17
	F	72.82	55.55	17.27	23.72
	A	18.63	11.91	6.72	36.07
	B1	12.87	8.81	4.06	31.55
	B2	6.56	4.93	1.63	24.85
	C	3.26	2.12	1.14	34.97

* The C1 special sample was drawn from the tongues at either end of the trench; the C2 special sample was taken from the adjacent material lacking roots.

† The C2 special–1 sample was obtained at a depth of about 2½ feet in a streak of material containing roots; the C2 special–2 sample was obtained from adjacent material lacking roots.

‡ The B2 special sample was obtained from the tongues which penetrate the C; the C special sample was obtained from adjacent material lacking roots.

§ The B special sample was taken from the narrow tongue with roots at the left side of the profile; the C special–1 sample was taken in the streak containing roots below the tongue of B; the C special–2 sample was taken from the adjacent material lacking roots.

TABLE VI. HYDROGEN ION CONCENTRATION (pH) VALUES

Horizon	*Profile number* 3	4	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
L	4.4	4.5	4.7	4.2	4.3	4.5	4.7	4.4	4.5	4.5	4.6	4.8	4.3	4.3	4.5	4.4	4.5
F	4.5	4.6	4.6	4.2	4.4	4.8	4.7	4.7	4.6	4.6	4.6	5.0	4.0	4.4	4.5	4.5	4.9
H	..	..	..	3.9	..	4.8	..	..	..	4.4	4.6	..	3.8	4.3	4.3	4.7	..
A	..	4.6	..	4.7	4.9	5.0	5.1	5.0	5.2	5.5	5.2	..	4.8	5.0	5.3	..	5.3
A_1	5.0	..	4.5	..	..	..	..	..	..	..	..	5.6	..	..	..	4.8	..
A_2	5.0	..	4.8	..	..	..	..	..	..	..	..	5.4	..	..	..	4.9	..
B	..	5.0	..	..	5.3	5.3	6.1	5.3	..	..	5.4	5.4	..	..	..	6.3	..
B–1	..	..	..	..	..	..	..	..	5.5	..	..	..	..	..	..	..	..
B–2	..	..	..	..	..	..	..	..	5.6	..	..	..	..	..	..	..	..
B–3	..	..	..	..	..	..	..	..	5.3	..	..	..	..	..	..	..	..
B_1	4.9	..	5.1	5.1	..	..	..	..	..	5.6	..	5.4	5.2	5.3	5.5	..	5.3
B_2	5.3	..	5.3	5.3	..	..	..	..	..	5.5	..	5.5	5.3	5.3	5.6	..	5.3
C	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5.6	5.5	5.4
C_x	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5.5	..	..
C_1	5.3	5.3	5.2	5.3	5.3	5.4	5.8	5.4	5.4	5.5	5.4	5.4	5.5	5.3	..	..	..
C_{1x}	..	..	..	..	..	..	..	..	..	..	..	..	..	5.3	..	..	..
C_1–1	..	..	..	..	..	..	..	5.2	..	..	..	..	..	..	..	..	..
C_1–2	..	..	..	..	..	..	..	5.6	..	..	..	..	..	..	..	..	..
C_2	5.5	5.4	5.6	5.1	..	5.6	6.4	5.4	5.5	5.4	5.5	5.6	5.7	..	..	..	..
C_2s*	..	..	..	..	5.2	..	..	..	..	..	..	..	..	..	..	..	..
C_2g*	..	..	..	..	5.2	..	..	..	..	..	..	..	..	..	..	..	..
C_{2z}	..	..	..	..	..	..	..	..	..	..	5.7	..	..	..	..	..	..
C_2–1	..	..	..	..	..	..	..	..	..	..	..	..	..	5.5	..	..	..
C_2–2	..	..	..	..	..	..	..	..	..	..	..	..	..	5.4	..	..	..
C_2–3	..	..	..	..	..	..	..	..	..	..	..	..	..	5.6	..	..	..
C_2–4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
C_2–5	..	..	..	..	..	..	..	..	..	..	..	..	..	5.3	..	..	..
C_3	..	5.5	5.5	..	5.5	..	5.5	..	..	..	5.5	..	..	..	..	..	..
C_3fs*	..	5.3	..	..	..	5.3	..	..	..	..	..	..	..	..	..	..	..

* s = sand; fs = fine sand; g = gravel.

FIGURES

FIGURE 1

STEM map showing distribution and diameter at breast height of trees in the vicinity of station 13. The position of the trench is indicated by the small rectangle near the center of the plot; size of area mapped, 60 by 70 feet.

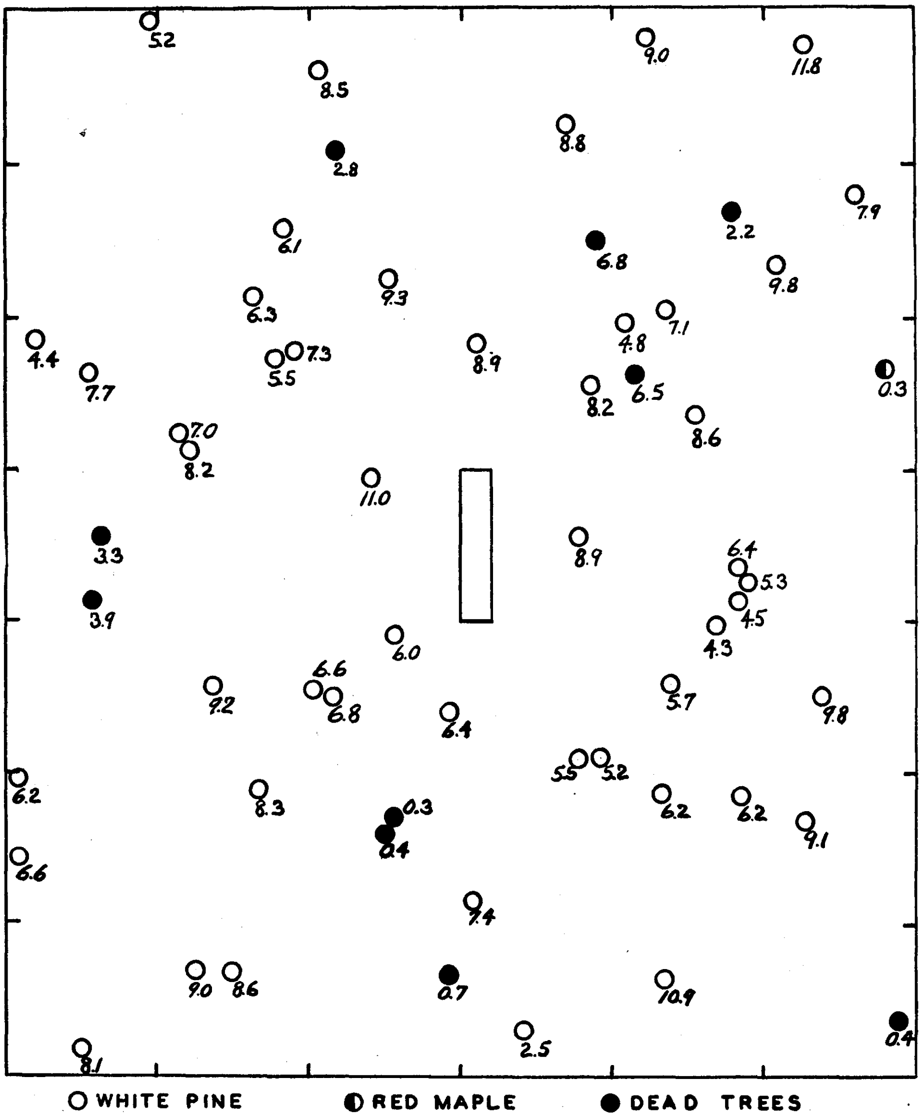
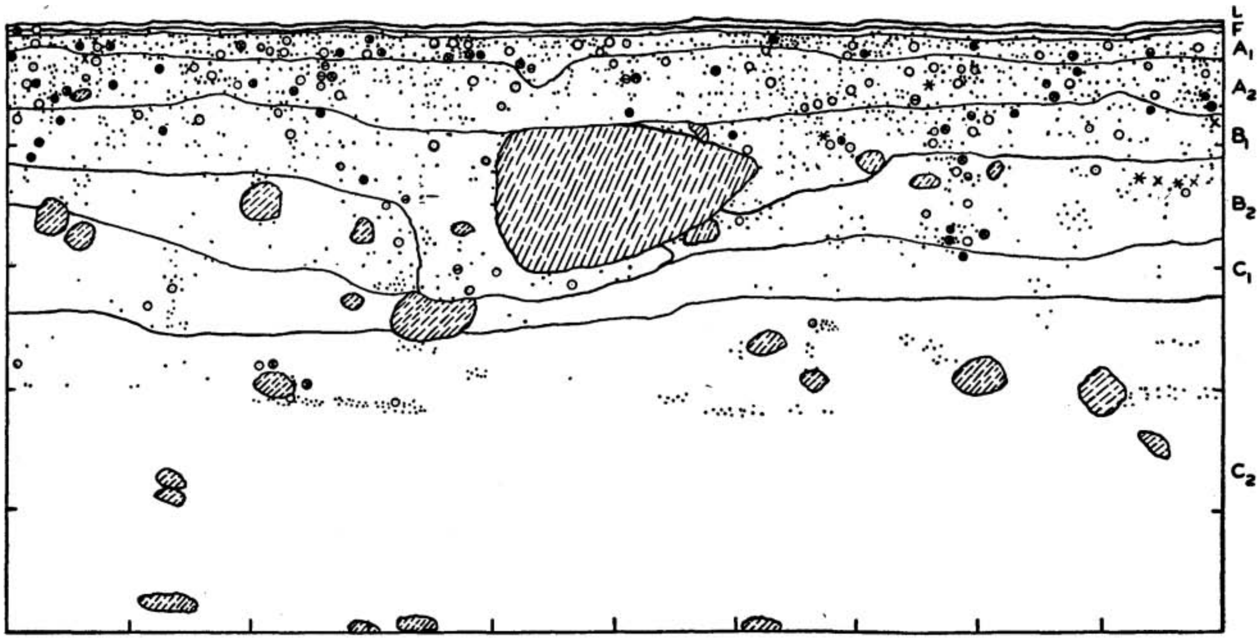

