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DISTURBANCE OF FOREST SOIL RESULTING FROM THE UPROOTING OF TREES

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Yale University
1940

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INTRODUCTION

IT is well known that the boles and crowns of trees frequently attain massive proportions. The fact that the root systems also attain great size, extending vertically into the soil and spreading out laterally, is less generally recognized. As a rule the lateral extension of a tree's roots is greater than that of its crown. With development to maturity the bole of a tree increases in length and the crown rises higher and higher above the ground level. This places an ever increasing strain on the supporting roots since with increasing length of the bole, leverage becomes greater. Further, the higher a tree crown rises above the ground level, the greater are the wind velocities to which it is subjected.

Uprooting of trees by wind is universal in forest regions. Scattered individuals or groups of trees, and even entire stands, are destroyed when air movement becomes sufficiently violent. This fact is confirmed by common experience. In some cases the force exerted on a tree by wind results in breakage in the crown or bole; in other cases the tree is uprooted. The latter is especially to be expected when the trees are tall and shallow rooted, and when growing in exposed topographic situations and on shallow or wet soils. Even deep rooted trees growing in well drained upland soils are uprooted by strong winds which follow periods of unusually heavy precipitation. The heavy rains which preceded the great New England hurricane of September 21, 1938, thoroughly saturated the soil, thus rendering trees very susceptible to windthrow. During the five-day period of September 17–21, 1938, seventeen or more inches of rain fell.

In 1935, while investigating tree-root distribution in the Yale Demonstration and Research Forest near Keene, New Hampshire, the writer was impressed by the extent to which the soil body in certain areas had been disturbed by the uprooting of trees. During the next year F. S. Griswold undertook an investigation of the morphological features of soil mounds and depressions resulting from windthrow. This work was extended during 1938 and the results were published in 1939 (Lutz and Griswold).

As work on the morphology of soil mounds progressed it became evident that disturbance of the soil material had resulted in other equally striking changes. Consequently, a number of physical and chemical properties were investigated during 1938, and subsequently. The objective was to determine the influence of soil disturbance, by the uprooting of trees, on various soil properties believed to have ecological and pedological significance.

REVIEW OF LITERATURE

ONE of the earliest writers to recognize that forest soil may be profoundly disturbed by the windthrow of trees was Shaler (1891). He wrote as follows (pp. 273–274): "When a forest is overturned by a strong wind the trees, unless they be tap-root species, are commonly torn from the ground or uprooted, and thus it occurs that the soil about the base of the bole is rended away so that it lies at right angles to its original position. This mass of uprent roots is often as much as ten feet in diameter, and contains a cubic yard or more of soil. The pit from which it has been torn is often two or three feet in depth. This cavity quickly becomes filled with vegetable waste, and as the roots decay the earth which they interlock gradually falls back upon the surface whence it came, burying, it may be, a thick layer of leaf mold to the depth of a foot or two below the surface." Shaler also pointed out (p. 269) that, "By the larger roots of our forest trees the soil is often, in the course of a generation of growth, in a surprising manner moved to and fro." The action of tree roots was likened by him to that of subsoil plows.

In 1893 Holmes described conditions near the Mississippi River at Little Falls, Minnesota, in the following words: "The surface was varied by countless humps and hollows, and I found, by careful inspection, that it was the site of an ancient forest which had been uprooted by a tornado. A few of the great root masses were still preserved, and in some cases where the wood had entirely disappeared the mounds of earth were still three feet high and the associated pits or hollows were nearly that deep. The humps and pits were so numerous as to disturb nearly one-half of the original level surface of the ground, and the disturbance must have extended in many cases to a depth of from four to six feet."

Van Hise (1904: 446–447) regarded soil disturbance by windthrown trees as very important. "How important this effect is can be appreciated only when one travels through the original forests. In such places there are seen almost everywhere hollows where trees have been uprooted and mounds where the material has fallen to the surface. Where tornadoes have swept through the forests, all the trees in their paths have been overthrown at once, and it seems as if almost the entire mass of soil and rock to a depth of several meters had been upturned. This process is well illustrated in the Lake Superior region. The paths of tornadoes vary from 30 meters to 2 kilometers or more in width. In traveling through the forests of this region one may find the paths of recent tornadoes, those a few years old, and those many years old."

Schenck (1924) clearly recognized the influence of windthrow in maintaining favorable forest soil conditions. He likened the disturbance of the soil by uprooted trees to that produced by plowing. Particular emphasis was placed on ecological effects of windthrow in virgin forests. The investigations of Wretlind (1934) in Sweden led to the conclusion that many irregularities in forest soil profiles are the result of trees having been uprooted.

In 1939 Lutz and Griswold presented evidence showing that profound changes in soil morphology result when trees are uprooted. Many of the peculiarities of forest soil morphology are to be attributed to the influence of tree roots.

Various writers have pointed out that mounds of soil created by uprooted trees are favorable places for the establishment and development of tree reproduction. Wiedemann (1924: 38) expressed views similar to those of Schenck and further stated that as a result of soil disturbance by uprooted trees the best conditions for humus decomposition and natural regeneration were created. Eide (1926) reported that in Norway, spruce regeneration on soil disturbed by windthrow was better than on undisturbed soil. Mork (1927) likewise recognized this fact and attributed the better reproduction to more favorable conditions for nitrification. Sernander (1936) in Sweden also reported that spruce seedlings developed better on upturned soil than on undisturbed soil. Olerinsky (1936) regarded disturbance of the soil by power logging, an influence comparable in its effect to windthrow, as favorable to decomposition of organic debris and the establishment of reproduction.

A review of the literature brings out three principal facts:

(1) That uprooting of forest trees is of widespread occurrence.

(2) That it results in drastic disturbance of forest soils.

(3) That such disturbance is of ecological importance.

Information concerning the effects of uprooting of trees on the physical and chemical properties of forest soils is almost wholly lacking.

LOCATION AND TYPE OF SOILS INVESTIGATED

MOST of the field work on which this report is based was carried out in, or adjacent to, the Yale Demonstration and Research Forest near Keene, New Hampshire. For details of location, climate, and vegetation the reader is referred to the reports of Stevens (1931) and Toumey (1932). Some supplementary work was also done in the Gale River Experimental Forest of the Northeastern Forest Experiment Station. This area is located near Pierce Bridge, New Hampshire. A few samples for determination of heavy mineral content were obtained near Colebrook, in northwestern Connecticut.

In the area near Keene, New Hampshire, where most of the work was done, the bedrock is granite and all of the region has been glaciated. When the ice melted some of the glacial drift spread over the land was sorted by streams and deposited as sand and gravel in stratified beds. Temporary lakes were formed and in these were deposited stratified materials, principally sands. Elevations at the different stations near Keene varied from approximately 500 to 600 feet above sea level.

The soils investigated belong to the Podzol and Brown Podzolic groups. As indicated in the succeeding sections, various phases of the work were conducted on soils belonging to the Merrimac and Hermon series. Merrimac soils developed from sandy or gravelly glacial outwash and occur in situations with relatively flat topography. As a rule they are excessively drained. The soils which are here referred to the Merrimac series are in many cases transitional between typical Merrimac and typical Colton. Merrimac soils are brown podzolic and Colton soils are podzols. In fact, a Colton soil may be regarded as a podzolized Merrimac. Hermon soils developed from fairly deep, non-calcareous glacial drift; they are podzols.

Although much of the land within the Yale Forest was cultivated in past time there was no evidence of disturbance resulting from agricultural use at the stations investigated. It does not appear possible that well defined mounds, together with their morphological peculiarities, could have persisted under cultivation.

With the exception of the work on soil temperature, the investigation of disturbed soils was confined to mounds and depressions which unquestionably resulted from uprooting of trees. Indications are that the mounds investigated were more than 80–100 years old; those examined in the Gale River Experimental Forest evidently were about 300 years old. Although it was impossible to accurately date the occurrence of the disturbance at any given station, ages of trees growing on the mounds did indicate a minimum length of time since windthrow occurred. The mounds varied from about 18 to 42 inches in height above the general ground level; average height was about 24 inches. They were 4 to 9 feet wide and averaged about 6 feet. In length they varied from 9 to 22 feet, averaging about 15 feet.

PHYSICAL PROPERTIES

THE physical properties of forest soils are highly important from the point of view of forest composition and growth. One of the primary objectives in the present investigation was to determine the extent to which soil disturbance had influenced physical conditions.

Morphology

The most important effects of uprooted trees on soil morphology have already been reported (Lutz and Griswold, 1939). During 1936 and 1938 excavations were made at eighteen stations in and adjacent to the Yale Demonstration and Research Forest near Keene, New Hampshire. At each station a trench two to three feet wide, three to seven feet deep, and ten to twenty-two feet long was opened. In 1939 several additional profiles were examined in the Gale River Experimental Forest of the Northeastern Forest Experiment Station. It has been shown that, as a result of disturbance, horizons may be very irregular, occasionally with long tongues from the upper layers penetrating deeply into the layers below. Further, horizons may be discontinuous and masses of soil material may be translocated to positions above or below those normally occupied. Frequently, material from upper and lower horizons is rather intimately mixed. The vertical and horizontal movement of rocks two or more feet in diameter is evidence of the tremendous forces involved. In short, disturbance of the upper three or four feet of the soil body by tree roots may be manifested in exceedingly diverse ways. This is illustrated in Figures 1, 2, 3, 5, and 6, which show some of the morphological peculiarities which are produced.

Soil disturbances by tree roots are regarded as important from several points of view. First, and most obvious, is the fact that a variety of micro-relief features are created. This variety of micro-relief features should tend to favor variety in vegetation composition. Recent work in Russia by Yurkevich and Lyahovich (1939) has emphasized the ecological importance of micro-relief in the establishment and development of forest trees. Further, as a result of disturbance the soil body exhibits greater heterogeneity, both vertically and horizontally; difficulties of soil sampling are increased.

Undisturbed podzols frequently have a considerable accumulation of organic debris overlying the mineral soil. Disturbance of the soil by uprooted trees results in burial of this organic debris or mixture with mineral material. As was indicated earlier, more favorable conditions are thus created for decomposition of the organic residues and establishment of reproduction. During the course of the last few years the writer has repeatedly encountered evidence that soil mounds are particularly suitable for germination and seedling development. In some areas where windthrow occurred many years ago nearly every mound now supports one or more large trees. This situation is illustrated in Figure 7 which shows the relation between distribution of trees on a one-tenth acre plot and micro-relief features. The layers of unincorporated organic matter are invariably thinner on soil mounds and thicker in the depressions than on adjacent undisturbed soil. During the course of development of podzol and brown podzolic soils a considerable amount of material in the A horizon is moved downward into the B layer. One of the effects of windthrow of trees is to return to the surface some of this translocated material, together with relatively unweathered minerals from the C horizon. Thus, as a result of the operation of natural forces over a long period of time, a forest soil may undergo a rather thorough working.

