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Richard T. Fisher, *Director*

THE EVOLUTION OF SOILS AS AFFECTED BY THE OLD FIELD WHITE PINE–MIXED HARDWOOD SUCCESSION IN CENTRAL NEW ENGLAND

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INTRODUCTION

THIS bulletin embodies a comparative study of the evolution of soil profiles under the old field white pine type of central New England and the hardwood succession which commonly follows it after logging. The soil conditions accompanying this type of conversion as observed on certain managed areas at Petersham have already been recorded in a paper entitled "Soil Changes and Silviculture on the Harvard Forest" (Ecology, January, 1928). In essence these changes consist of two contrasting conditions in the humus layers and the adjacent dark brown horizon or top soil — under the pine, a heavy accumulation of litter and duff with a thin top soil; under the succeeding hardwood, little or no organic material and a deep top soil. In the case described a distinctly podsolized profile has altered in twenty years to a typical mull or brown earth. Applying to but a few cases, this striking and rapid change from a comparatively degraded to a highly favorable soil raises a larger question as to the relationship between regional soil types as a whole and the commonest phases of succession in the present second growth forests. The accepted theory of soil origin, which is in effect that similar types of soil are the product of similar climates, makes it important to know how far and in what directions the unstable phases of forest vegetation, which have now so largely replaced the original forest, affect the profiles climatically characteristic of the region.

It is plain that if climatic factors are primarily responsible for differing types of soil, we should expect modifications to follow the varying influence of forest cover upon temperature, moisture, and radiation. As between forests which are largely evergreen and those which are deciduous, there is obviously on the forest floor a wide variation in seasonal temperatures, in the amount and penetration of rainfall, and in the intensity and duration of light. Any particular combination of these factors must also be limited in its effect upon soil metabolism by the character of the forest litter, the relative toughness, consistency, and perhaps chemical content of the leaves. Both these influences in turn affect the microflora and soil fauna, which play a part in the derivation of plant food. Thus we should expect that, on sites of similar topography and elevation, pronounced variation in forest composition of sufficiently long duration would result in corresponding changes of soil profile, especially in the depth, condition, and rate of decomposition in the humus layers.

It is the reactions of the humus layers to the varying conditions of forest density and composition that probably furnish the best clue to fertility. If one considers, for example, the characteristic forest soils from the sub-Arctic regions of eastern Canada to the Appalachian regions of Kentucky and Tennessee, it will be noticed that the most conspicuous differences lie in the depth and condition of the sum total of organic material that remains above the mineral soil. In the northern extremes these layers are excessively deep and slow to decompose. In the southern example they are shallow and subject to rapid decomposition. In respect to total seasonal growth the Appalachian forests are far ahead of the spruce stands of northeastern Canada. Naturally the greater part of this difference in production is due to the difference in seasonal temperatures. Nevertheless, a corresponding but less extreme difference in the depth of the humus layers is to be found in intermediate localities, where the total variation in general climatic factors is negligible. In such cases, as for example on certain managed areas of the Harvard Forest, a similar marked contrast in relative growth and production is also associated with the two tendencies in the development of the humus layers. In other words, where the annual fall of leaf litter decomposes rapidly and works into the mineral soil, growth is notably faster than where the humus layers deepen and build up with the age of the stand. These facts point to the conclusion that with approximately uniform rainfall and range of temperatures, the rate of decomposition of the humus layers is a fair index of soil fertility.

On first thought it might be supposed that the original or climax forest, representing presumably a stability of association resulting from the undisturbed influence of all natural factors combined, would furnish significant evidence of a relation between composition and soil. As regards extremes of climatic variation or of site, this is probably true. The coniferous types, for example, of the higher mountain slopes and the swamp or bog types of the upland regions represent both a simplified and relatively fixed composition and a set of physical factors which are susceptible of but little change. If, however, we consider the great bulk of the original forest in central New England — a region of transitional climatic factors, and, as regards species, a tension belt between the coniferous types of the north and the hardwoods of the central states — we find a relative instability in composition. The original upland forest, assuming again the exclusion of extremely dry or wet sites, contained many species of hardwood together with hemlock and white pine, the hemlock a more or less constant element and the pine variable in numbers and distribution. Although this forest over large areas was apparently stable in percentage composition of species, there is evidence for believing that on smaller areas, and over periods of several centuries, there was a tendency to fluctuation in dominance between softwoods and hardwoods. The natural adaptabilities of species to site were intermittently upset by lightning, fire, windthrow, ice storms, and sometimes insects or disease. Thus a declining group of pine and hemlock would be replaced by one of hardwoods, and vice versa. This tendency is indicated both by the frequent groupwise distribution of the softwood and hardwood elements in the stand and by the relative arrangement of the size or age classes. There is also, of course, in such a forest almost a stagnation of growth, due to the fact that all the younger generations of trees arising from intermittent seedling reproduction are progressively or periodically retarded, perhaps until very late in life, by the slowness with which the dominant trees fall out from old age or injury. This results in a far deeper and more persistent leaf canopy, down even to thickets of varied undergrowth, than is the case with a younger, more uniform stand, and tends to equalize any influences upon soil that either a hardwood or softwood association might exert alone. In the course of the present study fifty-four profiles were examined in virgin forest with a wide range of composition, but the differences in the type of soil profile were less striking than the differences in the associations of species. It would thus appear that in a mixed virgin forest of the type under discussion, the relationship of present composition to development of soil profiles is obscured.

With the second growth types examined in this study the case is very different. Due to circumstances of origin, the complexities of life history in the virgin forest have been largely eliminated. A century of tillage and grazing has obliterated all trace both of the original soil profile and any natural association of species as ultimately governed by site factors. The old field pine type originated in the main on upland sites of fairly deep soils. This is primarily because the early settlers confined their clearings to such locations and tended to avoid both excessively steep, rocky, or broken areas as well as pronounced swamps. Because of the comparative abundance and superior effectiveness of pine seed trees during the period of most extensive farm abandonment and the corresponding scarcity of the inferior, light-seeded hardwoods, which have since reached such abundance, most of the older pine stands are substantially pure, of roughly even age, and high density. The progress of these stands toward the usual merchantable maturity of sixty to eighty years has been almost invariably accompanied by a gradual infiltration of young hardwoods. The heavy-seeded species were dispersed and planted by rodents and birds, the resort of which to the forest usually increases with its age; the light-seeded species, like ash and maple, by wind and water. This development accounts for most of the usual hardwood succession after the logging of the pine. On areas where the hardwood advance growth was scanty or lacking, usually in the younger pine stands, there is an additional reproduction on the cleared area consisting of gray and paper birch, pin cherry, poplar, and red maple. In such cases these species may dominate the stand from the start.

It is significant that this secondary phase of hardwood is thoroughly accidental as to distribution. A brief examination of an old field pine forest will reveal distinct groups or patches of young hardwoods, sometimes as large as half an acre, in each of which one or more species may greatly predominate. In almost every case the origin may be traced either to neglected fence corner trees or to scattered old hardwoods in the pine stand, identifiable as specimens surviving from the previous era of farm and pasture. Just which species may have been on hand to furnish seed, either during or after the pine phase, is plainly a matter of accident. The resulting immense areas of promiscuously grouped broad-leaved species show a highly unstable composition, a tendency slowly to revert through various overlapping stages toward the original climax type. In so far as the reactions of the humus layers to these transitions are significant, it appears that "quality of locality," in the sense of capacity to support growth, may vary widely on the same physiographic site.