5.2
8.5
9.0
11.8
8.8
2.8
7.9
2.2
6.8
6.1
9.8
9.3
6.3
7.1
4.8
4.4
7.3
5.5
8.9
0.3
7.7
6.5
8.2
8.6
7.0
8.2
11.0
3.3
8.9
6.4
5.3
3.9
4.5
4.3
6.0
6.6
9.2
6.8
5.7
9.8
6.4
5.5
5.2
6.2
8.3
0.3
6.2
6.2
9.1
0.4
6.6
7.4
9.0
8.6
0.7
10.9
0.4
2.5
8.1
WHITE PINE
RED MAPLE
DEAD TREES

FIGURE 2

VIEW showing condition of forest and ground cover in the vicinity of'station 10. The stand is about 30 years old.

FIGURE 3

VIEW showing condition of forest and ground cover in the vicinity of station 12. The stand is about 40 years old.



L
F
A_1
A_2
B_1
B_2
C_1
C_2

FIGURE 5

HORIZON features and root distribution in profile 4. Most of the roots occur in the A and B horizons in the upper 18 inches of the soil body. In contrast to these layers, which contain considerable fine material, the C horizons are very coarse textured. A notable exception is the stratum of fine sand in the C_3 at a depth of $5\frac{1}{2}$ feet. In the lower part of this fine sand layer are numerous roots.

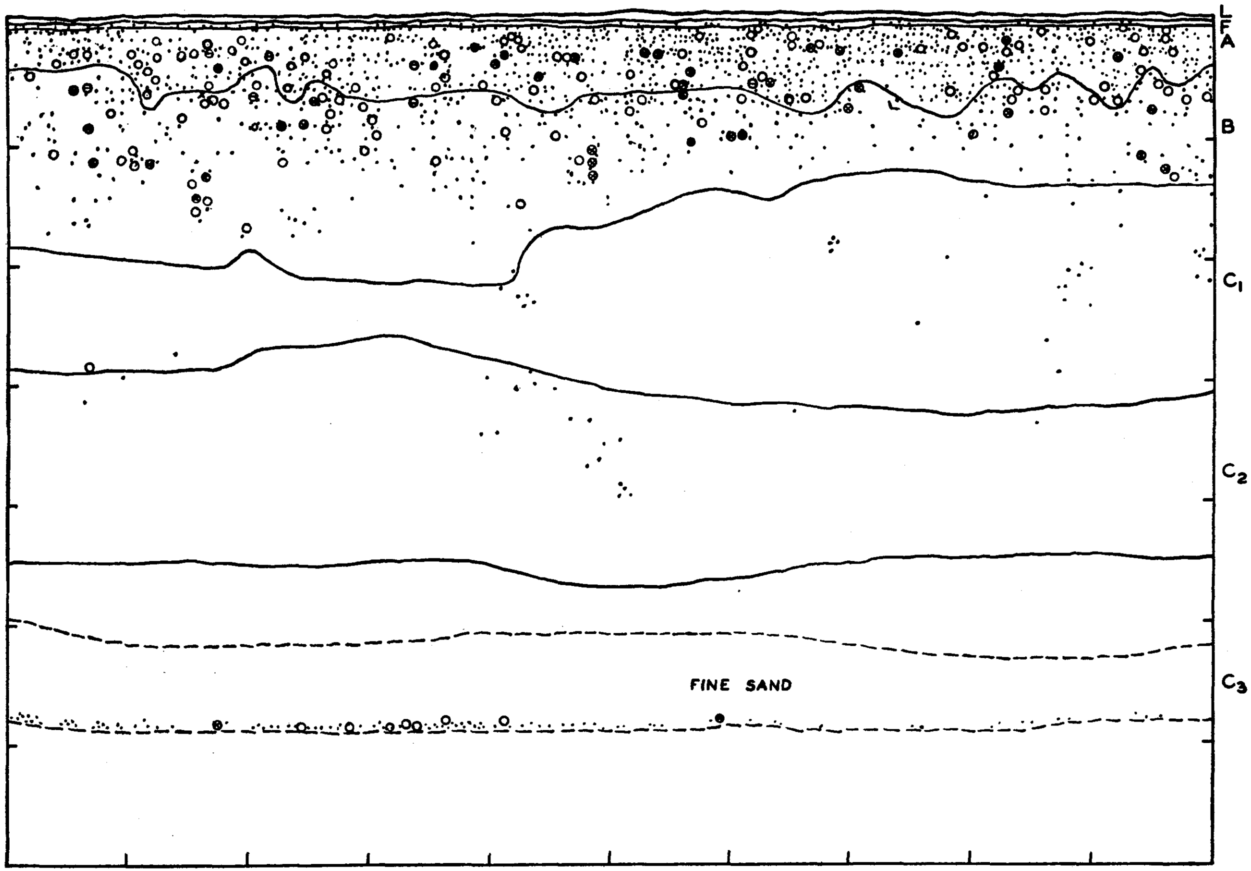

L
F
A
B
C1
C2
FINE SAND
C3

FIGURE 6

HORIZON features and root distribution in profile 7. The uniform distribution of roots and the depth to which they penetrate are noteworthy. The soil body to a depth of about 4½ feet is being exploited by roots. Absence of roots in the C_a horizon seems to be associated with the coarse sandy texture of the soil material and the influence of the water table. In August, 1934, the water table was encountered 5 feet 4 inches below the surface.