In addition to its ecological importance, disturbance of the soil body is also of pedological importance. The normal succession of horizons is disrupted. As a result of bringing material from the B and C horizons to the surface the soil body reverts to a more youthful condition. Thus, as a result of disturbance, a Hermon soil, which is a podzol, tends to assume the characteristics of a Gloucester soil, which belongs to the brown podzolic group. Similarly, disturbance in a Colton soil (podzol) results in a change toward a Merrimac soil (brown podzolic).

Surface Soil Temperature on Mounds

Both exposure and slope influence soil temperature. The radiation received per unit area of surface is proportional to the cosine of the angle formed between a perpendicular to the surface and the direction from which the radiation comes. Since the soil mounds caused by windthrown trees present a variety of exposure and slope conditions (Figure 7) it was anticipated that soil temperature would be influenced. The effect of exposure was investigated during the summers of 1936 and 1938.

Measurements were restricted to mounds in open areas where stands of eastern white pine recently had been clearcut. In the areas available suitable mounds resulting from windthrow were not at hand so artificial mounds were created. One mound was established in 1936 in a small clearcut area of about 0.7 acre in the Blake lot. This mound, hereafter referred to as Blake mound A, was about two feet high and had faces with a 20° slope oriented to the north, south, east, and west. The top was flat and about 3 feet square. A layer of white pine debris about ¼ inch thick was placed over the faces where maximum temperatures were measured. Thermometers, with their bulbs covered by the pine debris and ⅛ inch of mineral soil, were placed near the center of each of the slope surfaces and on the level top of the mound. Merrimac loamy sand soil, which occurs in this area, was used in forming the mound. In addition to the measurements made on the above mentioned mound during 1936, temperatures were also recorded in pans of soil having a 30° slope and exposed to the north, south, east, and west.

In 1938 a new mound (Blake mound C, illustrated in Figure 4) was formed in the Blake lot. It was similar to Blake mound A but had slopes of 30° and was not covered with pine needles. In the Lafontaine lot in a clearcut area of about three acres another mound, about 20 inches high, was formed using Hermon sandy loam soil. This mound (Lafontaine mound D) had faces with a 30° slope oriented to the north, south, east, and west. No covering of organic debris was applied. Summarized data concerning the influence of slope exposure on maximum temperature of the surface soil of the mounds are presented in Table 1.

The record of temperatures for Blake mound A extended from June 17, to August 14, 1936. On July 16 one of the highest maximum temperatures of the season (143° F.) was recorded on the south slope. On the same day the temperatures attained on the other positions were as follows: west, 125.5; level, 118.0; east, 113.0; north, 111.0° F. During the period of observation at mound A, mean maximum temperatures were highest on the south slope, followed in order by the west, level, east, and north positions. As may be observed in Table 1, the greatest mean difference in maximum surface soil temperature existed between the south and north slopes, the former being 13.5 ± 1.1° F. warmer than the latter.

Temperatures of soil exposed in pans during 1936 were recorded for the period July 4–August 14. The highest mean maximum temperature occurred on the south slope, followed in order by the west, level, east, and north positions. The highest maximum value recorded on the south slope was 141.0° F. On the same day the following temperatures were attained in the other positions: west, 134.0; level, 128.5; east, 123.0; north, 123.0° F. The greatest mean difference in maximum temperature existed between the south and north slopes, the former being 13.1 ± 1.0° F. warmer than the latter.

Records of maximum surface soil temperature at Blake mound C and at Lafontaine mound D covered the periods July 8–September 10, and July 8–September 7, 1938, respectively. As in 1936, the highest mean maximum temperature occurred on the south slope, followed by the west, east, and north positions. Temperatures were not taken on the level during 1938. The highest temperature recorded on the south slope of Blake mound C was 125.5° F. On the same day the maximum reached in the other positions was as follows: east, 116.5; west, 114.5; north, 90.5° F. The greatest mean difference in maximum temperature occurred between the south and north slopes. The former was 16.4 ± 1.4° F. warmer than the latter. At Lafontaine mound D the highest maximum temperature was recorded on the south slope, followed by the west, east, and north positions. The highest temperature recorded on the south slope was 127.0° F. For the same day maximum temperatures at the other positions were as follows: west, 111.5; east, 110.0; north, 110.0° F. The greatest mean difference in maximum temperature existed between the south and north slopes; the former was 13.4 ± 1.4° F. warmer than the latter.

The data of the writer do not permit a statement on the influence of degree of slope on soil temperature but it is clear that exposure is a significant factor. In practically all cases south exposures are very significantly[1] warmer than the other positions. Various other workers, for example, Wollny (1878, 1886, 1888), Kerner v. Marilaun (1891), Bühler (1895) and Kraus (1911: 110), have investigated the influence of exposure and slope on soil temperature. In general, their results concerning the influence of exposure on temperature show trends similar to those found in the present investigation. In his 1888 report Wollny indicated that degree of slope is of considerable importance. As the inclination increases, south slopes become warmer and north slopes become cooler. The effect of slope inclination on temperature is of less importance on east and west exposures.

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[1] In all cases significance was determined by use of Fisher's (1932) t test.

The mean differences in maximum surface soil temperature in Table 1 are large, but even larger are occasional daily differences which may reach 20 to 25 or more °F. when north and south slopes are compared. It is very probable that these differences in surface soil temperature are of ecological importance in the initial development of seedlings. Henne (1892) investigated the influence of different slope exposures on the early development of larch, fir, and spruce in Switzerland. In general the best development was secured on south exposures. This was attributed to the favorable effects of relatively high soil temperatures under conditions of sufficient soil moisture. Under field conditions, where soil temperatures are high and moisture frequently may be limiting, best development is to be expected on north or east slopes.

A few measurements were made to ascertain the influence of slope exposure on evaporation of water from the soil. However, these data are insufficient to warrant any definite conclusions. It will suffice to point out that a trend toward greater moisture losses from the south and west slopes than from the north and east slopes was indicated. Eser (1884) presented data from Germany which showed that the relative amount of water evaporated from soil on slopes having an inclination of 15° was of the following order: south, 100; east, 86.2; west, 84.0; north, 70.9. On slopes having an inclination of 30° the order was as follows: south, 100; east, 80.7; west, 73.2; north, 52.7. Eser's data indicated that with increasing inclination of a slope toward the south, evaporation losses were increased. Contrarily, with increasing inclination of a slope toward the north, evaporation decreased. Wollny (1888) reported that soil moisture was greatest on north slopes followed in order of decreasing moisture content by west, east, and south slopes. From the standpoint of moisture relations, conditions for seedling development are definitely more favorable on north than on south slopes.

Pore Volume

The pore volume of a soil represents the space not occupied by solid soil particles. In dry soil this space is occupied by air but under field conditions it is occupied jointly by air and moisture. Soils with large pore volume generally are less compact than those which have small pore volume. Consequently, pore volume has value as a criterion of the physical condition of a soil.

In the work here reported pore volume was determined using samples of soil-in-place collected in steel cylinders of one liter capacity. At each station not less than five, and usually eight or nine, samples were taken at random from a mound which unquestionably resulted from disturbance of the soil body by an uprooted tree, and an equal number were obtained from the adjacent undisturbed soil. No samples were taken from the depressions which invariably accompanied the mounds. The investigation of both physical and chemical properties was confined to samples of the upper 10 cm. of mineral soil. Decision to confine the work to this stratum was based on two considerations, (1) the surface soil is more susceptible to change than the deeper layers, and (2) the surface soil conditions are of primary importance for the establishment of reproduction. In all cases the organic debris was removed before the upper 10 cm. of mineral soil was sampled. On arrival at the laboratory the lower end of the cylinder containing the sample was covered with a filter paper to prevent loss of material. The filter paper was then covered with a screen of about 60 mesh and the cylinder with the sample was placed in a tank. Water was added to the tank so as to bring the water level up to about one-third the height of the cylinder. After allowing the system to stand for one hour, water was again flowed into the tank until the level stood at about two-thirds the cylinder height. After waiting another hour the water level was brought to the top of the cylinder. By following this practice it is believed that more complete replacement of the air in the mass is effected than could be obtained if the samples were immediately immersed in water. Twenty-four hours were allowed for samples to become water-logged.

The next step was to cover both ends of the cylinder with thin gum rubber covers, held tightly in place with strong rubber bands. This operation was performed while the samples were completely submerged. The cylinder with its ends covered was then removed, adhering moisture was dried, and the entire system weighed. Pore volume was then calculated as equivalent to the water contained in the soil within the cylinder. Summarized data are presented in Table 2.

At eleven stations 88 measurements of pore volume were made on mounds and 89 were made on adjacent undisturbed soil. The mean difference by which the pore volume of soil from the mounds exceeded that of soil from adjacent undisturbed areas was 5.8 ± 2.5 per cent; this difference is significant. The lowest pore volume values were obtained at station II; 1–15, with strongly podzolized Hermon sandy loam. The mean pore volume of soil from the mound (based on 7 samples) was 27.7 ± 1.0 per cent; adjacent undisturbed soil (based on 8 samples) had a pore volume of 13.2 ± 1.9 per cent. At station K; 19–34, with Merrimac sandy loam soil, much higher values were obtained. Here soil from the mound (based on 8 samples) had a pore volume of 66.7 ± 0.8 per cent whereas adjacent undisturbed soil (based on 8 samples) had a pore volume of 47.4 ± 1.8 per cent. At four of the eleven stations the average pore volume of the undisturbed soil was slightly higher than that of soil from the mounds; in no case, however, did the difference exceed 3.8 per cent.

It appears that pore volume of soil in mounds created by windthrow of trees on medium textured podzol and brown podzolic soils, such as those investigated, is significantly greater than that of the undisturbed soil. The increased pore volume is believed to be of ecological importance, representing a more favorable condition for tree development.

AIR CAPACITY

The space remaining in a soil mass after its water holding capacity is fully satisfied, is referred to as the air capacity. It is a measure of the non-capillary pore space of a soil and is one of the most important physical properties. Various investigators have demonstrated that, other things being equal, high air capacity values are usually associated with favorable soil conditions whereas low values generally indicate less favorable conditions. High air capacity of a soil usually means rapid infiltration of water into the soil body and favorable conditions for aeration.

In the present investigation air capacity was determined by measuring loss of gravitational water from water-logged samples. Following immersion of the cylinder samples in water for 24 hours they were removed, and, after weighing, allowed to drain on sandy soil material for one hour. The weight in grams of the gravitational water which moved out of the sample was regarded as equivalent to the air capacity in cubic centimeters. The samples employed were those used for determination of pore volume. Summarized data are presented in Table 2.