The chronology of the whole succession to which the present observations apply may be summed up as follows: an indeterminate past of mixed virgin forest, a hundred years of pasture and tillage, eighty years of pure white pine, and forty years of mixed hardwood. We have thus to-day two sharply distinct phases of forest composition, accidentally segregated by the circumstance of land history, beginning on bare land of uniform original soils with no distinct humus layers, developing in turn on the same areas, and occurring without relation to the original effect of local site factors upon distribution. With this fortunate elimination of variables, it may be concluded that the principal contrasts to be found in the evolution of the humus layers and contiguous dark brown zones under old field pine and succeeding hardwood may be traced to the influences of these contrasting phases of composition.

R. T. Fisher

FIELD OBSERVATIONS

The term "profile" as applied in soils investigations includes everything that is to be observed in a vertical cut through the soil exposing the various horizons (Glinka, 1927).

Since the soil profile is the direct result of all the influences of climate, it varies extensively in different regions and under varying cover types. The regional distribution of the northern coniferous forest in northern New England and in parts of Pennsylvania, New York, and the Lake States is approximately coincident with the distribution of the leached or podsol soils. The soils of this region, with certain exceptions, exhibit the podsol profile which is characteristic of this climatic soil type. The northern part of the central hardwoods region, south of the northern forest, is characterized generally by a different climatic soil formation, the brown forest soils. The forest soils of this region, with certain exceptions, develop a characteristic mull profile. In the transition zone between these two climatic regions, the location of this study, both soils occur, and it is possible to find a number of types which are intermediate between the extreme podsol and mull conditions.

The podsol profile is characterized by a thick mantle of litter and humus underlain by a zone of leaching, gray in color, from which organic matter and colloids have been washed down and redeposited in the enriched horizon beneath it. The mull profile is characterized by the absence of the leached zone and by marked structural differences.

Since the most complex arrangement of strata is found in the podsol profile, a diagram of such a profile will be used to display the different layers and zones, and the names and symbols applied to them. The soil profile in Figure 1 may be found under the white pine–hemlock type of virgin forest in this region. The classification of horizons is that of Glinka. The eluvial strata or horizons, designated by A, comprise

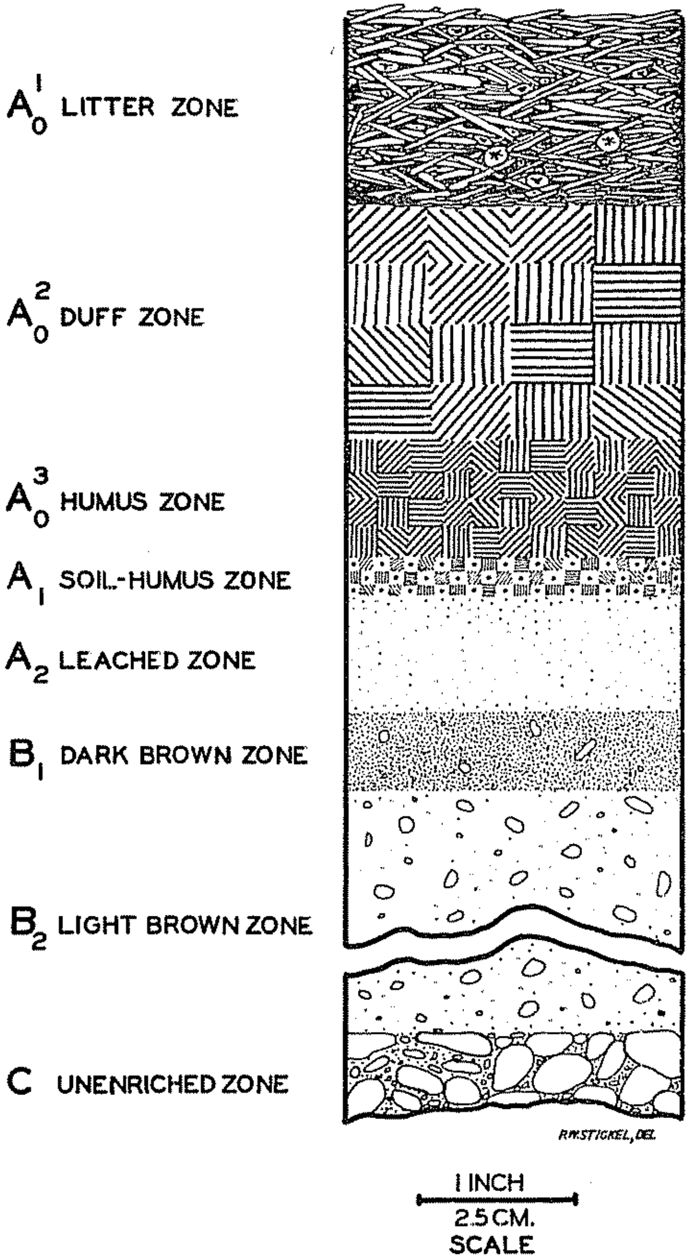

FIG. 1. PROFILE SHOWING TYPICAL HORIZONS OF PODSOL SOIL

those from which material has been removed either by chemical or mechanical means. The illuvial horizons, or those into which material has been carried, are designated by B. The unenriched, weathered horizon is designated by C.

The organic horizon is further subdivided into three zones: the litter zone, A_0^1, where no decomposition is apparent; the duff zone, A_0^2, where decomposition of the litter is in progress, but where traces of the original structure are quite evident; and the humus zone, A_0^3, where the organic matter has entirely disintegrated. The duff zone is Hesselman's horizon F, and the humus zone is his horizon H.

The transition or soil humus zone, A_1, of the leached or podsol horizon is one where decomposed organic matter is being incorporated in the leached mineral soil. This transition zone may be so thin in the undisturbed profile as to be almost indistinct. Under the young temporary types observed in this study, its depth was negligible. The leached zone, A_2, gray in color, from which the soil formation derives its name, is a layer from which organic matter and colloids have been extracted by the action of water and the organic acids.

The enriched horizon, B, is broken into zones on the basis of color differentiation. In the figure only two zones, the dark brown, B_1, and the light brown, B_2, are distinguished. In some profiles, however, it is necessary to further subdivide the enriched horizon into zones of upper and lower dark brown and upper and lower light brown. Marbut (1926) points out that the soil has a color profile, a structure profile, a consistency profile, a reaction profile, and finally a chemical profile. It is more common in soils investigations to distinguish horizons on the basis of color and then to relate the features of structure, consistency, reaction, and chemical composition to it.

The mineral horizon, C, is composed of weathered material which has not been enriched by deposition from the horizons above it.

In the mull profile it is convenient to use the same names and symbols for layers homologous to those in the podsol. In the best type of mull profile the organic horizon is narrow and is underlain by a well-worked dark brown horizon which gradually shades into the light brown. The leached zone is absent. It is possible to find profiles which are intermediate between the extreme podsol and mull formations. However, it is convenient to use the same designations for the series of horizons and zonal divisions of all types. The enriched horizon in a highly developed mull is characterized by a crummy structure and a high degree of tilth.

In the profile descriptions which were made in this study, the organic horizons were distinguished on the basis of the degree of decomposition. The mineral horizons were distinguished first on the basis of color, and then the color profile was related to variations of structure and consistency.