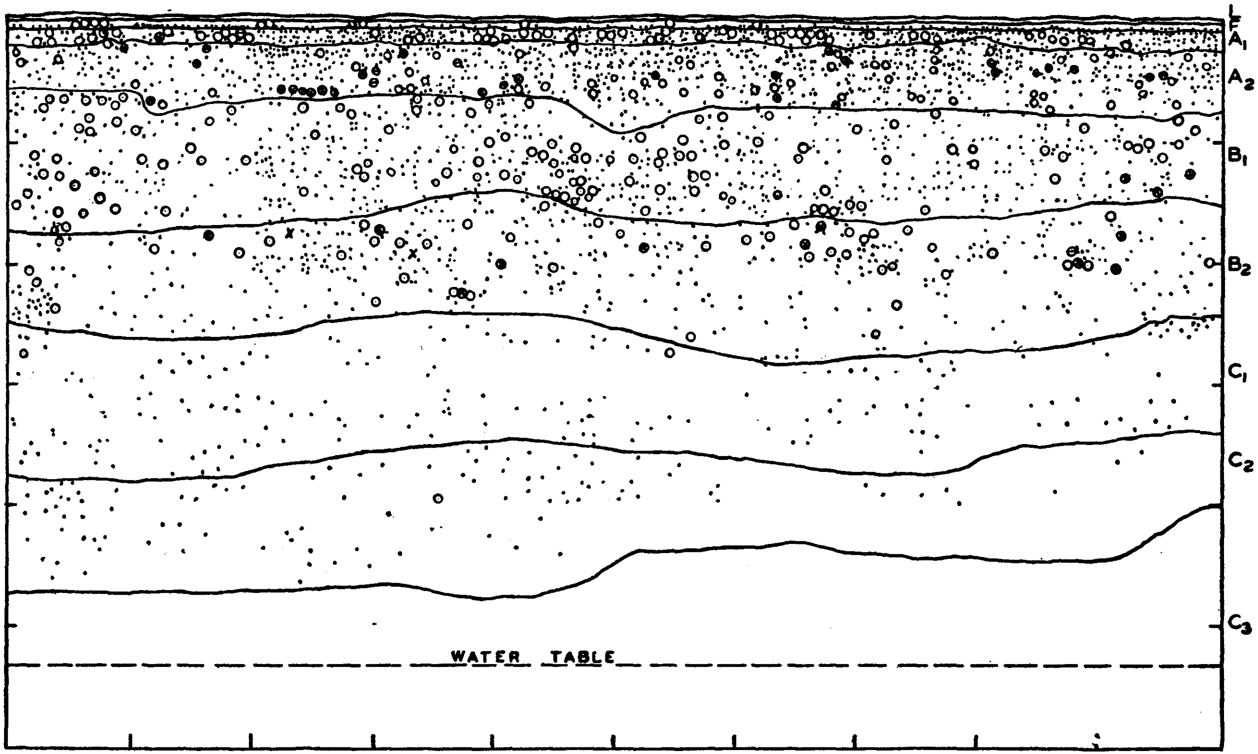

L
F
A1
A2
B1
B2
C1
C2
C3
WATER TABLE

FIGURE 7

HORIZON features and root distribution in profile 8. Most of the roots are confined to the A and B_1 horizons in the upper 14 inches. The A horizon contains 14 per cent silt and clay and the B_1 horizon contains 6.5 per cent. In the lower layers silt and clay are practically lacking. A few roots occur in streaks and spots in the C horizons where organic and inorganic colloidal matter is concentrated. The general lack of roots in the lower horizons reflects.the very low moisture holding capacity of these layers.

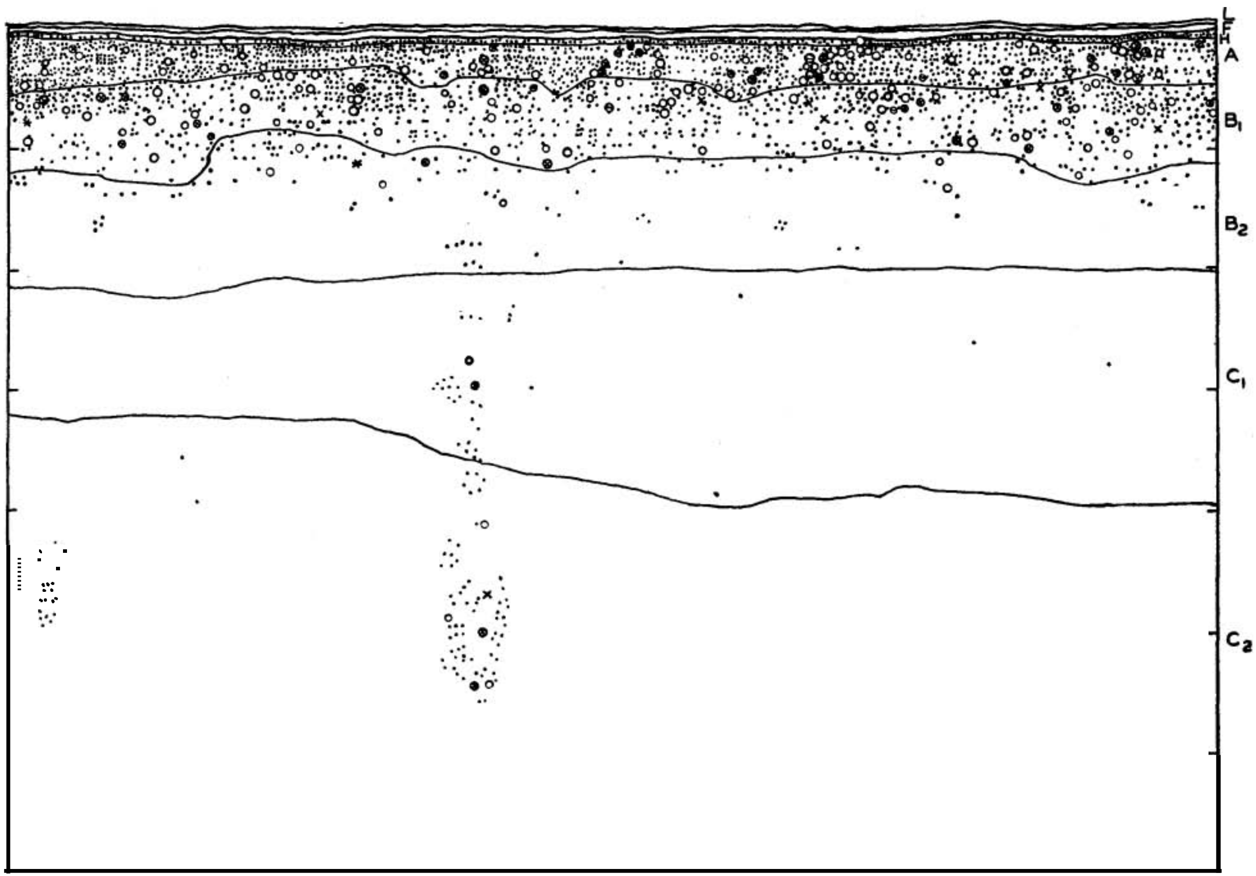

L
F
H
A
B_1
B_2
C_1
C_2

FIGURE 8

HORIZON features and root distribution in profile 9. Here, as in profile 4, is a concentration of roots in the A and B horizons. These layers contain more fine material than the C horizons with the exception of the stratum of fine sand in the C_3. The reason for development of roots in the gravelly lower part of the C_2 is not clear but the concentration in the fine sand stratum in the C_3 is evidently a response to more favorable moisture relations.