The mean difference by which the air capacity of soil from the mounds exceeded that of soil from adjacent undisturbed areas was 4.7 ± 1.1 per cent; this difference is very highly significant. Low air capacity values (as was the case with respect to pore volume) were obtained at station II; 1–15, with a well developed podzol soil, Hermon sandy loam. The mean air capacity of soil from the mound (based on 7 samples) was 12.1 ± 1.6 per cent; adjacent undisturbed soil (based on 8 samples) had an air capacity of 6.5 ± 0.7 per cent. At station K; 1–18, with Merrimac sandy loam soil, the relatively high value (based on 8 samples) of 17.7 ± 0.9 per cent was obtained on the mound; adjacent undisturbed soil (based on 10 samples) had an air capacity of 8.2 ± 0.7 per cent. At only one of the eleven stations did the mean air capacity of undisturbed soil exceed that of soil from the mound, the difference being 0.7 per cent. At this station, 17; 19–36, the soil was Hermon fine sandy loam and in undisturbed condition presented all the characteristics of an excellent coarse mull. It appears that disturbance of a good mull soil by uprooted trees may not result in any improvement; in fact the effect may be unfavorable.

The results indicate that the air capacity of medium textured podzol and brown podzolic soils is definitely increased as a result of natural disturbances such as windthrow. From an ecological standpoint the increased air capacity of soil in the mounds must be regarded as an improvement.

WATER HOLDING CAPACITY

The water holding capacity is, as the expression implies, the amount of water that soil material can hold against the force of gravity. It is an important physical property of soil. If the water holding capacity is either very low or very high ecological conditions may be relatively unfavorable for higher plants.

The cylinder samples used for determining pore volume were also used in measuring water holding capacity. Water content was determined following drainage for one hour on sandy soil material. Values were expressed in terms of percentage of volume. Summarized data are presented in Table 3.

No significant difference could be established between the water holding capacity of disturbed as compared to undisturbed soil. The lowest values were obtained at station II; 1–15, with strongly podzolized Hermon sandy loam soil. The mean water holding capacity of soil from the mound (based on 7 samples) was 15.6 ± 2.1 per cent; adjacent undisturbed soil had a water holding capacity (based on 8 samples) of 6.7 ± 1.6 per cent. The highest values were obtained at station 17; 1–18, with Hermon fine sandy loam. The mean value for soil from the mound (based on 9 samples) was 52.1 ± 1.8 per cent; adjacent undisturbed soil had a value (based on 9 samples) of 58.7 ± 1.2 per cent.

Disturbance of the soils under consideration resulted in an increase of water holding capacity in some cases but in others a decrease was noted.

When the data are considered as a whole no general trends can be established. This may be explained by the fact that water holding capacity is influenced by so many factors, chief among which are texture, content of organic matter, and structure.

Volume Weight

Volume weight, or apparent specific gravity, refers to the ratio between the dry weight of a given volume of soil and the weight of an equal volume of water. The value is useful in characterizing the physical condition of a soil since, other things being equal, a low volume weight signifies a relatively porous condition and a high volume weight signifies greater compactness. In general, the physical properties are more favorable in soils of low volume weight than in soils of high volume weight. The cylinder samples employed for pore volume determinations were also used for the measurement of volume weight.

The mean difference in volume weight of soil from the mounds and from adjacent undisturbed areas was 0.142 ± 0.065. In other words, on the average, 1000 cubic centimeters of soil from a mound weighed 142 ± 65 grams less than the same volume undisturbed soil. This difference is scarcely significant at the .05 level. Summarized data are presented in Table 3.

The highest volume weight values were obtained at station II; 1–15, with strongly podzolized Hermon sandy loam. The volume weight of soil on the mound (based on 7 samples) was 1.419 ± 0.029 whereas the value for adjacent undisturbed soil (based on 8 samples) was 1.719 ± 0.012. The lowest volume weight was found at station 17; 1–18, with Hermon fine sandy loam. This was an excellent coarse mull. Soil on the mound had a volume weight (based on 9 samples) of 0.817 ± 0.034 and adjacent undisturbed soil (based on 9 samples) had a value of 0.753 ± 0.025. Here, as in the case of the air capacity values at station 17; 19–36, disturbance of a coarse mull appears to have resulted in slightly less favorable conditions.

It may be pointed out that in spite of the fact that a significant difference with respect to volume weight could not be established between disturbed and undisturbed soils, the average volume weight of disturbed soil at seven of the eleven stations was less than that of the undisturbed soil. There appears to be a tendency for disturbed soils to have lower volume weight than those undisturbed. This is to be expected since the former have a higher pore volume and air capacity than the latter.

INFILTRATION OF WATER

The rate of infiltration of water into a soil is influenced to a marked extent by its air capacity. Soils having large air capacity values generally permit rapid infiltration of water. Relatively high infiltration rates in medium and fine textured soils are usually associated with favorable physical conditions.

In the present work infiltration rates were measured by means of steel cylinders 20 cm. high having a cross sectional area of 100 cm.^{2} After removal of the organic debris the cylinders were driven into the soil to a depth of 10 cm. A fine mesh screen or a piece of muslin was then placed on the inside of the cylinder to prevent turbulence of the soil material. One liter of water was added and the time required for it to pass into the soil was recorded. At 12 stations from 10–16 measurements were made both on mounds and on adjacent undisturbed soil. A total of 161 measurements were made on mounds and 163 on undisturbed soil. Summarized data are presented in Table 4.

The mean difference in time required for infiltration of one liter of water on mounds and on undisturbed soil was 620 ± 155 seconds. This difference is very highly significant. Without any exceptions the rate of infiltration was greatest on the mounds.

The greatest difference in rate of infiltration was measured at station II; 1–15, with strongly podzolized Hermon sandy loam soil. On the mound (based on 10 measurements) it took 140 ± 19 seconds for infiltration of one liter of water; on the adjacent undisturbed soil (based on 12 measurements) it took 1714 ± 497 seconds. The smallest difference in rate of infiltration was measured in Hermon fine sandy loam soil at the Gale River Experimental Forest. Soil on the mounds showed an infiltration rate (based on 16 measurements) of 311 ± 66 seconds; on the undisturbed soil (based on 14 measurements) the rate was 418 ± 60 seconds.

The relatively high rate of infiltration noted in the soil on the mounds is to be expected in view of the greater air capacity of these soils. As mentioned earlier air capacity is a measure of the non-capillary pore space and it is these pores which function in infiltration of water. The increased permeability to water is regarded as favorable from the standpoint of plant and hydrologic relations.

MECHANICAL ANALYSIS

The relative amounts of inorganic particles in various size classes, as revealed by mechanical analysis, is an important physical feature of soils. In undisturbed profiles of the soils investigated the B and C horizon material is generally coarser textured than that in the A layer. Consequently, it was expected that the disturbance resulting from trees being uprooted would be reflected in a higher proportion of coarse particles in the uppermost layers of the mineral soil. Further, it was anticipated that in cases of soil profiles with hardpan (*Ortstein*) layers, fragments of the cemented material would be moved upward in the soil body.

Mechanical analyses were carried out using the cylinder samples employed in the determinations of pore volume, air capacity, water holding capacity, and volume weight. After air drying, the individual soil samples were first separated into the following fractions: (1) material 40–5 mm., (2) material 5–2 mm., and (3) material less than 2 mm. in diameter. From the data for the individual samples, average values were computed for the disturbed and undisturbed soil at each station. Summarized data are presented in Table 5.

The disturbed soils contain significantly more material in the 40–5 mm. group and in the 5–2 mm. group than the undisturbed soils. The mean differences are 2.4 ± 0.6 and 1.2 ± 0.5 per cent, respectively. Conversely, the disturbed soils contain significantly less material in the size group < 2 mm. than the undisturbed soils. The mean difference was 3.6 ± 0.8 per cent.

After the fine earth (material < 2 mm.) had been separated from the individual cylinder samples a composite sample representing the disturbed and undisturbed soil at each station was obtained. These composite samples were then subjected to mechanical analysis following the method of Bouyoucos (1936). The data are presented in Table 6, which also gives the series and textural class to which the soils belong.

A comparison of the percentage of each fraction in the disturbed and undisturbed soils indicated that differences were non-significant in all cases except one. The content of material 2.0–1.0 mm. in diameter was significantly higher in disturbed soils than in undisturbed; the mean difference was 1.1 ± 0.4 per cent. The disturbed soils appear to contain slightly lower percentages of the fractions smaller than 0.25 mm. than the undisturbed soils, but in no cases are the differences significant.

In the soils investigated the effect of disturbance on texture has been a significant increase in the content of fractions larger than 1.0 mm. in diameter. This has resulted from the transfer of coarse soil particles, including fragments of hardpan (*Ortstein*), from the B and C horizons to the surface. At five stations the disturbed soil was assigned to the same textural class as the undisturbed soil. The disturbed soil at the other six stations had to be assigned to textural classes different from those applied to the corresponding undisturbed soils. In all cases where disturbance resulted in a change of texture, the change was toward a lower proportion of the finer particles. The writer is not disposed to attribute ecological significance to the textural differences found since they are relatively small.

HEAVY MINERAL INDEX

The mineralogical composition of a soil is important from the standpoint of its fertility. Other things being equal, soils containing a relatively high percentage of minerals which supply nutrient elements to plants generally are more fertile than soils which contain a relatively low percentage. The practical man has frequently recognized this difference and referred to the former soils as mineralogically rich, or strong, and to the latter soils as mineralogically poor, or weak. The mineralogical composition of soil material is of interest not only in relation to fertility but also in relation to soil development. As a rule, the more severely leached a soil is, the lower will be the proportion of heavy minerals found in the A horizon.

The primary soil minerals may conveniently be divided into two broad groups. The first includes the so-called light minerals (specific gravity < 2.680), chief among which are quartz, orthoclase, albite, and oligoclase. The second group includes the so-called heavy minerals (specific gravity > 2.680) of which labradorite, anorthite, augite, hornblende, moscovite, biotite, and apatite may be mentioned. Minerals in the first group weather with difficulty and, with the exception of orthoclase which is a source of potassium, contribute little in the way of plant food. The so-called heavy minerals in the second group weather more readily and represent important sources of nutrient elements; they may be regarded as more valuable than the so-called light minerals.

It has been found that the content of heavy minerals in podzol and podzolic soils generally increases with increasing depth below the surface. Translocation of B or C horizon material to the surface, which frequently occurs when trees are uprooted, should result in a higher percentage of heavy minerals in the upper layers of disturbed soils than in adjacent undisturbed soils.

In the investigation here reported the content of heavy minerals in the soil fraction 0.50–.25 mm. in diameter was determined following the method of Tamm (1934). Most of the separations were made with tetrabromethane (acetylene tetrabromide) but bromoform or Thoulet's solution may be used equally well. The data are presented in Table 7.

In all cases the percentage of heavy minerals in the upper four inches of mineral soil was higher in the disturbed soils than in the adjacent undisturbed soils. The mean difference was 2.70 ± 0.50 per cent. This difference is very highly significant. Disturbance of a forest soil, particularly a podzol, by windthrown trees enriches the surface soil in minerals which are valuable as sources of plant nutrients. The soil turbulence resulting from windthrow of trees to some extent counteracts the effects of podzolization.