Material Studied

The stands used to test the differences in development between soils under pine and under succeeding hardwoods were found on and in the vicinity of the Harvard Forest in the town of Petersham, Worcester County, Massachusetts. The regional topography is distinguished by broad ridges from 800 to 1300 feet above sea level with a general north and south trend. The original soils and climate are substantially uniform for the locality.

The soils of Worcester County are described by Latimer, Martin, and Lanphear (1927), who state that these soils have undergone comparatively slight changes since deposition of the glacial till. These changes are mainly in the accumulation of organic matter and the assumption of a brown color due to combinations of iron oxidation products and organic matter. The soil-making processes operate slowly in Massachusetts, since the climate is humid and temperate, with rather severe winters and short, cool summers which bring considerable rain alternating with brief, warm, sultry periods.

The average annual temperature is about 47° F.; and that of the summer, 69° F. The mean annual precipitation is forty-two inches, well distributed throughout the year. The growing season includes about one hundred and eighty-three days, from April 20 to October 20.

The plots for the study of profiles were located on Gloucester, Charlton, and Brookfield soils. The Gloucester series occupies more area in Worcester County than any other one series. Gloucester soils have brown surface and yellowish brown to yellow subsoils, which, at twenty to thirty inches down, grade into a fine-grained, gray, unweathered material. Subsoils are usually of the same or lighter texture than the surface soils. This series represents comparatively shallow deposits of glacial till derived mainly from gray granites and gneisses. The Charlton is similar to the Gloucester, though somewhat finer textured because of softer parent rocks, and has a characteristic faintly mottled greenish subsoil. The Brookfield loam has a rusty or reddish brown cast, but at fifteen to twenty inches is ocherous yellow, becoming paler with greater depth, slightly lighter in texture, and the unweathered material may have a greenish color. These three series proved on analysis to be sufficiently alike so that the plots on them were considered comparable and averaged together. According to Dr. Lanphear, who accompanied the party on an early field trip, profile studies on all three could safely be combined. No plots on sandy soils were included in the compilations.

In choosing a pine or a hardwood stand, the first consideration was completeness of the crown canopy. "Spots" under openings in the canopy were carefully avoided. The number of years the crown canopy had been closed was significant, since the study concerned soil changes under such conditions. This duration of crown closure was estimated on about half of the plots. It was quite accurate for the pine stands, but somewhat less so for the hardwoods. The average period before closure of the pine stands is ten years; of the hardwoods, seven.

The age range of the pine plots was ten to eighty years. The hardwoods were five to forty years of age. Since no hardwood stands over forty years old were found that could be proved to have followed old field pine, a few hardwood stands over this age that had been culled as woodlots were examined for data comparable with that obtainable from the older pine stands. Owing to lack of early density in reproduction, no completely closed pine stands under ten years of age were found.

The plots had to fit certain requirements as to composition. No pine plots with more than ten to fifteen per cent of hardwoods or hemlock in mixture were used in compiling the pine data. As the major interest was in the soil conditions under the better species, suitable hardwood stands were more difficult to discover, because of the great variety of broad-leaved trees and the range of proportions in which they occur. The hardwood stands examined were practically even-aged, as they originated after the clearcutting of pine. While in stands under forty there was but one canopy, in hardwood over forty there were two or three distinct crown levels: the major stand, the sapling undergrowth, and a light layer of seedlings and shrubs. The composition in stands over forty years of age was based on the overstory and sapling levels.

An attempt was made to obtain plots of various aspect, moisture, and slope conditions. Most of the hardwood stands were found under moist conditions on southeast, south, and westerly exposures; the pine stands used were about evenly divided between north and south slopes. However, as might be inferred from the old field origin, topographic differences between the two series of plots are negligible.

After the selection of the stand, a circular plot was estimated. One-quarter acre was used in large or merchantable sized timber; one-tenth acre in pole sizes, two to ten inches

D. B. H.; and one-hundredth acre in smaller sizes. Plots were described uniformly with notes taken on the type, form, origin, age, and composition of the stand; on soil class and drainage conditions; on topography, aspect, and slope; on advance reproduction, ground cover, and material in the litter.

Three profile holes were dug within a radius of fifteen feet about the plot centre. Machetes were used to expose a vertical face at least six inches wide, on which the average profile was judged. To reach the C horizon a soil augur was necessary, due to the depth of the light brown layer. Samples were taken on representative plots after the measurements of horizon depth, and physical condition descriptions were made. These soil samples for laboratory analysis were gathered by horizons or zones within a horizon in such a manner as to obtain an average sample for the layer.

In addition to the second growth stands studied about Petersham, profiles were investigated in the virgin forest on the Pisgah Tract owned by the Harvard Forest in southern New Hampshire. Here the hardwood stands were about 150 to 160 years old, and the pine-hemlock over 200. These profiles may be considered samples of conditions formerly obtaining in the climax forest on the areas where the contrasted pine and hardwood plots were located. Similarly, out of interest as to the effects of mixtures of hardwoods and pine and of certain other conifers, a few plots were studied in such stands at Petersham.

Depth Measurements

In the present study, depth measurements of horizons and zones were taken to tenths of inches. A trace was considered as anything less than one tenth of an inch and was recorded in the data as .05. It was found helpful to peg the profile with toothpicks at points which gave the average depth for each layer and to measure between these markers. Due to the prevalence of rocks and boulders in many of the plots, it was impossible to reach the mineral horizon, C, with the auger. For this reason there were fewer measurements for the depth of the lower part of the enriched horizon, the light brown.

To investigate the relation of horizon depth to age of stand, factors of site, and forest composition, the depths of the profiles in sixty-two pine plots and sixty-two hardwood plots were measured. Following is the distribution of the profiles measured among the age classes:

Age classes	10	20	30	40	50	60	70	80	Total
Number of pine profiles	12	21	39	24	39	33	9	10	187
Number of hardwood profiles	51*	47*	57*	9*	0	6†	9†	6†	185

* Hardwoods following pine. † Hardwoods culled or seeded in on old fields

The frequency of distribution of the depth measurements for the pine profiles is shown in Table 1. This table gives the variations found in the depths of horizons within the different age classes. The measurements for the different age classes in each type were averaged, and are shown graphically in Figure 2.

Analysis of the data shows that the pine profiles in the ten-year age class reflect the influence of the cultivated fields upon which the pine stands developed. The litter zone is narrow; the duff zone is generally less than an inch deep; and there is practically no true humus. The dark brown zone of the enriched horizon is deep, averaging nine inches. This is about the depth of the old culture horizon before the occupancy of the pine. In the figure the bottom of the enriched horizon is denoted by a broken line at twenty inches, which is the average depth at which the C horizon begins, as determined by 105 measurements. As stated before, measurements could not be taken to the base of the enriched horizon in all cases, due to the prevalence of rocks and boulders. The profiles in the twenty-year age class show an increase in the amount of duff or raw humus, and a small amount of true