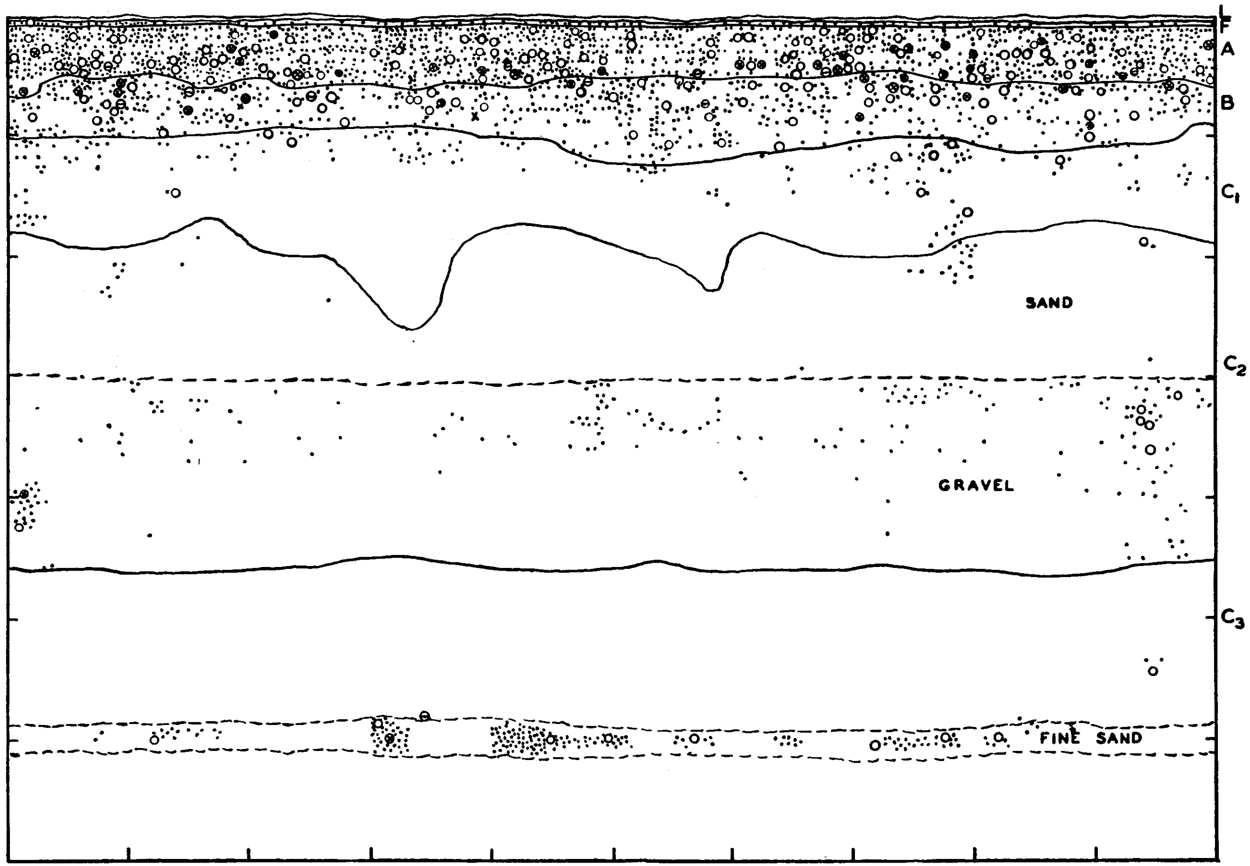

L
F
A
B
C1
SAND
C2
GRAVEL
C3
FINE SAND

FIGURE 9

HORIZON features and root distribution in profile 10. The outstanding feature in this profile is the lack of roots in the C_2 horizon; with few exceptions the roots are confined to the A, B, and C_1 horizons in the upper two feet of the soil body. The C_2 horizon is light gray to grayish white and very compact. The moisture equivalent of the C_2 material is 3.1 per cent which is considerably lower than in the A, B, and C_1 layers.

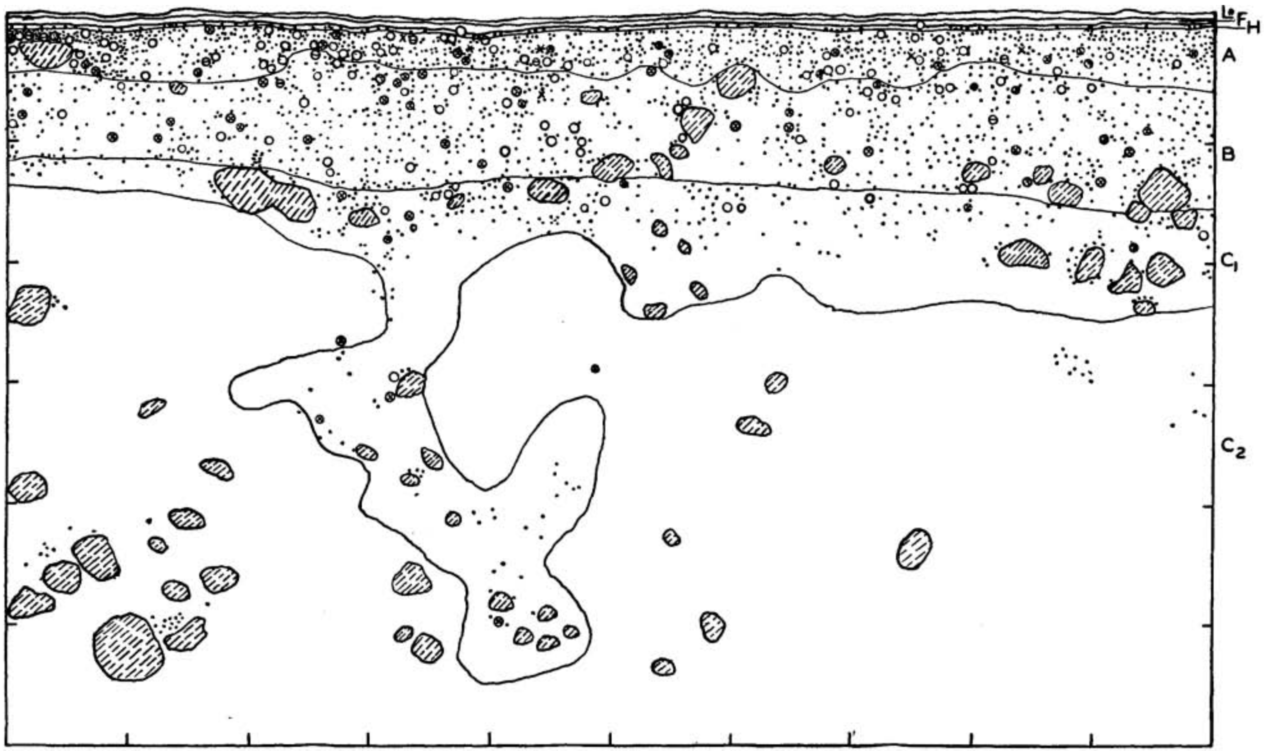

L
F
H
A
B
C1
C2

FIGURE 10

HORIZON features and root distribution in profile 11. The concentration of roots in the A and B horizons of this profile profile is remarkable in view of the shallow nature of these members. In the C horizons only a few roots occur and they tend to be localized.

In the A horizon the content of silt and clay is 23.5 per cent and in the B horizon 17.0 per cent. These amounts contrast sharply with the values of 1.5 per cent silt and clay in the C_1 and 2.0 per cent in the C_2.