Moisture Equivalent

The moisture equivalent is a useful value for comparing soils from the standpoint of their physical properties. It is indicative of the water holding capacity and is influenced by the content of organic and inorganic colloids and by the structure of the material.

Composite samples of soil material which passed a 2 mm. sieve were used for the determinations of moisture equivalent following the method of Veihmeyer, Oserkowsky, and Tester (1928). The composite samples were similar to those employed in the mechanical analysis and represented disturbed and undisturbed soil at each station. The data are presented in Table 7. No significant difference could be established between the two groups of soils. This is not surprising since it also was impossible to establish differences between the soils with respect to the water holding capacity and the content of fine soil particles.

Color

Color is a characteristic which has long been used by laymen and scientists as an aid in classifying soils. The most abundant soil minerals, for example, quartz and the feldspars, are light colored. Dark colors generally result from the presence of materials such as organic matter and compounds of iron or manganese, often in relatively small amounts.

In regions having podzol and brown podzolic soils the writer repeatedly has observed that the color of surface mineral soil of mounds resulting from windthrow has a larger component of yellow and red than is seen in adjacent undisturbed material. This is borne out by analysis of soil color using Munsell color discs. In undisturbed profiles iron compounds are removed from the A horizon and tend to accumulate in the B layers, giving the latter dark yellowish or reddish brown colors. When this B horizon material is brought to the surface by uprooting of trees the condition mentioned above results.

CHEMICAL PROPERTIES

THE view is frequently expressed that, as a rule, the chemical properties of soils are less important in forest production than the physical properties. This generalization does not meet with anything like complete acceptance but even if it did one would not be justified in concluding that chemical properties of soils can be ignored. Actually, the chemical, physical, and biological properties are all more or less interdependent.

The samples employed in the determinations which are discussed in the following pages were similar to those used for the mechanical analyses. Each station was represented by a sample of both the disturbed and undisturbed mineral soil from the upper four inches. Each sample was a composite of not less than five and usually eight or nine random sub-samples.

TOTAL NITROGEN

Total nitrogen, exclusive of nitrate nitrogen, was determined by the Kjeldahl method. The results are presented in Table 8. The highest value found was 0.235 per cent in disturbed soil at station K; 19–34 and the lowest was 0.042 in undisturbed soil at station II; 1–15. No significant difference in nitrogen content could be established between the disturbed and undisturbed soils.

ORGANIC CARBON

Organic carbon was determined by the method of Schollenberger as modified by Allison (1935). The values presented in Table 8 represent the percentages of carbon actually found; they are unadjusted values. The highest value obtained was 4.13 per cent in disturbed soil at station K; 19–34 and the lowest was 0.59 in undisturbed soil at station II; 1–15. No significant difference in carbon content of the disturbed and undisturbed soils could be demonstrated.

CARBON-NITROGEN RATIOS

The ratio of carbon to nitrogen gives an indication of this state of decomposition of the soil organic matter. As decomposition proceeds the ratio becomes more narrow and may approach ten, that is, ten parts of carbon to one of nitrogen. Ratios were computed for both disturbed and undisturbed soils and are presented in Table 8. The lowest ratio found was 12.9 in disturbed soil at station 17; 19–36 and the highest was 34.3 in undisturbed soil at station V; 1–18. No significant difference with respect to carbon-nitrogen ratios could be established between the disturbed and undisturbed soils.

EXCHANGEABLE CALCIUM

Among the various chemical elements in the soil, calcium occupies a unique position. In addition to being essential to plant nutrition, calcium exerts an important influence on the physical, chemical, and biological properties of soils. Consequently, it seemed desirable to learn whether disturbance of the soil body resulted in any changes in the content of this element.

The readily soluble or exchangeable calcium was determined by the method of Williams (1928). The precipitate was washed with distilled water saturated with calcium oxalate as suggested by Bassett (1934). Results are presented in Table 9. The highest content of exchangeable calcium found was 3.19 m.e. per 100 gms. of undisturbed soil at station 17; 19–36; the lowest was 0.02 in undisturbed soil at station II; 1–15. Judged by the values obtained for other soil properties and by the character of the forest stand, the soils at these stations were, respectively, the best and poorest examined. Comparison of the exchangeable calcium in the disturbed and undisturbed soil at all of the stations failed to reveal any significant difference.

READILY SOLUBLE PHOSPHORUS

Readily soluble phosphorus was determined by the method of Truog (1930) which employs as a solvent a 0.002 N. sulphuric acid solution buffered with ammonium sulphate to a pH of 3.0. The results of these determinations are presented in Table 9. The highest value found was 3.04 mgm. per 100 gms. of undisturbed soil at station K; 1–18; the lowest 1.02 in the disturbed soil at station 17; 1–18. Analysis of the results showed that there was no significant difference between the disturbed and undisturbed soils with respect to readily soluble phosphorus.

HYDROGEN ION CONCENTRATION

The hydrogen ion concentration of the air dried soils was determined in a water suspension using the quinhydrone electrode. Results are presented in Table 9. For purposes of comparing the hydrogen ion concentration of the disturbed and undisturbed soils the pH values were first converted to grams of hydrogen ions per liter of solution. It was found that there was a very highly significant difference between the disturbed and undisturbed soils, the latter containing the greater amount of hydrogen ions. The mean difference was 0.00001122 ± 0.00000352 gms. of hydrogen ions per liter. The average pH of the disturbed soils was 4.82 whereas that of the undisturbed soils was 4.58.Thus, disturbance resulted in decreased acidity.

That the difference found is biologically significant may well be questioned. However, the tendency toward a less acid condition in the soils investigated must be regarded as a change toward a more favorable condition.

Buffer Relations

As a general rule forest soils possessing a relatively high buffer capacity toward change of reaction upon the addition of acids are more favorable for plant development than soils of lower buffer capacity.

The method used in measuring buffer capacity was as follows. Five gram samples of soil material were placed in a series of Erlenmeyer flasks. Varying quantities of 0.1 N. HCl and carbon dioxide-free distilled water were then added so as to produce a series with additions of 0.0, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, and 2.0 milligram equivalents of hydrogen ions. The volume in all cases was kept constant at 100 cc. The samples were allowed to stand, with occasional shaking, for 24 hours at which time the pH was determined using a quinhydrone electrode.

The more important results obtained are presented as buffer curves in Figures 8 and 9, and in Table 10. Figures 8 and 9 show that in most cases the buffer curves rise rather sharply at first and then tend to flatten. This means that with small additions of acid a higher percentage of the added hydrogen ions is inactivated than is the case when the additions of acid are greater. It may be noted that with three exceptions (stations GR; 1–10; 17; 1–18; V; 1–18) the curves representing the disturbed soil stand above those representing the adjacent undisturbed soil. Thus, it is apparent that the former soils are in general better buffered than the latter.

With addition of one milligram equivalent of hydrogen the mean difference in percentage inactivated by disturbed and undisturbed soil was 16.23 ± 7.00. This difference is significant and shows that the buffer capacity of disturbed soils is greater than that of undisturbed material. The highest percentage of hydrogen ions inactivated (1 m.e. added) was 93.8 by undisturbed soil at station GR; 1–10 and the lowest was 19.1 by undisturbed soil at station K; 19–34. With addition of two milligram equivalents of hydrogen the mean difference in percentage inactivated by disturbed and undisturbed soil was 14.40 ± 6.64. This difference is scarcely significant at the five per cent level. The highest percentage of hydrogen ions inactivated (2 m.e. added) was 90.3 by undisturbed soil at station GR; 1–10 and the lowest 17.8 by undisturbed soil at station K; 19–34.

When the data are considered as a whole it is evident that disturbance has resulted in increased buffer capacity of the soil material. Presumably, this increase was brought about by the translocation upward of material from the B and C horizons together with changes in the nature of the incorporated organic matter. The increased buffer capacity is regarded as favorable from an ecological standpoint.

Base Exchange Relations

The base exchange properties of the disturbed and undisturbed soils were examined using the methods of Pierre and Scarseth (1931). The results are presented in Table 11. Comparison of the exchangeable hydrogen in the two soil conditions failed to reveal any significant differences. Likewise, no significant differences in exchangeable bases and total exchange capacity could be demonstrated. There did appear to be a tendency toward a higher content of exchangeable bases and a higher total exchange capacity in the disturbed soils. In the disturbed soils the percentage of base saturation was significantly higher than in the undisturbed soils. The mean difference was 10.3 ± 3.9 per cent.

From an ecological point of view the increase in percentage of base saturation, as a result of soil disturbance, is regarded as favorable. The relative proportion of bases, most of which are plant nutrients, has been increased and the proportion of hydrogen has decreased.

SUMMARY AND CONCLUSIONS

WINDTHROW, with the generally attendant uprooting of trees, is a universal phenomenon in forest regions. Occasional violent storms of hurricane intensity may operate over extensive areas and cause entire stands to be uprooted. Less spectacular, but more common, is the windthrow of scattered individuals or groups of trees which occurs during normal years. Over long periods of time the soil under forest stands may repeatedly be subjected to disturbance when trees are uprooted. This type of natural disturbance of the soil body is peculiar to land bearing forest stands; it may be likened to plowing by the agriculturist.

During 1936 and 1938 excavations were made at eighteen stations in and adjacent to the Yale Demonstration and Research Forest near Keene, New Hampshire, for the purpose of investigating the influence of tree windthrow on soil morphology. At each station a trench two to three feet wide, three to seven feet deep and ten to twenty-two feet long was opened. In 1939 several additional profiles were examined in the Gale River Experimental Forest of the Northeastern Forest Experiment Station. In view of the fact that soil mounds caused by windthrown trees present a variety of exposure and slope conditions, an influence on surface temperature was anticipated. Consequently surface soil temperatures were measured during 1936 and 1938 on the north, east, south, and west slope exposures of several artificial mounds. Physical and chemical properties of disturbed and undisturbed soil were investigated at eleven stations. The mounds investigated were formed at least 80–100 years ago and in some cases they evidently were about 300 years old. Presumably, the differences between disturbed and undisturbed soil would have been even greater had recently formed mounds been used. The soils employed in the investigations belonged to the Merrimac and Hermon series which are included in the Brown Podzolic and Podzol groups, respectively.

Following are the principal results obtained in the investigation.

1. It has been demonstrated that, as a result of disturbance by the uprooting of trees, forest soil horizons may be very irregular, occasionally with long tongues from the upper layers penetrating deeply into the layers below. Horizons may be discontinuous and masses of soil material may be translocated to positions above or below those normally occupied.

Frequently material from upper and lower horizons is rather intimately mixed. Mixture of organic debris with mineral soil creates more favorable conditions for decomposition of the organic matter and for establishment of reproduction. In some areas nearly every mound is occupied either by young seedlings or by mature trees. This indicates that they afford particularly favorable conditions for germination and subsequent development. Materials which have been moved downward, in solution or suspension, from the A horizon to the B horizon are in part returned to the surface, together with minerals from the C horizon. This represents, in effect, a rather thorough working of the soil. As a result of bringing material from the B and C horizons to the surface the soil body reverts to a more youthful condition. Thus, as a result of disturbance a Hermon soil, which is a podzol, tends to assume the characteristics of a Gloucester soil, which belongs to the brown podzolic group. Similarly, disturbance in a Colton soil (podzol) results in a change toward a Merrimac soil (brown podzolic). Uprooting of trees results in a variety of microrelief features which should tend to favor variety in vegetation composition.