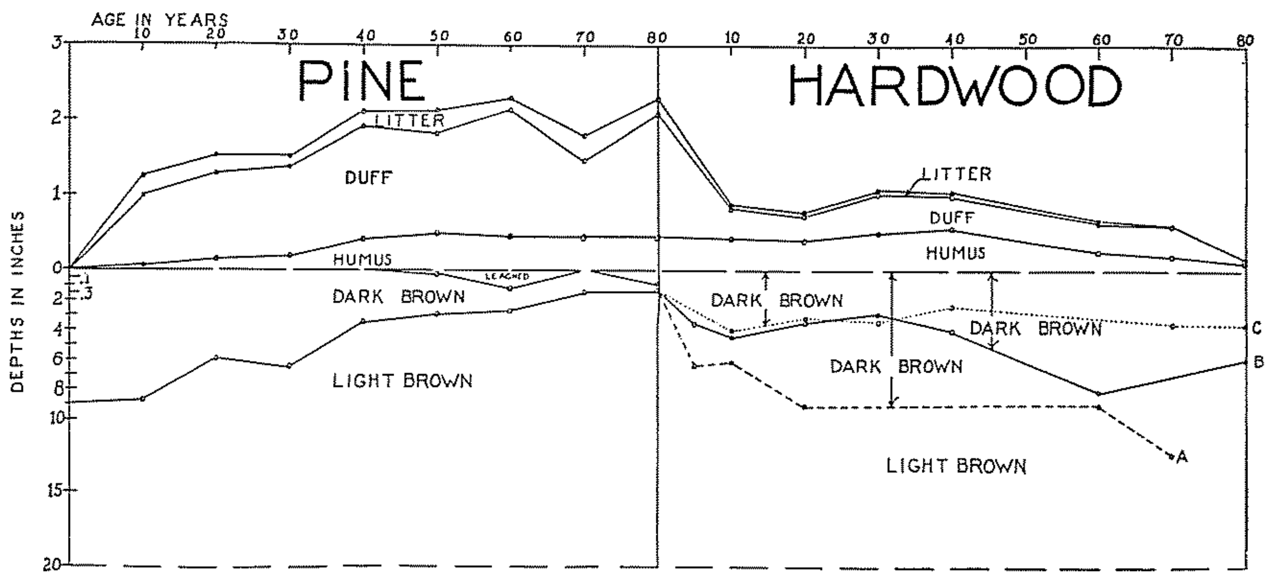

Fig. 2. EVOLUTION OF PROFILES UNDER OLD FIELD PINE AND SUCCEEDING HARDWOOD

TABLE 1

PLOTS IN OLD FIELD PINE

Frequency Distribution of Profile Measurements

Horizon	Depth in inches	Age in years							
		10	20	30	40	50	60	70	80
Litter	1.0– 0.8	1	. .	1	1	2	1	.	. .
	0.8– 0.6	1	1	1	2	1	.	1	. .
	0.6– 0.4	1	1	2	2	11	6	4	2
	0.4– 0.2	2	5	8	4	15	12	1	3
	0.2– 0.0	7	14	27	15	10	14	3	5
Duff	3.0– 2.8			1	1	. .	3	. .	1
	2.8– 2.6	. .		. .	. .	. .	.	.	1
	2.6– 2.4			.	.	1	2		. .
	2.4– 2.2	. .	.	3	2	1	2	.	.
	2.2– 2.0	3	3	. .	3	5	4		2
	2.0– 1.8	. .	. .	2	1	1	1	.	1
	1.8– 1.6		1	2	2	.	2	.	1
	1.6– 1.4		4	4	5	9	5	2	
	1.4– 1.2	.	5	6	4	7	. .	3	. .
	1.2– 1.0	3	4	8	1	9	11	.	1
	1.0– 0.8	.	2	5	2	2	2	.	1
	0.8– 0.6	1	2	3	3	3	. .	2	2
	0.6– 0.4	1	.	4	.	1	1	2	. .
	0.4– 0.2	4	. .	1		.		.	.
	0.2– 0.0	. .	. .	. .		. .	.	. .	.
Humus	1.2– 1.0	.	.	.	.	2	3	.	. .
	1.0– 0.8	. .		.	2	1	1	1	1
	0.8– 0.6	.	. .	. .	1	6	5	2	4
	0.6– 0.4	. .	3	8	12	18	15	4	1
	0.4– 0.2	. .	6	11	6	10	9	1	1
	0.2– 0.0	12	12	20	3	2	.	1	3
Leached	0.6– 0.4	. .	. .	.	.	1		.	2
	0.4– 0.2	.	. .	. .	. .		. .	. .	.
	0.2– 0.1		.	. .	.	. .	6	. .	1
	0.1– 0.05	. .	. .	1	4	10	16	.	3
	0.0	12	21	38	20	28	16	9	4
Dark brown	14.0–13.0	3	. .	1	.		. .		. .
	13.0–12.0	1	. .	2		. .	.	.	. .
	12.0–11.0	1	.	4			.		. .
	11.0–10.0	. .	2	2	.	.	.	.	. .
	10.0– 9.0	.	. .	4	. .	. .		.	. .
	9.0– 8.0	. .	5	3	1	. .	.		. .
	8.0– 7.0	1	1	2	.	. .	.		.
	7.0– 6.0	2	3	3	1	3	1	.	. .
	6.0– 5.0	2	1	2	2	.	2	.	1
	5.0– 4.0	2	6	7	4	3	3	1	. .
	4.0– 3.0	. .	3	4	8	9	8	1	. .
	3.0– 2.0	.	. .	4	4	16	12	2	1
	2.0– 1.0	.	. .	1	4	7	7	1	4
	1.0– 0.0	. .	. .	. .	. .	1		4	4

humus. The dark brown zone has narrowed to an average depth of about six inches. In the thirty-year class the total organic horizon does not change in depth, but there is a slightly larger proportion of true humus. The dark brown zone is slightly deeper. The profiles in the forty-year age class show an increase in the depth of all organic zones. Several profiles show a trace of leaching. The dark brown horizon narrows considerably. The profiles in the fifty-year age class show a further increase in the depth of the organic horizon and a higher proportion of humus. Ten profiles out of thirty-nine show a trace of leaching and one has a well defined leached layer. It should be noted that in Figure 2 the leached zone is plotted on the same scale as the organic horizon. The dark brown zone in this age class has narrowed to an average depth of three inches. At sixty years the profiles are marked by a deeper organic horizon and a higher proportion of raw humus. Seventeen out of thirty-three profiles show a trace of leaching. The dark brown zone becomes even more shallow. At seventy years the organic horizon shows a considerable decrease in depth; but at eighty years it increases to the same depth as at sixty years, leading one to believe that the break at seventy years is due to a lack of sufficient data. The profiles at seventy and eighty years are marked by further decrease in the depth of the dark brown layer. At eighty years it has an average depth of less than 1.5 inches.