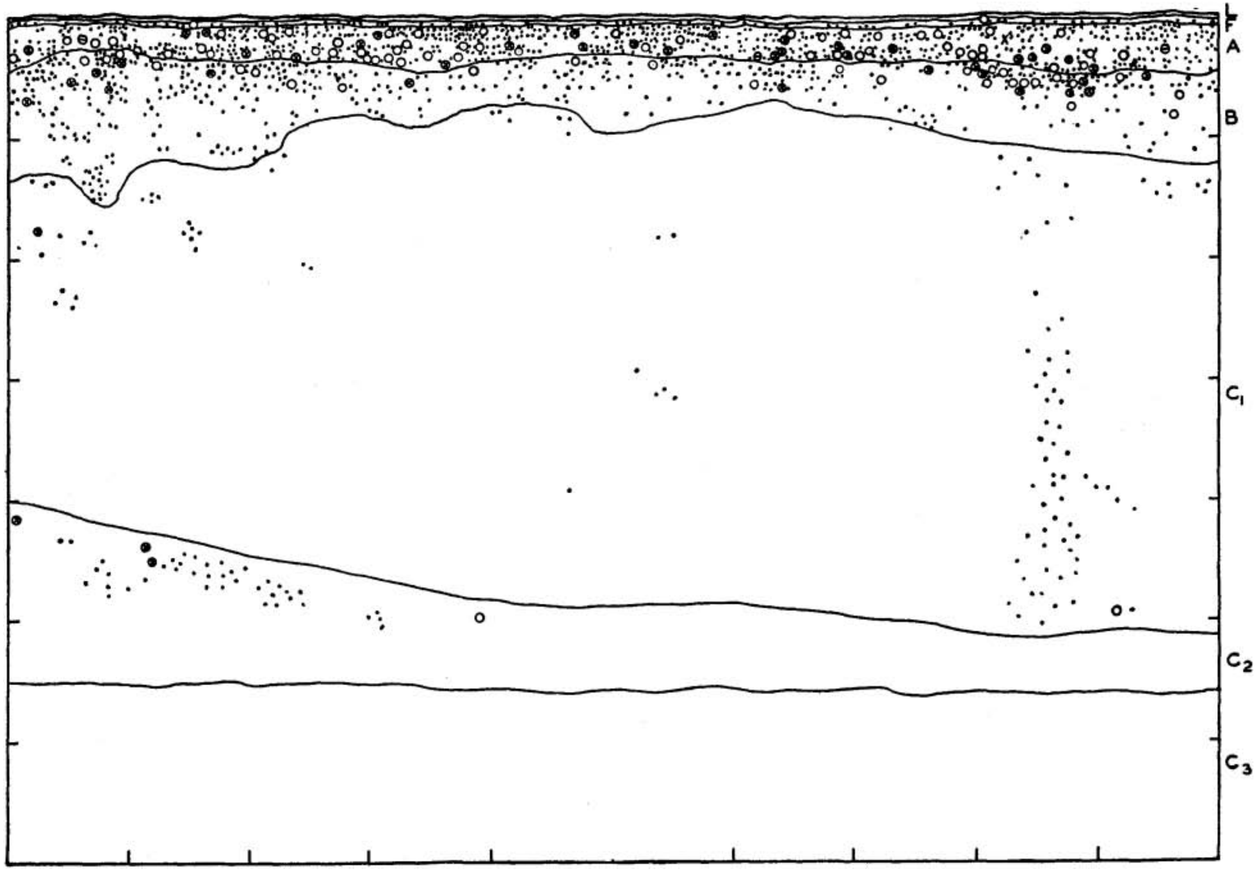

L
F
A
B
C1
C2
C3

FIGURE 11

HORIZON features and root distribution in profile 12. In this and all succeeding charts the periphery of roots larger than 1.0 inch diameter is drawn to scale.

The greatest concentration of roots is in the A and B horizons which occupy the upper two feet of the soil body. In the C_1 horizon roots are absent from the coarse sand material (C_1-2) but are scattered through the bodies of loamy medium sand (C_1) and fine sandy loam (C_{1-1}). It is not surprising that in general roots are lacking in the C_2 and C_{2x} layers which are gray in color and very compact.


L
F
A
B
C1
C2
C2x
C3
1
2
3
4
5
6

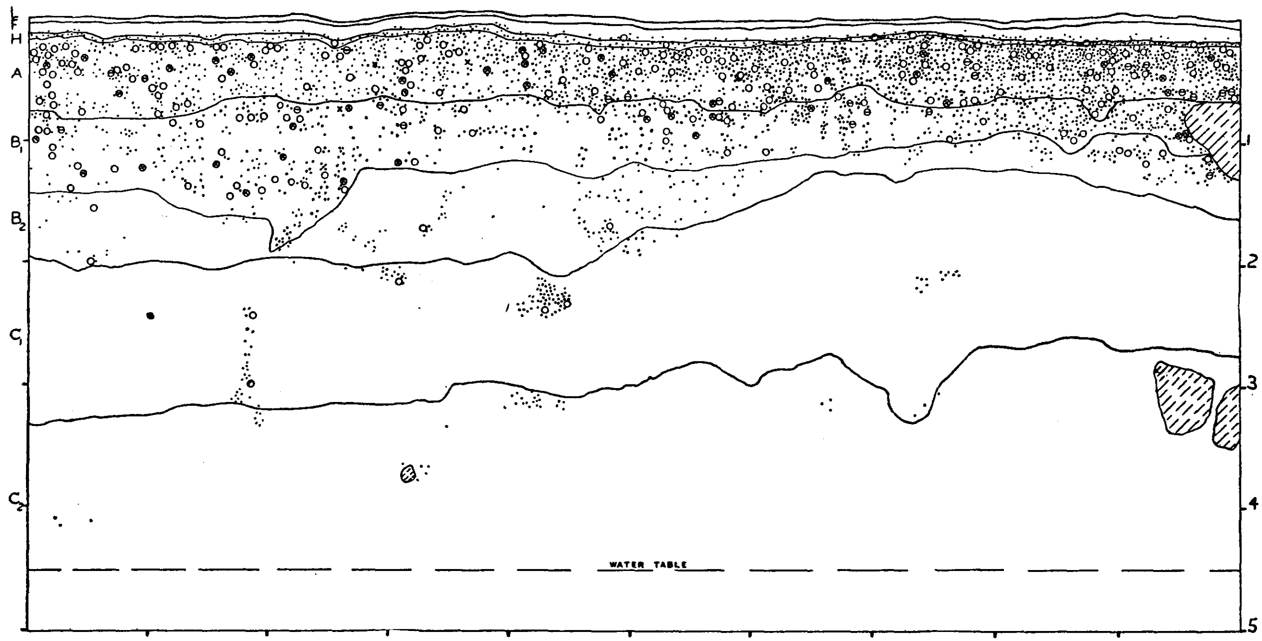
FIGURE 12

HORIZON features and root distribution in profile 13. In this profile root distribution is fairly good to a depth of about 3 feet. Below this depth, in the C_2 and C_a, roots are almost lacking. Failure of roots to develop more deeply may be explained by the coarse texture of the lower horizons and their low moisture equivalent values. The content of silt and clay in the C_2 was 3.0 per cent whereas the lowest value noted in the horizons above was 9.8 per cent in the B-1.