2. Maximum surface soil temperatures on mounds comparable to those created by uprooted trees show significant differences when different slope exposures are compared. The mean maximum surface temperatures were highest on the south exposures, followed in order of decreasing temperatures, by the west, level, east, and north positions. In 1936 at Blake mound A, surface soil temperatures were measured on north, east, south, and west facing slopes having an inclination of 20°. Similar measurements were taken in soil material in pans having the same exposures but with an inclination of 30°. In both cases maximum temperatures on the level were recorded. The mean differences in maximum surface soil temperature between the south and north slopes at Blake mound A was 13.5 ± 1.1° F.; the comparable difference between the temperature on the south and north slopes of soil in pans was 13.1 ± 1.0° F. In 1938 measurements were again made on 30° slopes exposed to the cardinal directions. The mean difference in maximum surface soil temperature on south and north slopes at Blake mound C and at Lafontaine mound D was 16.4 ± 1.4° F. and 13.4 ± 1.4° F., respectively. Although the mean differences in maximum temperatures on the various exposures are substantial, even greater are the differences which are obtained on individual days; these may amount to 20–25 or more °F.

Under conditions of generally high soil temperature and low soil moisture the mound slopes exposed to the north and east present relatively more favorable conditions for establishment of regeneration than level areas or slopes exposed to the south or west. With conditions of generally low soil temperature and high soil moisture the mound slopes exposed to the south and west present relatively more favorable conditions than level areas or slopes exposed to the north or east.

3. Pore volume in the upper 10 cm. of disturbed soils was significantly higher than that of undisturbed soils. The mean difference was 5.8 ± 2.5 per cent. This change is regarded as favorable from the standpoint of plant development.

4. The air capacity of disturbed soils was significantly higher than that of undisturbed soil. The mean difference was 4.7 ± 1.1 per cent. This change is regarded as favorable from an ecological standpoint.

5. No significant difference with respect to water holding capacity could be demonstrated.

6. The average volume weight of soil from mounds was 142 ± 65 grams less per 1000 cm.^{3} than that of adjacent undisturbed soil. However, the difference is scarcely significant.

7. The rate of infiltration of water into the soil on the mounds was significantly greater than the rate of infiltration into undisturbed soil. The mean difference in time for the infiltration of one liter of water was 620 ± 155 seconds. Increased permeability of the disturbed soils to water is regarded as favorable from the standpoint of both ecology and hydrology.

8. As a result of disturbance by uprooted trees the surface soil of mounds tends to be coarser textured than the adjacent undisturbed material. This situation results from the upward translocation of coarse material from the B and C horizons. The content of particles coarser than 1.0 mm. in diameter is significantly greater in the disturbed soils. On the average disturbed soils contained 2.4 ± 0.6 per cent more material in the 40–5 mm. size class, 1.2 ± 0.5 per cent more material in the 5–2 mm. size class, and 1.1 ± 0.4 per cent more material in the 2–1 mm. size class than did undisturbed soils. The content of fine earth (material $<$ 2 mm.) was 3.6 ± 0.8 per cent less in the disturbed soils than in the undisturbed material. All of the differences noted are significant. At five stations both disturbed and undisturbed soil was assigned to the same textural class but at six stations the disturbed soil fell in a different, coarser class. The differences found were small and the writer is not disposed to regard them as having ecological importance.

9. Significantly more heavy minerals (sp. gr. $>$ 2.680) were found in soil from the mounds than in adjacent undisturbed soil. The mean difference was 2.70 ± 0.50 per cent. The increased content of heavy minerals in the disturbed soil is viewed as a favorable change since they are an important potential source of nutrient elements used by plants.

10. No significant difference in moisture equivalent could be established in the two soil conditions.

11. The color of the soil of mounds usually had a larger component of yellow and red than the adjacent undisturbed soil.

12. No significant differences between disturbed and undisturbed soils

could be established with respect to total nitrogen, organic carbon, carbon-nitrogen ratios, exchangeable calcium, or readily soluble phosphorus.

13. The hydrogen ion concentration of soil from mounds was significantly less than in undisturbed soil. The average pH of soil from the former was 4.82 whereas that of soil from the latter was 4.58. It is questionable whether the small differences found are of ecological significance.

14. The buffer capacity of disturbed soils is significantly greater than that of undisturbed soil material. With addition of one milligram equivalent of hydrogen to 5 grams of soil the mean difference in percentage inactivated by disturbed and undisturbed soil was 16.23 ± 7.00. The differences found are regarded as having ecological significance.

15. No differences could be established between the two soil conditions with respect to exchangeable hydrogen, content of exchangeable bases, or total exchange capacity. However, in disturbed soils the percentage of base saturation was significantly higher than in undisturbed soils. The mean difference was 10.3 ± 3.9 per cent. From an ecological point of view this increase in percentage of base saturation is regarded as favorable.

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APPENDIX

APPENDIX

TABLE I. THE INFLUENCE OF EXPOSURE OF MOUND SLOPES ON MAXIMUM SURFACE SOIL TEMPERATURES

Station designation	*Period of observation*	*Mean difference in maximum surface soil temperatures on different exposures, °F.*
Blake A, 20° slope	June 17–August 14, 1936	S. 13.5 ± 1.1 > N.
		W. 9.8 ± 1.1 > N.
		S. 8.0 ± 1.2 > E.
		S. 7.4 ± 1.4 > L.
		L. 6.5 ± 1.3 > N.
		E. 5.2 ± 1.2 > N.
		W. 4.3 ± 1.0 > E.
		S. 3.5 ± 1.0 > W.
		W. 3.2 ± 1.2 > L.
		L. 1.1 ± 1.0 > E.*
Blake, soil in pans, 30° slope	July 4–August 14, 1936	S. 13.1 ± 1.0 > N.
		W. 12.9 ± 1.0 > N.
		L. 8.0 ± 0.9 > N.
		S. 7.6 ± 0.8 > E.
		W. 7.4 ± 1.1 > E.
		E. 5.5 ± 1.1 > N.
		S. 5.3 ± 0.6 > L.
		W. 4.9 ± 0.8 > L.
		L. 2.4 ± 0.7 > E.
		S. 0.1 ± 0.6 > W.*
Blake C, 30° slope	July 8–September 10, 1938	S. 16.4 ± 1.4 > N.
		W. 13.8 ± 1.1 > N.
		E. 13.5 ± 1.2 > N.
		S. 3.1 ± 0.6 > E.
		S. 2.9 ± 0.6 > W.
		W. 0.3 ± 0.6 > E.*
Lafontaine D, 30° slope	July 8–September 7, 1938	S. 13.4 ± 1.4 > N.
		W. 9.8 ± 1.0 > N.
		S. 8.1 ± 0.9 > E.
		E. 5.3 ± 0.6 > N.
		W. 4.6 ± 0.6 > E.
		S. 3.6 ± 0.5 > W.

S. = south; N. = north; E. = east; W. = west; L. = level.

*Difference not significant; other differences significant at the 0.01 level.

TABLE 2. SUMMARIZED PORE VOLUME AND AIR CAPACITY DATA FOR DISTURBED AND UNDISTURBED SOILS

Station	*Mean pore volume, per cent*		*Mean air capacity, per cent volume*	
	Disturbed soil	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
I; 1–16	60.5 ± 2.4	44.3 ± 1.2	17.2 ± 1.7	6.2 ± 0.6
II; 1–15	27.7 ± 1.0	13.2 ± 1.9	12.1 ± 1.6	6.5 ± 0.7
V; 1–18	66.1 ± 2.6	64.1 ± 1.9	17.4 ± 1.2	10.4 ± 0.6
17; 1–18	68.1 ± 2.1	69.2 ± 1.5	16.1 ± 0.8	10.5 ± 0.4
17; 19–36	60.2 ± 3.3	62.8 ± 3.2	18.5 ± 0.8	19.2 ± 1.1
K; 1–18	58.2 ± 1.2	55.7 ± 1.9	17.7 ± 0.9	8.2 ± 0.7
K; 19–34	66.7 ± 0.8	47.4 ± 1.8	12.7 ± 1.0	8.6 ± 1.2
K; 35–50	63.7 ± 0.5	50.4 ± 1.6	12.1 ± 0.3	8.3 ± 1.7
K; 51–66	57.8 ± 1.8	59.3 ± 1.6	15.3 ± 1.4	12.9 ± 1.0
K; 67–82	62.5 ± 0.9	57.6 ± 2.2	13.9 ± 1.4	10.4 ± 1.2
GR; 1–10	60.0 ± 1.9	63.8 ± 1.8	9.8 ± 1.2	9.6 ± 0.5

TABLE 3. SUMMARIZED WATER HOLDING CAPACITY AND VOLUME WEIGHT DATA FOR DISTURBED AND UNDISTURBED SOILS

Station	*Mean water holding capacity, per cent volume*		*Mean volume weight*	
	Disturbed soil	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
I; 1–16	43.4 ± 2.2	38.2 ± 1.2	0.973 ± 0.041	1.389 ± 0.037
II; 1–15	15.6 ± 2.1	6.7 ± 1.6	1.419 ± 0.029	1.719 ± 0.012
V; 1–18	48.7 ± 2.0	53.6 ± 1.9	0.849 ± 0.061	0.946 ± 0.047
17; 1–18	52.1 ± 1.8	58.7 ± 1.2	0.817 ± 0.034	0.753 ± 0.025
17; 19–36	41.7 ± 2.9	43.6 ± 3.2	0.951 ± 0.025	0.892 ± 0.029
K; 1–18	40.5 ± 1.8	47.5 ± 1.8	1.096 ± 0.025	1.132 ± 0.048
K; 19–34	54.0 ± 0.6	38.8 ± 0.8	0.809 ± 0.025	1.323 ± 0.038
K; 35–50	51.4 ± 0.3	42.1 ± 1.9	0.942 ± 0.009	1.271 ± 0.043
K; 51–66	42.5 ± 2.1	46.4 ± 1.4	1.076 ± 0.046	1.040 ± 0.047
K; 67–82	48.6 ± 0.8	47.3 ± 1.3	0.955 ± 0.026	1.099 ± 0.046
GR; 1–10	48.2 ± 2.2	53.7 ± 1.8	0.989 ± 0.049	0.871 ± 0.055