During the first ten years of the hardwood occupation the organic layers accumulated under the pine disappear, most of the current hardwood litter decomposes annually, and the entire organic horizon is less than an inch deep. The dark brown horizon deepens considerably. In the older age classes of the hardwoods the organic horizon continues to remain a shallow layer, generally less than an inch deep with practically no litter and with about equal amounts of duff and humus. The dark brown horizon fluctuates considerably. In order to bring out any relationship between this fluctuation and the composition of the prevailing leaf litter,

TABLE 2

PLOTS IN MIXED HARDWOODS

Composition of Stands (Expressed in Percentage of Total Basal Area) and Depths of Dark Brown Zone

Plot	Age class	Group	Red oak	White oak	Beech	White pine	Chestnut	Hornbeam	Pin cherry	Black cherry	Gray birch	Aspen	Black birch	Soft maple	Hard maple	Yellow birch	White birch	Basswood	Elm	White ash	Dark brown zone Depths in inches 1	2	3	Average depth
94	5	B	5	..	..	..	..	..	..	3	..	..	86	6	..	..	..	..	..	..	2.7	3.0	3.0	2.8
47	..	B	13	..	..	..	8	..	..	..	..	8	..	71	..	..	..	..	..	..	4.0	3.0	7.0	4.7
73	..	A	3	3	..	..	..	..	..	1	..	..	..	29	..	..	..	47	..	17	7.0	6.0	7.0	6.7
67	10	C	40	..	5	10	5	..	..	..	..	..	..	..	..	..	40	..	..	..	2.5	3.9	2.8	3.1
131	..	C	26	17	..	..	5	..	..	..	..	..	..	42	..	..	7	3	..	..	5.0	5.0	4.5	4.9
83	..	B	15	..	..	..	..	..	..	2	..	..	37	30	..	8	..	..	..	8	3.0	3.0	2.0	2.7
134	..	B	8	1	..	..	..	..	..	..	..	..	66	14	..	1	..	..	1	9	4.0	1.7	3.0	2.9
78	..	B	2	..	..	..	1	..	..	23	..	4	..	41	..	..	11	..	..	18	5.0	4.0	4.0	4.3
132	..	B	17	12	..	..	5	..	..	..	..	..	8	31	..	3	10	..	..	14	4.6	4.5	4.3	4.4
79	..	B	2	4	..	1	..	..	..	5	..	..	..	82	..	..	4	..	..	2	4.0	4.5	5.0	4.5
85	..	B	28	..	..	..	..	..	1	2	..	..	8	44	..	..	..	..	..	17	5.7	5.0	3.0	4.6
81	..	B	2	2	..	..	..	..	..	1	..	74	6	13	..	..	1	..	..	1	4.0	5.5	5.0	4.8
69	..	B	25	..	..	..	..	..	..	..	..	..	10	44	..	..	..	..	..	21	6.0	10.0	7.0	7.6
87	..	A	10	..	..	1	..	..	..	..	..	1	4	19	..	..	8	..	..	57	5.2	4.0	4.5	4.6
89	..	A	12	..	..	..	..	..	..	..	..	4	..	12	..	..	42	..	..	30	5.0	5.0	5.5	5.2
74	..	A	13	..	..	..	..	..	..	..	..	..	5	14	..	..	..	..	..	68	8.5	7.0	9.0	8.2
116	..	A	..	..	..	..	..	..	..	..	..	..	..	14	6	..	..	..	..	80	5.0	10.0	10.0	8.3
114	20	C	39	12	..	..	..	..	..	..	6	..	1	22	..	..	..	..	..	20	1.7	2.2	2.5	2.1
105	..	C	1	69	..	..	..	..	..	..	..	..	..	5	..	..	..	..	..	25	4.0	7.0	2.3	4.4
141	..	B	..	..	..	..	..	..	..	..	84	15	..	1	..	..	..	..	..	..	6.4	0	0	2.1
119	..	B	20	..	..	..	..	..	..	..	32	4	..	..	42	..	..	..	1	1	3.0	2.8	..	2.9
93	..	B	23	..	..	..	..	1	..	14	12	15	..	10	2	3	15	1	..	4	2.0	3.5	3.5	3.0
142	..	B	2	..	..	..	..	..	..	3	17	71	1	5	..	..	..	..	..	1	3.0	4.1	2.7	3.3
139	..	B	1	..	..	..	..	..	..	1	18	67	3	10	..	..	..	..	..	..	5.0	1.3	4.0	3.4
159	..	B	..	..	..	2	..	..	..	2	..	..	..	..	96	..	..	..	..	..	3.0	4.0	3.5	3.5
100	..	B	3	..	..	..	..	23	..	1	6	..	1	36	..	..	4	..	6	20	3.5	3.8	4.0	3.8
86	..	B	1	..	..	..	..	..	..	1	..	88	5	3	..	1	..	..	..	1	4.0	4.4	3.4	3.9
149	..	B	..	..	..	..	..	..	1	..	44	4	27	10	1	..	13	..	..	..	4.5	3.5	5.0	4.3

167	..	B	16	1	..	.	1	..	..	29	30	..	10	9	3	..	..	..	..	1	6.0	5.0	5.0	5.3
108	..	A	..	..	..	3	..	..	..	1	..	1	14	1	..	22	58	..	..	.	7.0	6.5	7.0	6.8
160	..	A	..	..	..	..	..	..	.	..	12	..	.	..	..	..	.	.	6	82	..	7.0	9.0	8.0
70	..	A	.	..	..	..	..	..	.	..	..	..	2	..	48	..	..	2	..	48	11.0	9.0	10.0	10.0
107	..	A	..	.	..	..	..	..	..	22	..	..	9	14	..	19	36	..	..	..	18.0	2.0	18.0	12.6
140	30	C	78	1	..	6	.	..	..	2	4	..	..	8	1	.	..	..	.	..	5.0	1.0	1.4	2.5
101	..	C	63	..	1	..	..	..	..	..	1	.	..	28	.	2	..	..	..	5	1.0	4.0	3.0	2.7
111	..	C	55	..	..	..	..	..	..	..	4	..	.	41	..	..	.	..	..	.	3.0	2.5	3.0	2.8
54	..	C	49	.	..	..	..	..	.	.	..	1	.	33	..	..	17	..	..	..	3.4	1.6	3.8	2.9
96	..	C	15	35	..	..	..	..	.	1	6	..	..	42	.	..	1	..	..	..	3.0	3.5	3.0	3.2
92	..	C	61	2	2	..	..	1	..	..	32	..	..	1	1	..	..	..	..	..	4.6	3.5	2.3	3.5
95	.	C	12	35	.	..	..	..	..	..	.	..	..	34	..	.	19	..	..	..	3.0	4.0	3.5	3.5
122	.	C	56	7	2	2	..	..	..	..	15	.	..	17	1	..	.	..	..	..	4.0	3.4	3.6	3.7
124	..	C	60	2	..	3	..	..	.	1	..	..	.	32	1	..	..	..	..	1	6.0	7.0	5.0	6.0
91	..	B	39	..	..	..	..	..	.	1	22	1	..	35	.	..	..	2	..	..	0.3	0.1	2.6	1.0
102	..	B	32	..	..	..	..	..	..	..	5	..	7	46	3	3	..	..	..	4	1.0	1.5	1.4	1.3
125	..	B	8	.	2	..	..	..	..	1	19	12	..	58	..	..	.	..	..	..	1.6	2.2	4.0	2.6
126	..	B	12	..	..	..	..	..	..	..	4	..	46	33	..	..	.	..	..	5	3.5	0.3	4.0	2.6
127	.	B	8	2	..	1	..	.	13	8	..	..	..	68	.	..	..	..	.	.	3.0	2.3	3.0	2.8
62	..	B	4	.	..	8	..	..	..	1	3	5	2	36	.	..	18	..	..	23	2.5	4.5	3.0	3.3
123	..	B	..	22	.	16	..	..	..	..	9	.	10	41	..	2	.	..	..	..	3.5	2.5	4.5	3.5
128	.	B	43	..	..	.	..	..	..	3	8	..	..	46	..	..	..	..	.	.	4.5	3.5	2.5	3.5
113	..	B	29	..	..	..	..	..	.	13	16	..	..	16	.	10	16	..	..	..	3.2	4.0	3.7	3.7
155	..	B	21	3	..	2	..	..	..	..	16	..	2	34	15	..	.	.	..	7	4.0	3.0	5.0	4.0
68	40	C	29	..	3	9	..	..	.	8	..	..	..	33	..	.	18	..	..	..	2.0	3.4	1.0	2.1
148	..	C	73	3	2	6	..	2	..	3	.	..	..	3	6	.	2	..	..	..	1.8	2.0	4.0	2.6
97	..	B	6	9	..	..	..	8	..	..	6	.	..	23	22	5	8	.	..	13	4.0	4.5	3.5	4.0
156	60	B	30	..	5	5	..	..	.	..	..	..	..	18	7	.	..	5	1	29	8.0	8.0	9.0	8.3
147	..	A	10	..	24	1	..	..	..	..	..	..	..	6	9	28	.	12	9	1	6.0	11.0	11.5	9.5
146	70	C	84	4	..	..	..	.	..	..	..	..	..	3	8	..	..	..	..	1	3.8	3.5	2.0	3.1
145	..	C	40	..	..	6	..	5	..	..	..	..	..	33	5	..	..	7	..	4	3.5	6.0	3.8	4.4
135	..	A	6	..	..	1	..	..	..	..	.	..	..	19	..	..	..	..	6	68	4.5	13.0	20.0	12.5
144	80	C	53	..	6	2	..	1	..	..	..	..	1	12	13	4	7	1	..	..	1.3	1.2	9.0	3.8
136	..	B	14	10	..	..	..	..	..	..	..	..	..	60	..	..	..	..	..	16	9.0	4.0	5.0	6.0