L
F
A
B
C1
C2
C3
1
2
3
1
2
3
4
5
6

FIGURE 13

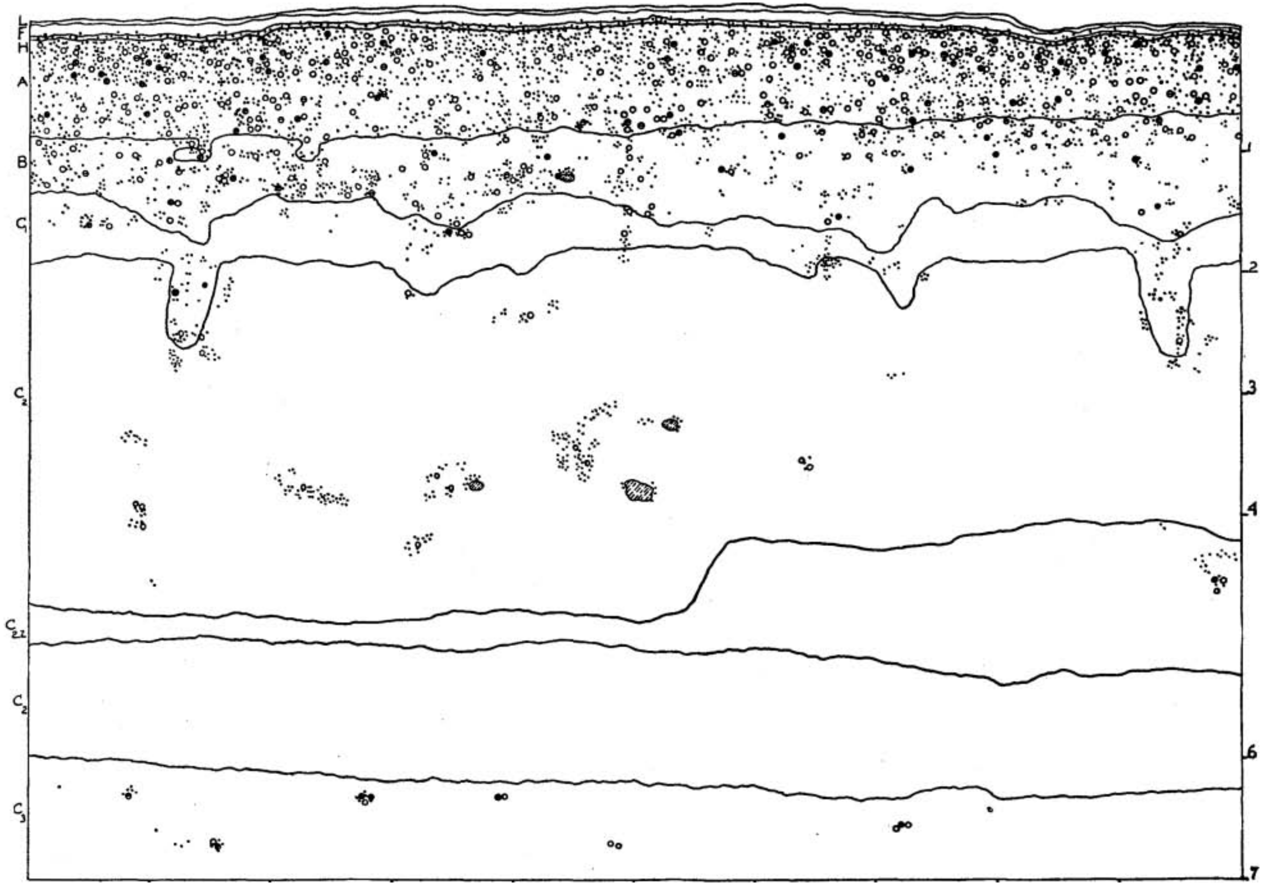
HORIZON features and root distribution in profile 14. The largest number of roots occur in the A and B_1 horizons. In the B_2 and C_1 layers the number is much smaller and distribution is poor; evidently this condition is associated with low water holding capacity of the soil. Absence of roots in the C_2 horizon seems to result from the very compact nature of the material and the high water table.



L
F
H
A
B1
B2
C1
C2
WATER TABLE
1
2
3
4
5

FIGURE 14

HORIZON features and root distribution in profile 15. The content of silt and clay in the A horizon is 20.6 per cent, in the B horizon 18.8 per cent, and in the C_1 horizon 6.1 per cent. In the other sub-horizons of the C the content of silt and clay does not exceed 4.0 per cent. It is believed that to a considerable extent root distribution in this profile is a response to textural differences in the horizons.



L
F
H
A
B
C_1
C_2
C_{22}
C_2
C_3
1
2
3
4
6
7

FIGURE 15

HORIZON features and root distribution in profile 16. Roots are concentrated in the upper two feet of the soil body in the A_1, A_2, B_1, B_2 and C_1 horizons. The marked reduction in number of roots in the C_2 horizon seems to result from the compact character of this layer rather than unfavorable moisture relations. The profile is fairly heavy textured throughout; only in the C_2 layer does the content of silt and clay drop to 29.2 per cent. An excellent stand of pine occurs at this station.

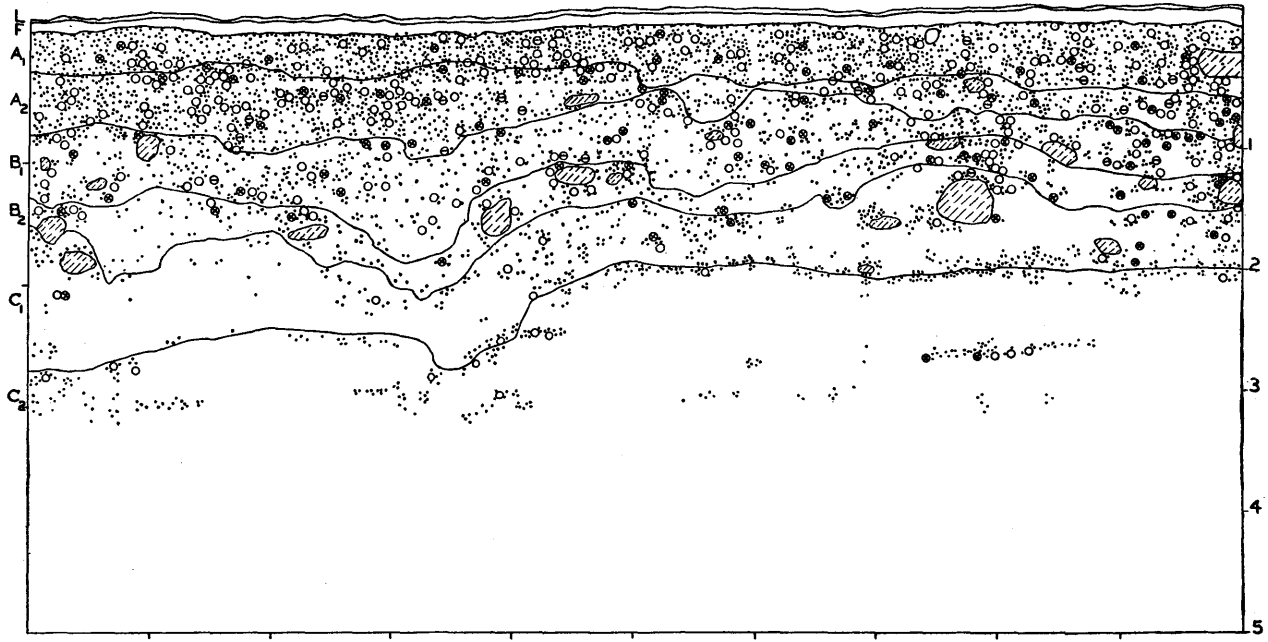
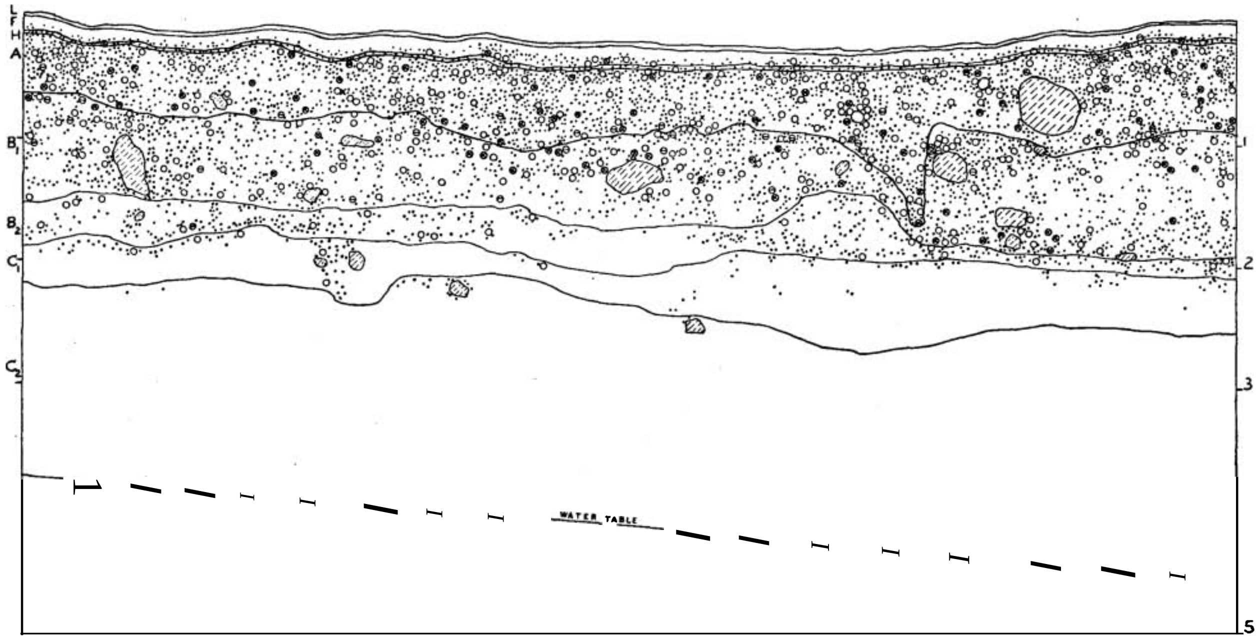