APPENDIX

TABLE 4. SUMMARIZED INFILTRATION RATES FOR DISTURBED AND UNDISTURBED SOILS

Station	*Disturbed soil*	*Undisturbed soil*
	Mean infiltration rate, seconds per liter	
I; 1–16	289 ± 43	1475 ± 311
II; 1–15	140 ± 19	1714 ± 497
III; 1–24	162 ± 13	403 ± 62
V; 1–18	167 ± 22	497 ± 45
17; 1–18	184 ± 31	332 ± 33
17; 19–36	116 ± 23	209 ± 53
K; 1–18	141 ± 20	896 ± 102
K; 19–34	188 ± 22	1546 ± 253
K; 35–50	224 ± 20	1250 ± 140
K; 51–66	123 ± 24	282 ± 19
K; 67–82	198 ± 19	656 ± 91
GR; 1–10	311 ± 66	418 ± 60

TABLE 5. MECHANICAL COMPOSITION OF DISTURBED AND UNDISTURBED SURFACE SOILS

Station	*Disturbed soil*	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
	Fraction 40–5 mm., mean percentage		*Fraction 5–2 mm., mean percentage*		*Fraction < 2 mm., mean percentage*	
I; 1–16	1.1 ± 0.2	1.0 ± 0.2	4.8 ± 0.2	2.9 ± 0.2	94.1 ± 0.7	96.1 ± 0.2
II; 1–15	1.8 ± 0.8	0.5 ± 0.2	4.1 ± 0.6	1.9 ± 0.1	93.8 ± 1.3	97.7 ± 0.2
V; 1–18	14.3 ± 4.9	12.2 ± 3.7	6.3 ± 0.5	5.7 ± 0.4	79.4 ± 4.6	82.1 ± 3.9
17; 1–18	10.8 ± 2.5	5.4 ± 1.0	6.4 ± 0.7	6.8 ± 0.8	82.8 ± 3.2	87.8 ± 1.4
17; 19–36	20.2 ± 2.8	15.0 ± 1.4	7.8 ± 0.6	7.8 ± 0.7	71.0 ± 2.8	77.2 ± 1.4
K; 1–18	8.3 ± 1.8	4.6 ± 0.6	13.5 ± 0.8	12.3 ± 0.8	78.3 ± 1.7	83.2 ± 1.3
K; 19–34	4.3 ± 0.2	2.7 ± 0.3	11.0 ± 0.4	10.8 ± 0.6	84.7 ± 0.5	86.5 ± 0.9
K; 35–50	2.8 ± 0.4	2.4 ± 0.4	6.9 ± 0.5	8.3 ± 0.4	90.3 ± 0.9	89.3 ± 0.6
K; 51–66	6.2 ± 0.8	4.0 ± 0.6	14.3 ± 1.1	11.1 ± 0.9	79.5 ± 1.7	84.9 ± 1.3
K; 67–82	5.2 ± 0.5	5.0 ± 0.7	12.6 ± 0.3	11.5 ± 1.0	82.2 ± 1.1	82.3 ± 1.1
GR; 1–10	11.6 ± 1.2	7.3 ± 1.3	10.0 ± 0.7	5.8 ± 0.5	78.4 ± 1.5	86.9 ± 1.9

TABLE 6. MECHANICAL COMPOSITION OF DISTURBED AND UNDISTURBED SURFACE SOILS
(in terms of percentages)

Station	*Condition of soil**	*Soil fraction, mm. diameter*								*"Total colloids"*	*Soil type†*
		2.0–1.0	*1.0–0.5*	*0.5–0.25*	*0.25–0.10*	*0.10–0.05*	*0.05–0.005*	*<0.005*	*<0.002*		
I; 1–16	D	6.7	16.4	20.5	20.5	12.6	18.1	5.2	4.7	9.4	Hsl
	U	6.6	16.5	19.7	20.2	13.9	19.8	3.3	2.2	7.4	Hsl
II; 1–15	D	6.6	18.0	22.0	24.7	12.5	11.0	5.2	4.2	7.4	Hlfs
	U	3.4	13.7	22.0	27.8	12.9	16.0	4.2	3.7	7.9	Hsl
V; 1–18	D	4.2	8.1	12.7	20.8	19.9	28.3	6.0	5.5	11.0	Hsl
	U	3.9	9.2	14.2	22.6	17.2	25.9	7.0	6.0	12.0	Hsl
17; 1–18	D	4.1	6.0	8.8	17.2	24.2	33.2	6.5	4.0	11.2	Hfsl
	U	3.9	7.6	10.3	22.7	20.2	28.8	6.5	4.0	11.2	Hfsl
17; 19–36	D	4.4	6.9	10.9	18.3	15.1	33.7	10.7	8.7	20.9	Hfsl
	U	4.8	6.6	10.1	17.5	19.3	31.0	10.7	8.7	20.4	Hfsl
K; 1–18	D	12.1	18.0	21.0	26.3	8.9	9.2	4.5	2.5	6.7	Ms
	U	9.2	15.1	19.0	24.9	11.2	15.1	5.5	4.0	8.2	Msl
K; 19–34	D	8.9	15.7	20.8	22.1	12.1	15.4	5.0	4.0	7.7	Msl
	U	7.4	16.8	23.9	20.2	10.5	15.2	6.0	4.5	9.2	Msl
K; 35–50	D	9.6	21.0	21.3	25.5	8.6	10.7	3.3	2.3	4.3	Ms
	U	9.8	18.9	17.4	24.4	9.5	15.5	4.5	2.7	8.5	Mls
K; 51–66	D	13.5	20.0	19.6	23.8	8.2	9.9	5.0	3.7	8.2	Ms
	U	12.3	20.0	20.5	23.6	8.4	11.3	3.9	2.7	8.0	Mls
K; 67–82	D	11.6	20.5	20.9	24.7	10.4	8.3	3.6	2.9	6.3	Ms
	U	10.9	18.2	15.2	24.8	9.4	16.4	5.1	3.9	9.8	Msl
GR; 1–10	D	5.0	8.0	12.5	18.4	23.8	27.8	4.5	3.0	9.5	Hsl
	U	2.8	5.5	9.9	17.3	28.8	29.2	6.5	4.8	12.5	Hfsl

*D = disturbed soil; U = undisturbed soil.

†H = Hermon soil series; M = Merrimac soil series; sl = sandy loam; lfs = loamy fine sand; fsl = fine sandy loam; s = sand; ls = loamy sand.

APPENDIX

TABLE 7. HEAVY MINERAL INDEX AND MOISTURE EQUIVALENT DATA FOR DISTURBED AND UNDISTURBED SOILS

Station	*Heavy mineral index, per cent*		*Moisture equivalent, per cent of dry weight*	
	Disturbed soil	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
I; 1–16	10.06	8.22	12.17	11.35
II; 1–15	10.19	7.59	9.62	8.84
V; 1–18	7.94	6.16	18.65	18.86
17; 1–18	7.57	5.29	21.03	22.92
17; 19–36	8.19	7.46	27.20	28.21
K; 1–18	9.38	8.07	9.97	13.00
K; 19–34	8.29	7.11	18.83	9.89
K; 35–50	8.70	5.88	13.97	11.43
K; 51–66	12.10	8.07	13.54	13.40
K; 67–82	9.38	6.87	10.51	10.26
GR; 1–10	13.94	6.81	....	....
C; 1–10	14.33	10.07	....	....

TABLE 8. TOTAL NITROGEN, ORGANIC CARBON, AND CARBON-NITROGEN RATIOS, IN DISTURBED AND UNDISTURBED SOILS

Station	*Total nitrogen, per cent of weight*		*Carbon content, per cent of weight*		*Carbon-nitrogen ratio (C ÷ N)*	
	Disturbed soil	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
I; 1–16	0.067	0.065	1.08	0.92	16.1	14.2
II; 1–15	0.059	0.042	0.96	0.59	16.3	14.0
V; 1–18	0.115	0.070	2.38	2.40	20.7	34.3
17; 1–18	0.087	0.214	2.02	3.64	23.2	17.0
17; 19–36	0.186	0.193	2.40	3.31	12.9	17.2
K; 1–18	0.097	0.157	1.32	2.36	13.6	15.0
K; 19–34	0.235	0.078	4.13	1.30	17.6	16.7
K; 35–50	0.145	0.094	2.53	1.49	17.4	15.8
K; 51–66	0.113	0.127	1.87	2.42	16.6	19.1
K; 67–82	0.188	0.167	3.44	2.39	18.3	14.3
GR; 1–10	0.094	0.104	1.96	2.51	20.8	24.1

TABLE 9. EXCHANGEABLE CALCIUM, READILY SOLUBLE PHOSPHORUS, AND HYDROGEN ION CONCENTRATION IN DISTURBED AND UNDISTURBED SOILS

Station	*Exchangeable calcium, m.e. per 100 gm. soil*		*Phosphorus content, mgm. per 100 gm. soil*		*Hydrogen ion concentration, pH*	
	Disturbed soil	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*	*Disturbed soil*	*Undisturbed soil*
I; 1–16	0.22	0.18	1.77	2.04	4.87	4.66
II; 1–15	0.16	0.02	2.12	1.13	4.85	4.54
V; 1–18	2.11	0.70	1.66	1.80	5.33	4.90
17; 1–18	0.68	1.45	1.02	1.63	5.19	5.08
17; 19–36	1.98	3.19	1.51	1.98	5.40	5.15
K; 1–18	0.24	0.31	1.70	3.04	4.81	4.25
K; 19–34	0.08	0.06	1.90	1.89	4.22	4.25
K; 35–50	0.14	0.28	2.08	2.03	4.74	4.53
K; 51–66	0.14	0.14	1.86	2.02	5.10	4.73
K; 67–82	0.14	0.19	2.53	2.80	4.80	4.45
GR; 1–10	0.68	1.08	...	...	5.14	4.82

TABLE 10. BUFFER RELATIONS IN DISTURBED AND UNDISTURBED SOILS

Station	*Disturbed soil*		*Undisturbed soil*	
	Percentage inactivated of 1 m.e. [H] added, 5 gm. soil	*Percentage inactivated of 2 m.e. [H] added, 5 gm. soil*	*Percentage inactivated of 1 m.e. [H] added, 5 gm. soil*	*Percentage inactivated of 2 m.e. [H] added, 5 gm. soil*
I; 1–16	77.1	64.6	37.2	35.1
II; 1–15	54.1	45.1	29.3	30.1
V; 1–18	75.6	66.3	81.6	71.1
17; 1–18	83.1	73.0	88.6	82.0
17; 19–36	86.0	73.0	77.6	64.5
K; 1–18	71.6	62.8	64.6	53.5
K; 19–34	86.6	79.8	19.1	17.8
K; 35–50	71.7	68.6	46.3	35.2
K; 51–66	90.1	80.0	80.2	65.8
K; 67–82	74.7	62.8	54.4	45.2
GR; 1–10	80.6	73.0	93.8	90.3