the plots were thrown into three classes, A, B, C, based upon susceptibility of the leaves to decomposition, as shown by the results of type conversions on the Harvard Forest. In Table 2 are presented the compositions of the sixty-two hardwood plots and the depths of the dark brown zones under them. It will be noted that the A plots, which contain a preponderance of white ash, elm, basswood, white birch, and yellow birch, usually have a deeper dark brown zone than the B plots, containing a preponderance of hornbeam, pin cherry, black cherry, aspen, black birch, soft maple, and hard maple; also that the B plots generally have deeper dark brown zones than the C plots, containing a preponderance of red oak, white oak, beech, white pine, and chestnut. The average depths of the dark brown zone in the A, B, and C classes have been plotted in Figure 2. The depth of the dark brown in the B plots is very close to the average for the hardwood type as a whole.

These relations of composition to the depth of the dark brown horizon are not without significance. It may be argued that the more exacting species would naturally be found on the better soils, but the old field background precludes this possibility. The distribution of hardwood species on cut-over pine lands is largely accidental, and is plainly governed by the occurrence of sporadic seed trees in the previous pine or fence corner survivals from the old fields (Patton, 1922). Furthermore, the period since the old field condition is too short for the effect of site factors upon distribution to assert itself. It seems plain, therefore, that in stands under eighty years old, the various species help to develop and maintain the soil conditions with which foresters usually associate them. In the present case the differing effect of the several groups A, B, and C, gains additional significance from the fact that all have originated on a similar and degraded soil.

During the field work it appeared that the best type of mull profile occurred under mixed hardwood stands of the better species on gentle slopes with a good supply of outwardmoving ground water. Under such conditions the profiles contained an extremely shallow organic horizon and a well-worked dark brown zone, measuring in some instances from sixteen to twenty inches in depth. Decomposition proceeded so rapidly on these sites that by midsummer there was practically no organic matter on the surface of the ground. It also appeared that well-developed leached layers under old field pine stands less than eighty years old were generally found on low, moist sites, and seemed to be developments of slow drainage. Examples of these two extremes in soil conversion have been described in detail by Fisher (1928). No effect could be deduced from minor variations of slope and aspect.

Tilth

The physical condition of the soil to some extent determines the virility of the crop; for as the condition of the soil is favorable or unfavorable for plant growth, the tilth of the soil is characterized as good or poor. Tilth may be analyzed as the result of the combination of consistency, structure, and flocculation. By consistency is meant the firmness of the soil; by structure, the relative size and number of soil particles formed from the sands, silts, clays, and organic colloids which make up the soil mass; and by flocculation, the degree of agglutination of the soil colloids into crumbs or floccules. The soil structure is classified into four divisions: grainy, where the soil particles are made up of single large grains, as in the sands; granular, where a few larger particles are present, as in sandy loams; crummy, where there is a still greater proportion of particles which are larger than those of the granules, as in the loams; and columnar, where the soil mass is composed very largely of colloidal material and fractures, as in the manner of clay. Good tilth in a soil is associated with a crummy structure and a high degree of flocculation.

Consistency was measured in the field by the degree of resistance offered by the soil to penetration. It was classified as loose, friable, tenacious, or tough in the ascending order of resistance. The soil structure was measured by placing a sample of the soil in the cupped palm of one hand and then bringing the cupped palm of the other hand smartly down over it, creating a sudden compression of the air, which dispersed the soil into its various particles. Flocculation was determined by the feel and appearance of the soil, and classified as no flocculation present, fairly well flocculated, well flocculated, and highly flocculated.

From an examination of the field data, which are briefly summarized in Table 3, it will be seen that there is considerable difference in the physical condition of soils of the dark brown horizons under pine and under mixed hardwood forests which followed the logging of pine stands. This fact becomes more significant when it is remembered that the different types of stand were located on soils having the same texture. Under the younger age classes of the pines there is a wide variation in consistency from loose to tough, with, however, a greater proportion loose or friable. As the pine stands increase in age, the soils become more compact, a larger proportion becoming tenacious. After the cutting of the pines and the establishment of a young stand of hardwoods, the soil again loosens up, with ninety-three per cent of the cases friable under the older age classes.

It is seen that the structure of the soil under pines does not change very much with increasing age, the major portion of the soils examined being either granular or crummy under all age classes, with, however, a small number of them columnar in the older ages. The hardwoods have a decided effect on the soil, changing the granular and columnar soil structure found under the pines to a hundred per cent crummy structure under the older hardwood groups.

The degree of flocculation is quite different under the two types, there being very little under the pines; and this de-

TABLE 3

STRUCTURE, CONSISTENCY, AND FLOCCULATION OF THE SOIL UNDER PINE AND HARDWOOD STANDS

Forest type	Age class in years	Total number of profiles	Horizons								Flocculation in per cent of profiles			
			Consistency in per cent of profiles				Structure in per cent of profiles							
			Loose	Friable	Tenacious	Tough	Grainy	Granular	Crummy	Columnar	None	Fair	Good	High
			Dark Brown											
Pine..........	0–45	100	20	65	11	4	..	21	79	..	59	38	3	..
	45–80	81	12	67	21	..	..	21	76	3	78	22	..	..
Hardwood ...	0–45	164	12	80	8	..	..	9	91	..	13	45	40	2
	45–80	25	7	93	..	..	..	..	100	..	..	..	50	50
			Light Brown											
Pine..........	0–45	92	..	35	60	5	5	90	5	..	..	..	..	..
	45–80	85	1	29	67	3	4	84	11	1	..	..	..	..
Hardwood	0–45	160	1	62	34	3	..	85	15	..	..	..	..	..
	45–80	17	..	79	16	5	..	71	29	..	..	..	..	..

creases with age to practically no flocculation at eighty years. Under the hardwoods flocculation is generally good and increases with age to a maximum in the older age classes. However, a number of soils examined under young hardwood stands which had a high proportion of either red oak, gray birch, or poplar had very little flocculation, the soil being very similar to that under the pine.