L
F
A1
A2
B1
B2
C1
C2
1
2
3
4
5

FIGURE 16

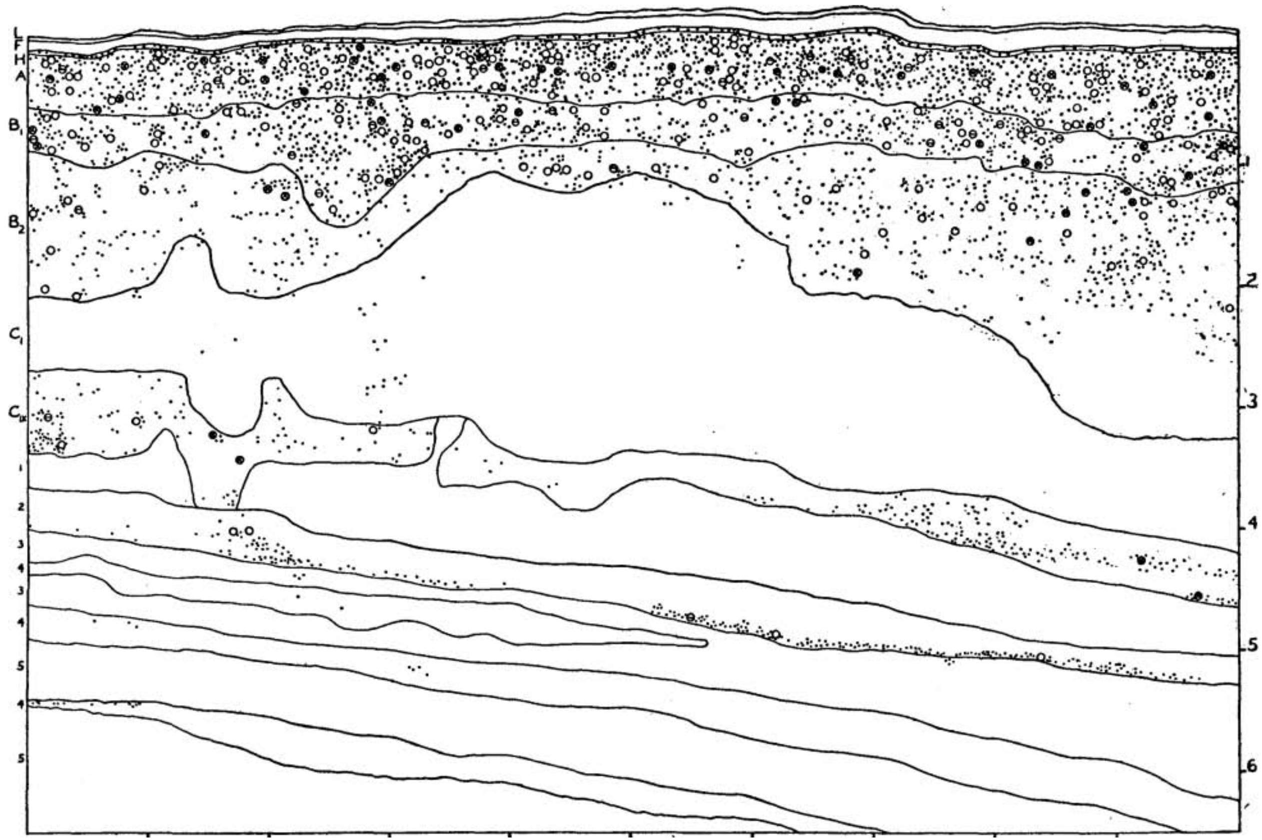
HORIZON features and root distribution in profile 17. Most of the roots in this profile are confined to the A and B horizons in the upper two feet of the soil body. The lack of roots in the C_2 horizon seems to result from a combination of slow drainage and extremely compact soil material. A splendid stand of rapidly growing pine occurs at this station.



L
F
H
A
B1
B2
C1
C2
1
2
3
WATER TABLE
5

FIGURE 17

HORIZON features and root distribution in profile 18. This profile is especially interesting since it illustrates in a striking manner the influence of soil texture on root distribution. In the C_1 horizon practically no roots were encountered whereas considerable numbers occur in the B_2. The content of silt and clay in the B_2 horizon is 15.1 per cent and in the C_1 5.0 per cent. Immediately below the C_1 is a stratum designated as C_{1x} which supports many roots. The silt and clay content of this layer is 38.4 per cent. In the C_2 horizon the stratum designated as C_2-2 is much finer textured than the material either above or below and supports numerous roots especially along its lower boundary.



L
F
H
A
B1
B2
C1
Cix
1
2
3
4
3
4
5
4
5
1
2
3
4
5
6

FIGURE 18

HORIZON features and root distribution in profile 19. An interesting feature of this profile is the influence which the large rock has on horizon development. The B_1 and B_2 horizons both dip downward around the sides of this rock. Very few roots enter the gravelly coarse sand C horizon which has a moisture equivalent of 2.5 per cent. The B_2 horizon, which is well occupied by roots, has a moisture equivalent of 8.7 per cent.