APPENDIX

TABLE II. BASE EXCHANGE RELATIONS IN DISTURBED AND UNDISTURBED SOILS

Station	*Disturbed soil*				*Undisturbed soil*			
	Exchangeable hydrogen, m.e. per 100 gm. soil	*Exchangeable bases, m.e. per 100 gm. soil*	*Total exchange capacity, m.e. per 100 gm. soil*	*Percentage base saturation*	*Exchangeable hydrogen, m.e. per 100 gm. soil*	*Exchangeable bases, m.e. per 100 gm. soil*	*Total exchange capacity, m.e. per 100 gm. soil*	*Percentage base saturation*
I; 1–16	4.30	4.30	8.60	50.0	3.77	1.58	5.35	29.5
II; 1–15	2.62	5.03	7.65	65.8	2.05	2.70	4.75	56.8
V; 1–18	6.36	12.04	18.40	65.4	8.21	11.79	20.00	59.0
17; 1–18	6.53	8.57	15.10	56.8	11.38	11.92	23.30	51.2
17; 19–36	7.04	13.31	20.35	65.4	7.79	15.31	23.10	66.3
K; 1–18	10.32	4.88	15.20	32.1	16.30	2.46	18.76	13.1
K; 19–34	24.59	5.61	30.20	18.6	4.97	0.72	5.69	12.6
K; 35–50	9.74	7.04	16.78	42.0	7.14	2.46	9.60	25.6
K; 51–66	6.43	5.80	12.23	47.4	8.90	4.42	13.32	33.2
K; 67–82	11.45	8.45	19.90	42.5	14.38	1.47	15.85	9.3
GR; 1–10	9.12	3.73	12.85	29.0	13.00	11.10	24.10	46.0

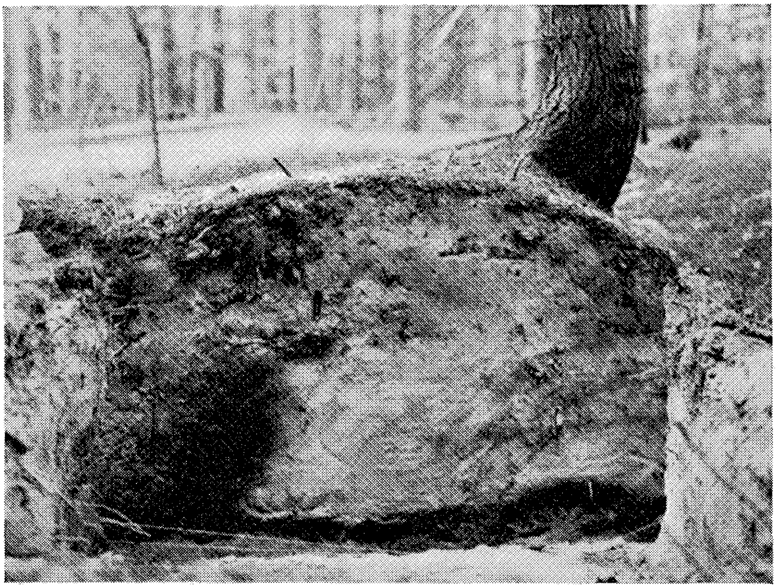
ILLUSTRATIONS

FIGURE 1

View of a profile through a mound of Hermon sandy loam soil material. An interesting feature is the unusual thickness and abrupt termination of the relict A horizon material. This resulted from folding when a tree was windthrown. Yale Demonstration and Research Forest, Keene, New Hampshire.

FIGURE 2

View of a profile through a mound of Hermon sandy loam soil material. The relict A horizon is in a nearly vertical position. Gale River Experimental Forest, Pierce Bridge, New Hampshire.



Courtesy, The American Journal of Science.

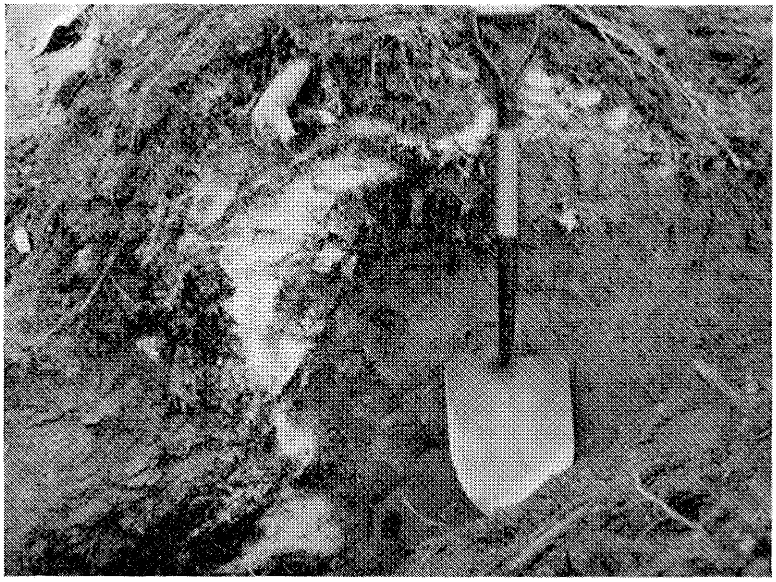


FIGURE 3

View of a profile through Hermon sandy loam which was disturbed by a windthrown tree. The uprooted tree fell in a direction toward the left side of the figure. Gale River Experimental Forest, Pierce Bridge, New Hampshire.

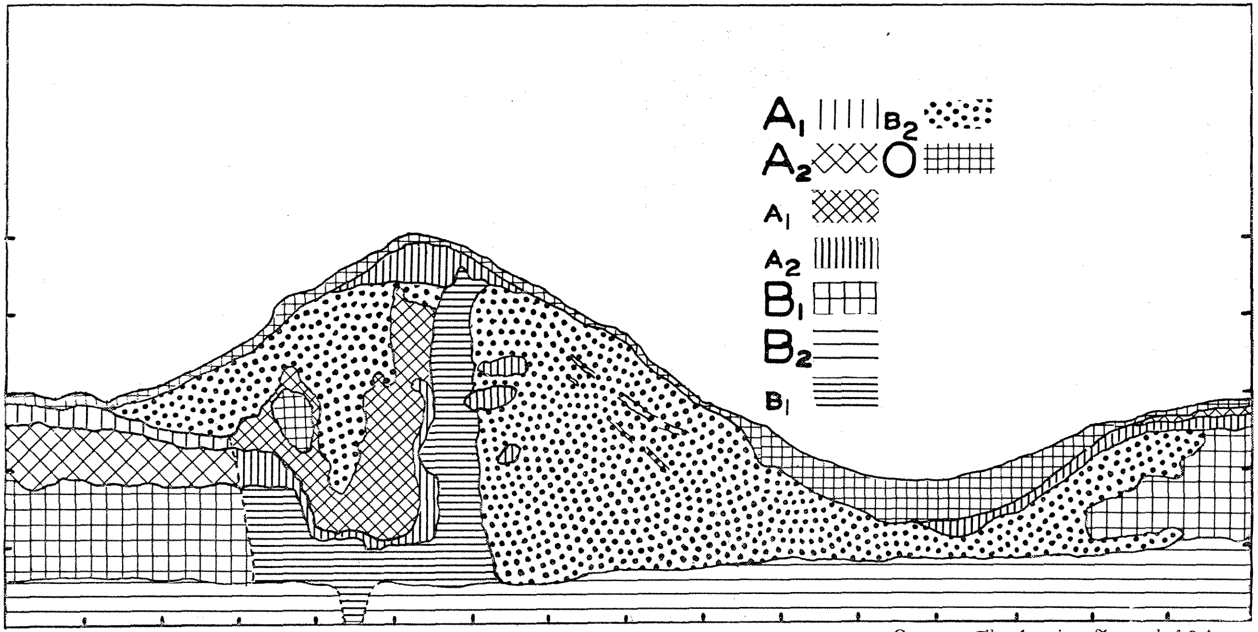
FIGURE 4

View of Blake mound C formed in 1938 for measuring the influence of slope exposure on surface soil temperature. Yale Demonstration and Research Forest, near Keene, New Hampshire.

FIGURE 5

Disturbance in Merrimac soil resulting from a tree having been uprooted.

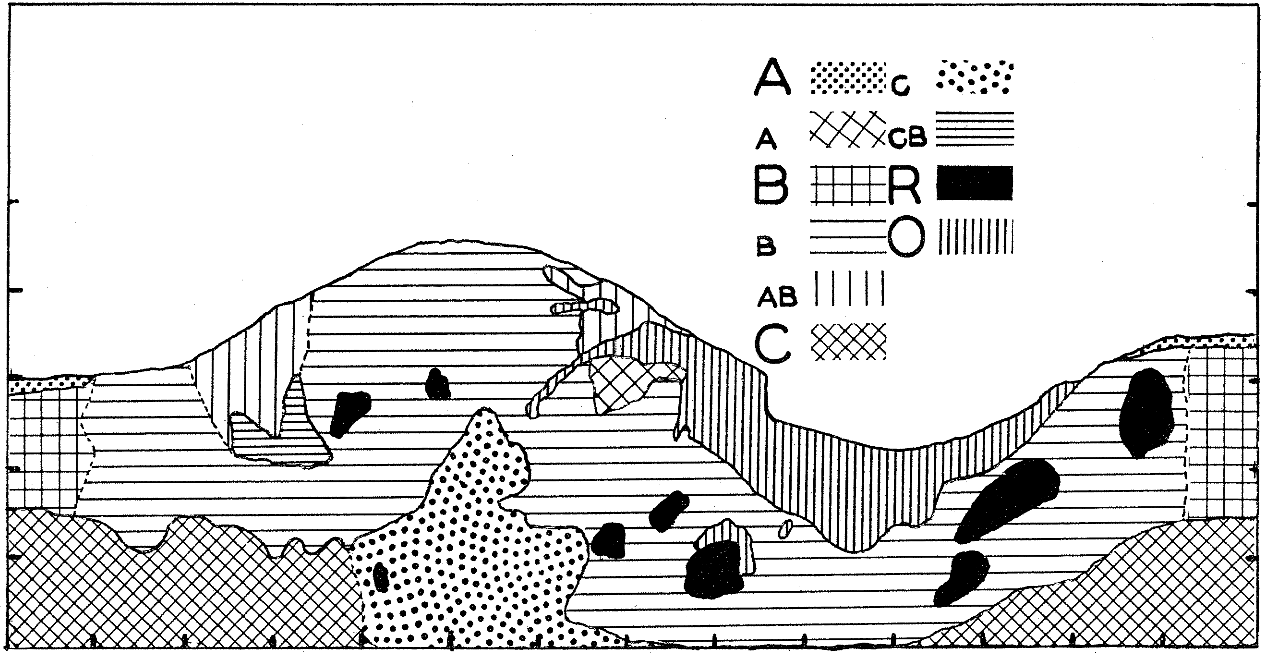
Capital letters in the legend designate undisturbed horizons, as follows: A—the zone of eluviation, B—the zone of illuviation, C—the unweathered or parent material. Corresponding small letters indicate that the material in these horizons has been disturbed. Organic debris is indicated by the letter O. Each interval between the graduations along the sides and bottom of the chart represents one foot. Adjacent to the Yale Demonstration and Research Forest, near Keene, New Hampshire.