In the light brown horizons there are throughout tendencies similar to those in the dark brown horizons; but the soil is generally more tenacious and granular, which is probably due to the smaller amount of organic matter present. Flocculation is absent in the light brown zones.

Although soil texture can be only very slowly changed, from the above conclusions it is evident that the soil tilth can be greatly changed within a single forest crop rotation. Changes in tilth are the result of the movement of soil water, rainfall, temperature changes, the alternate thawing and freezing, wetting and drying of the soil, changes in the organic content, activity of soil fauna, such as earthworms, mice, and ants, and cultivation. Cultivation has the same general effect on the soil as alternate thawing and freezing, wetting and drying, which loosens and rearranges the particles of the soil mass. A forest crop can change the tilth of the soil by altering any one of the above factors. A softwood stand with its dense foliage shades the soil from the direct rays of the sun, keeping the range of soil temperature narrower than it otherwise would be. This lowering of the temperature retards the decomposition of the leaf litter, which with increasing age of the stand forms a thick layer over the surface of the soil. This organic layer, besides absorbing much of the rainfall, precludes sudden and extreme temperature changes and the rapid drying-out of the soil after rainfalls. Thus the soil is kept under fairly uniform moisture and temperature conditions for comparatively long intervals, a condition which is unfavorable for loosening the structure. Under a hardwood forest the ground is more directly exposed to the sun's rays, resulting in a higher temperature. This accelerates the decomposition of the leaf litter so that very little organic matter accumulates at the soil surface to prevent rapid temperature and moisture changes. The frequent thawing and freezing, drying and wetting of the soil, and the addition of organic colloids from the decomposed litter under hardwoods loosen and flocculate the soil. Thus, in a relatively short period of time, the soils under pine stands with poor tilth are changed by the ensuing hardwood stand to a good physical condition.

Biological Observations

Ground Cover

On all the plots studied notes were taken on the relative abundance of the ground cover, and the species of plant were listed as few, many, or abundant, according to their occurrence. Under hardwood forests the flora is very much denser than that under pines, although the species comprising the ground cover are, with a few exceptions, practically the same. The two exceptions are the absence of wood aster (*Aster acuminatus*) under the pines and its abundance under the hardwoods; and the abundance of the false lily of the valley (*Maianthemum canadense*) under the pines and its scarcity under hardwoods. The occurrence of the same species on widely different profiles may be explained by the fact that the soil reaction under both types of forest is very similar. The most numerous plant species noted are listed in the order of their abundance as follows: *Rubus spp.* (mostly *R. villosus*), ferns (*Aspidium spp.* and *Pteris*), *Gaultheria procumbens, Aster acuminatus, Maianthemum canadense, Lycopodium sp., Mitchella repens, Tiarella sp., Polytrichum commune, Vaccinium sp., Viburnum alnifolium, Viburnum acerifolium, Coptis trifolia,* and *Viola spp.*

Earthworms

Earthworms were noted in digging many of the hardwood profiles and were always associated with soils having good tilth. They were generally absent in the soils of the pine forests, being seen in only one stand, a twenty-year-old pine plantation planted on a field previously well cultivated. It was interesting to note the presence of earthworms in soils of such high acidity (pH 3.8 to 5.4), since Arrhenius (1921) found that most earthworms could not live in very acid soils.

Root Systems

The feeding roots of the pine trees were usually concentrated in the thick organic layers and in the upper zone of the dark brown horizons. This concentration of the feeding roots is probably due to the greater abundance of available nitrogen in the surface layers of the pine profiles. In the hardwood stands such a zonation of the feeding roots was seldom seen.

LABORATORY TESTS

The field observations raise several questions which may be answered only through detailed information available from laboratory tests. Thus we may ask if the horizons separated on the basis of color are really different in chemical or physical constitution. Are the light brown horizons under hardwoods and pine similar or dissimilar? Is there any relation between moisture content or the species composing the stand and the organic material of the enriched horizon? What can be learned of the chemical nature of the organic material by which the brown horizons are enriched? What are the acidity conditions and what bearing do the organic materials have on these conditions? What may be the relation between the organic matter and nitrogen in the mineral horizons?

During the field operations samples were obtained from the various horizons and preserved in waxed fibre containers.

To prevent changes in acidity and nitrogen content they were air dried as soon as they were brought into the laboratory. They were then sieved and the 2 mm. separate retained for analysis for the size classes of mineral material, ignition loss, pH (or acidities), buffer content, and total nitrogen.

Texture

The physical condition of the soil is built on a mineral skeleton of different sizes of gravels, sands, silts, and clays. The proportions of these fractions determine the texture of the soil. Soil texture governs many of the fundamental soil qualities, largely through surface relationships. Hilgard (1914) quotes King's calculation (1907) that in ordinary loam soils the sum of the surfaces of soil grains is about an acre per cubic foot, while in fine clay soils it rises to as much as four acres. Since hygroscopic water is retained by the surface, it is readily perceived how important the textural qualities are in regard to the water relations of the soil. The textural qualities are also important in nutrient availability, since the nutrients are in many cases held by adsorption on this surface.

The ease of drainage increases the more sandy the soil. In dune sands Albert (1927) has found that as the proportions of material 0.2 mm. and under increase, the more exacting species increase in number and vigor. Weis (1929) has substantiated these results on Danish heath soils.

A check of the similarity of texture is therefore essential in plots on which the transformation of organic materials is studied. The first purpose of the textural determination was to classify the soils of the plots as sands, loams, or clays, as defined by the U. S. Bureau of Soils. Davis and Bennett (1927) so name soils by the proportions of sands, silts, and clays in the 2 mm. fractions.

Increase of surface-volume ratio of the soil is greatest in the colloid or fine particle sizes, that is, the clay and fine silt portions. The proportions of these sizes are of great importance in soil water relationships. When water is adsorbed on a surface, heat is liberated. This heat may be used as a measure of the force with which the water is bound and as a test for the presence of colloid surfaces. Bouyoucos (1927) has found that fine silts larger than 0.008 mm. in diameter do not exhibit heat of wetting. Anderson (1924) has shown that colloid surfaces show heat of wetting.

In a determination of soil texture, rapidity and ease of operation are of more importance than the extremely accurate separation of particles. Elaborate methods could not be used for the number of samples involved in this study, so the Bouyoucos hydrometer method was used. The basis of this method is subsidence of thoroughly dispersed, deflocculated soil in a water column with stated periodic readings of a special hydrometer giving grams of dry soil per liter of suspension. Indices of colloid or fine particle contents may be quickly and easily derived by sedimentation. The values obtained by the hydrometer method show reasonable agreement with those by the heat of wetting method (Bouyoucos, 1927).

Method of Determination

The hydrometer method is based upon an empirical formula, Stoke's Law, for the rate of fall of small spherical particles in liquid. The law is valid for both macroscopic and microscopic solid bodies (Freundlich, 1922, p. 403). The condition of sphericity of particles required by Stoke's Law is not fulfilled in soils, but equivalent diameters are found. Where times of fall and column height (Bouyoucos used 32.5 cm.) are constant, velocity of fall varies directly with the coefficient of viscosity. Particle sizes at these times vary. For the same particle size range in each sample, the time must be varied with the coefficient of viscosity. The formula is

$$v = \frac{2gd^2 (S - S_1)\,6}{9nt\,40} \qquad (1)$$

where v is distance one particle of d size falls in one minute;
g is pull of gravity (980 dynes);
d is diameter of particles in mm.;
S is specific gravity of soil (average value, 2.65);
S_1 is specific gravity of water (1);
nt is coefficient of viscosity of water at t temperature (see Figure 3 for value of nt);
$\frac{6}{40}$ is used to express v in terms of cm. per minute and also diameters in mm.