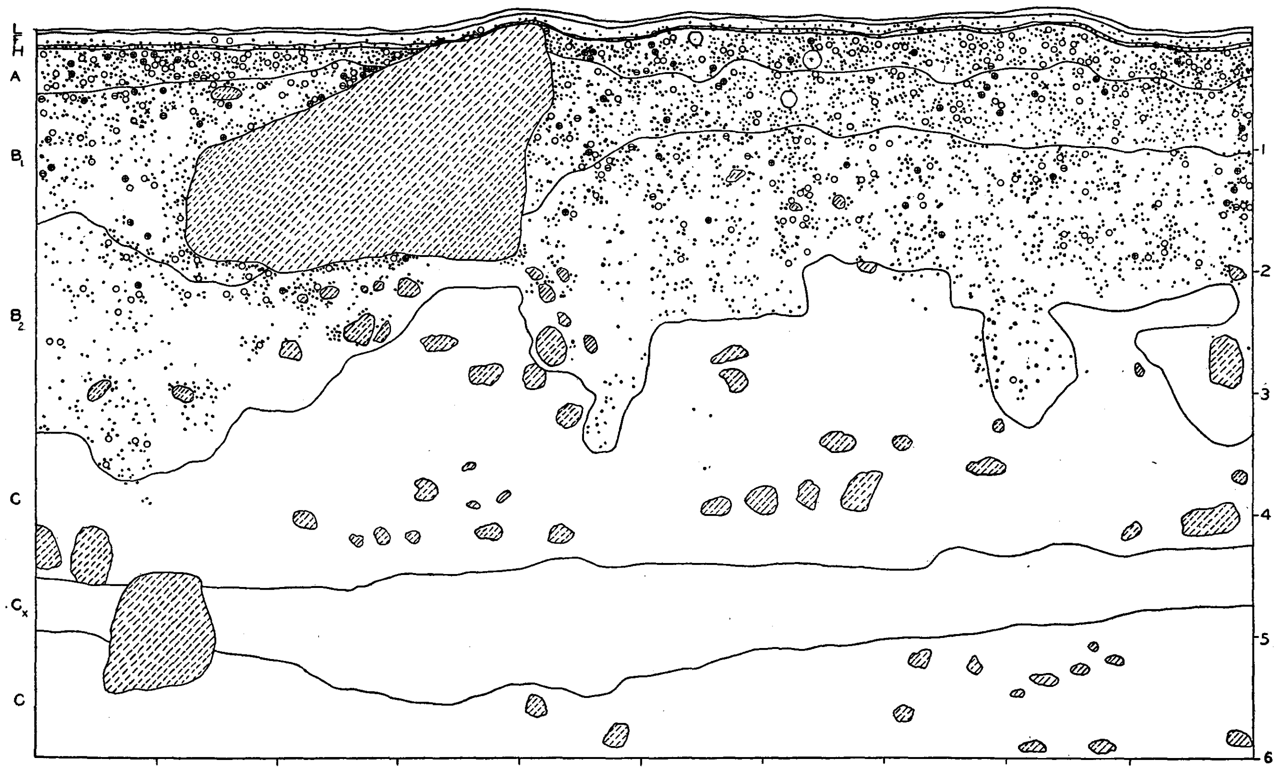

L
F
H
A
B1
B2
C
Cx
C
1
2
3
4
5
6

FIGURE 19

HORIZON features and root distribution in profile 20. This soil has been strongly influenced by a high water table. It is surprising to find roots distributed so deeply in material which is evidently very poorly drained. The lack of roots in the C horizon seems to be associated with the very compact character of the material and possibly also with poor drainage.

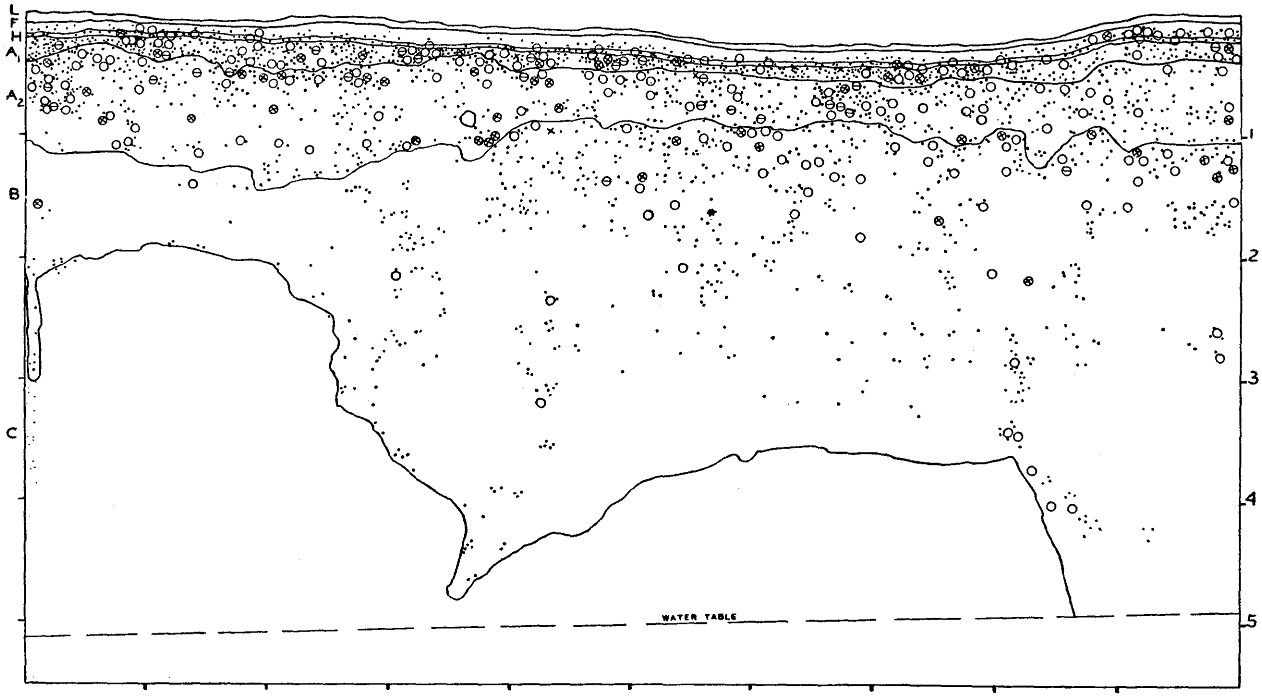
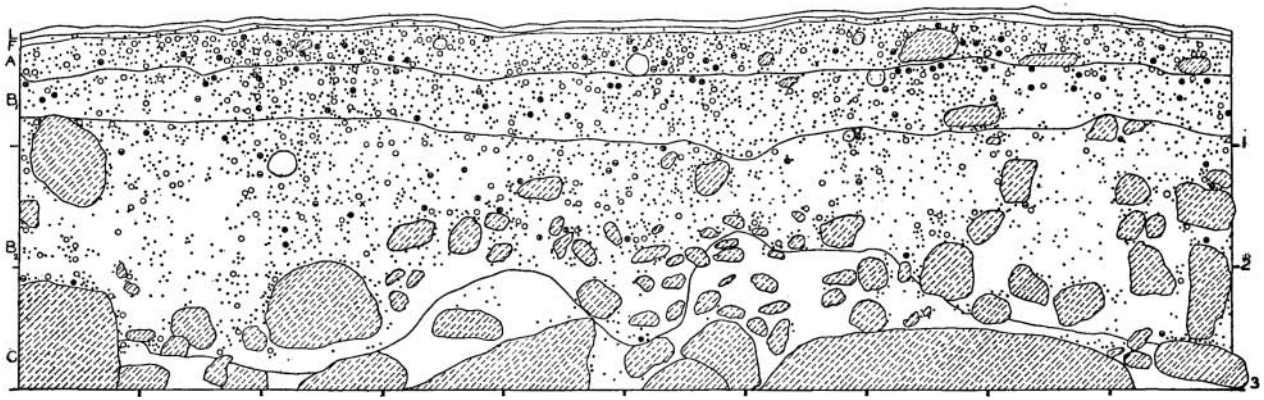

L
F
H
A1
A2
B
C
1
2
3
4
5
WATER TABLE

FIGURE 20

HORIZON features and root distribution in profile 21. Root distribution is excellent to a depth of about 2½ feet. There is a noticeable reduction of roots in the C horizon but this is not surprising when the coarse texture of the material is considered. The marked textural difference in the B_2 and C material is reflected in the moisture equivalent values which are 11.8 and 6.3 per cent, respectively. It was impossible to attain a depth greater than 3 feet because of rocks.


L
F
A
B1
B2
C
1
2
3

End of Document