Courtesy, The American Journal of Science.

FIGURE 6

Disturbance in Hermon soil resulting from a tree having been uprooted. For interpretation of letters used see Figure 5; combinations of small letters indicate mixtures of material from two horizons. Rocks are indicated by the letter R. Yale Demonstration and Research Forest, near Keene, New Hampshire.



Courtesy, The American Journal of Science.

FIGURE 7

Map of topography and tree positions on a one-tenth acre plot. Contour interval, one-half foot; tree positions shown in black; hollows are indicated by depression contours. The micro-relief features which have developed on the initially flat surface of this glacial lake deposit are the result of trees having been uprooted; a variety of slope exposures occur. It may be noted that a majority of the trees are located on mounds.

The forest stand, which was about 175 years old, consisted principally of *Pinus strobus* L., *Tsuga canadensis* (L.) Carr., and *Fagus grandifolia* Ehrh. It was entirely destroyed by the hurricane of September 21, 1938, most of the trees being uprooted. Five Mile Drive, near Keene, New Hampshire.

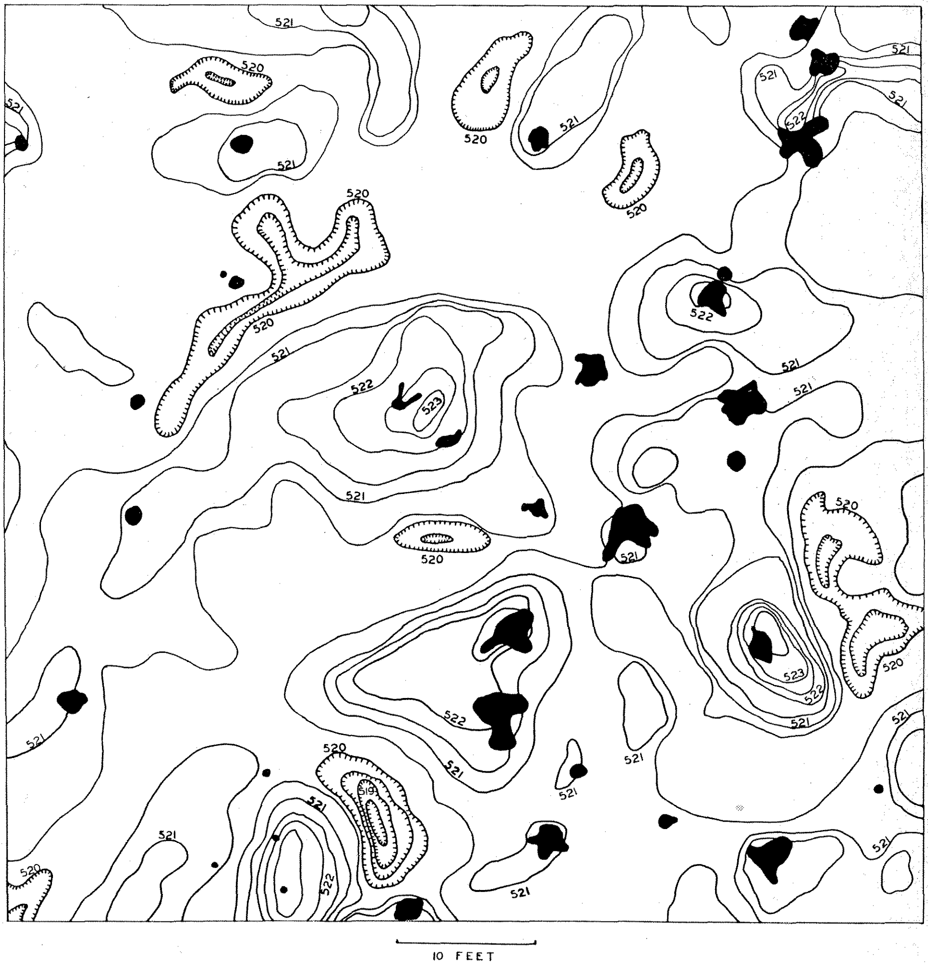

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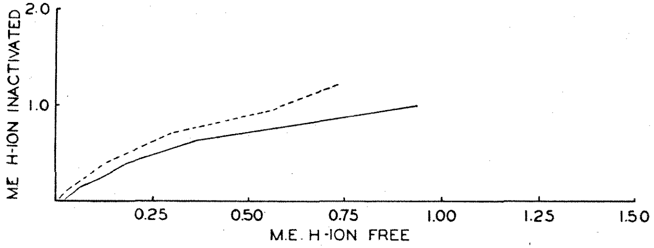
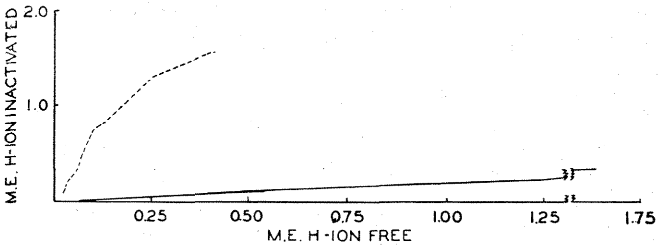
FIGURE 8

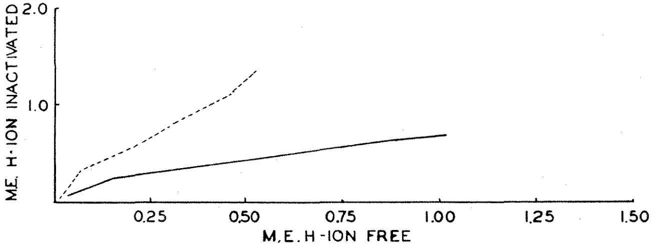
Antiacid buffering effect of disturbed and undisturbed soil material. Based on five gram samples in a volume of 100 cc. Curves for disturbed soil are shown as broken lines and those for undisturbed soil as solid lines.



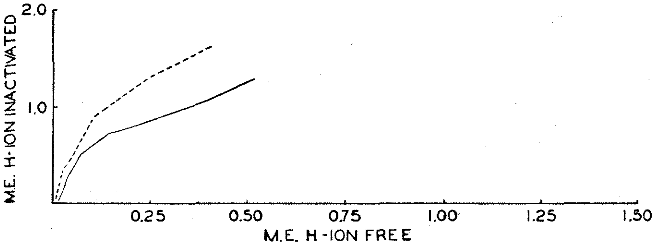
STATION K-1,18



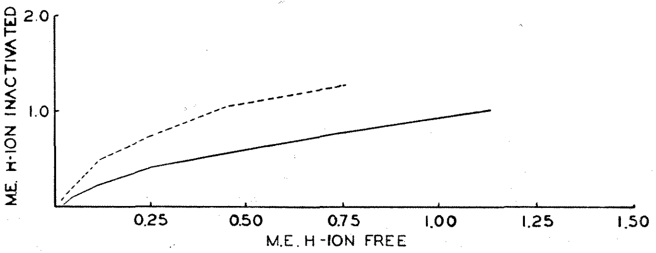
STATION K-19,34



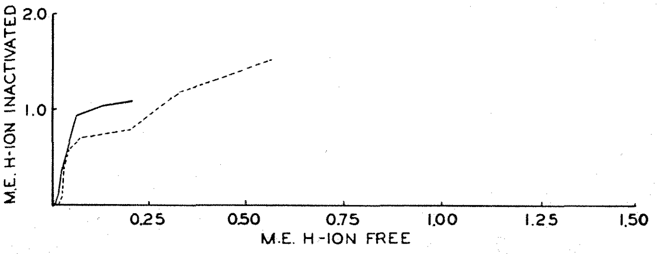
STATION K-35,50



STATION K-51,66



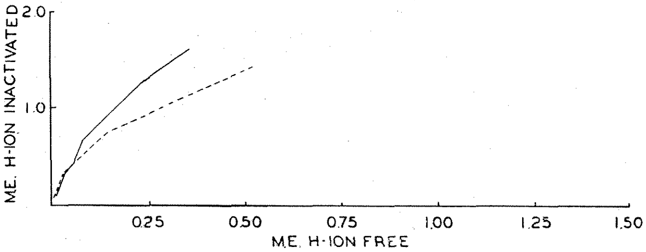
STATION K-67,82



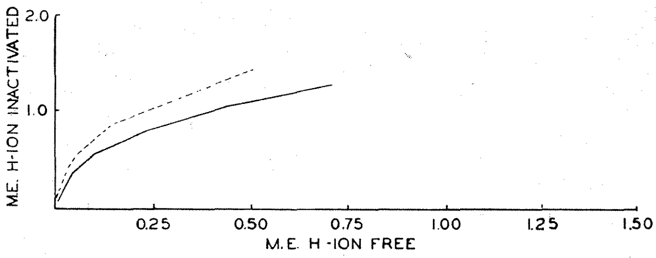
STATION GR-1,10

FIGURE 9

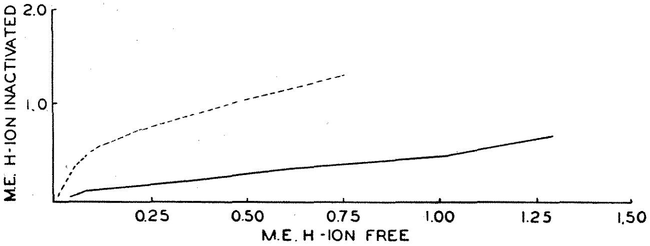
Antiacid buffering effect of disturbed and undisturbed soil material. Based on five gram samples in a volume of 100 cc. Curves for disturbed soil are shown as broken lines and those for undisturbed soil as solid lines.



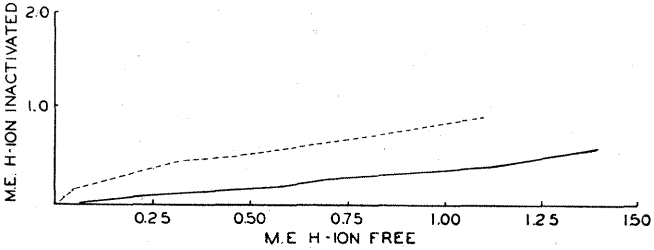
STATION 17-1,18



STATION 17-19,36



STATION I-1,16



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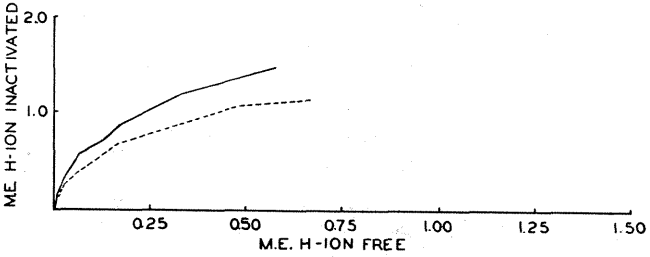

STATION V-1,18

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