From (1) by combining we get

$$v = \frac{53.9d^2}{nt} \text{ or } vnt = 53.9d^2 \qquad (2)$$

where T is the time of settling in minutes and h is column height in centimeters,

$$T = \frac{h}{v} \text{ or } v = \frac{h}{T} \qquad (3)$$

and

$$\frac{32.5}{T} nt = 53.9d^2 \text{ or } T = \frac{32.5}{53.9d^2} \times nt \qquad (4)$$

Hence for 20° C. and the 0.0201 mm. particle size,

$$T_{20} = \frac{32.5}{53.9d^2} \times .01 = \frac{.325}{53.9d^2} = 14.92 \text{ or } 15 \text{ minutes} \qquad (5)$$

but at a temperature of 5° C., the time for the same class is

$$T_5 = T_{20} \times nt = 15 \times 1.52 = 22.8 \text{ minutes} \qquad (6)$$

A graph on logarithmic scale is shown (Fig. 3) with values for 20° C. and lines for 17° and 5° C. It will be seen that for a given particle size, the time of settling varies with temperature.

The influence of temperature is exerted through changes in the viscosity and density of the water. Errors due to the change in buoyancy with temperature should not be greater than an error in the assumed value for the specific gravity of the soil, 2.65, and may be neglected. For a temperature correction Bouyoucos recommends a correction of 0.35 per cent of the soil per degree F. It is added when the temperature is above and subtracted when it is below 67° F. Just how this correction was derived is difficult to surmise. Increasing the amounts of soil for a given particle size to offset changes in the viscosity coefficient cannot be relied upon, as the distribution of particles within the range of size is un-

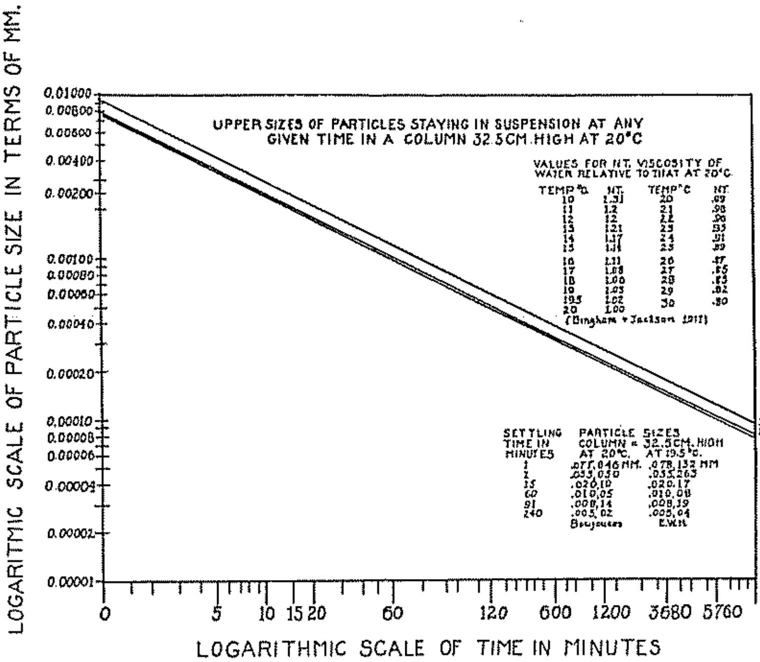

Fig 3 RATES OF SETTLING OF VARIOUS-SIZED SOIL PARTICLES IN WATER OF DIFFERENT TEMPERATURES

known. Therefore, the variation of time of reading to obtain given particle sizes at varying temperatures must be found from the formula or by laying out temperature lines on the graph.

Homogeneous samples of the 2 mm. fraction were oven dried at 95° to 110° C. for two days and then 100 g. were taken for analysis. The method as given by Bouyoucos (1927) was then followed.

Of the sixty-two plots obtained for each forest type, twenty-seven in each type were tested for texture. Tests including all the mineral horizons of five profiles among the hardwood and four among the pine plots are shown in Tables 4 and 5. In Table 6 texture analyses are shown for the three mineral horizons of both types. Except for the C horizon, the results represent twenty-seven hardwood and twenty-five pine plots.

TABLE 4

TEXTURE VARIATIONS IN HARDWOOD PROFILES

By Per Cents

Plot	Horizon	Very coarse and coarse 2-.5 mm.	Medium .5-.25 mm.	Fine and very fine .25-.05 mm.	Total sand 2-.05 mm.	Silt .05-.005 mm.	Clay .005 mm. and under
83	DB	15.79	37.97	16.06	69.82	24.86	5.32
	LB	11.35	16.82	41.15	69.32	30.68	
	C	15.80	18.07	46.68	80.55	16.95	2.50
131	DB	18.50	20.00	34.34	72.84	22.98	4.18
	LB	15.62	15.27	41.79	72.68	21.06	6.26
	C	21.03	20.33	41.40	82.76	16.59	0.65
132	UDB 1-2	16.95	20.27	33.60	70.82	23.36	5.82
	LDB 1-2	16.19	13.43	37.38	67.00	26.00	7.00
	LB	17.48	27.42	27.92	73.32	17.68	9.00
	C	18.24	18.54	41.90	78.68	16.32	5.00
86	DB	13.05	16.70	38.30	68.05	26.95	5.00
	LB	11.01	15.83	42.34	69.18	30.82	
	C	16.30	18.64	44.43	79.37	15.63	5.00
149	DB	14.35	11.55	42.78	68.68	25.00	6.32
	LB	14.20	14.53	41.59	70.32	22.36	7.32
	C	12.97	14.33	47.70	75.00	19.13	5.87

DB = dark brown; LB = light brown.
All these are sandy loams except 83 C, which is a sand.

All the samples belong in the lighter half of the sandy loam range. The averages indicate that the 2 mm. fractions of the pine and hardwood plots were uniform in texture and hence truly comparable. Since almost half of the plots were tested, the probable variation from these results in the untested plots is negligible.

TABLE 5

TEXTURE VARIATIONS IN PINE PROFILES

By Per Cents

Plot	Horizon	Very coarse and coarse 2-.5 mm	Medium 5-.25 mm.	Fine and very fine .25-.05 mm	Total sand 2-.05 mm.	Silt .05-.005 mm.	Clay .005 mm. and under
88	DB	11.53	10.39	51.76	73.68	21.32	5.00
	LB	12.73	14.97	47.85	75.55	20.82	3.63
	C	18.48	18.12	48.03	84.63	13.55	1.82
99	DB	17.20	17.72	39.76	74.68	19.64	5.68
	LB	18.99	18.01	39.00	76.00	17.32	6.68
	C	15.78	15.65	48.57	80.00	16.32	3.68
174	DB	26.00	17.96	31.72	75.68	19.82	4.50
	LB	40.28	18.68	21.22	80.18	16.00	3.82
	C	10.45	8.89	69.98	89.32	6.68	4.00
44	DB	16.87	17.22	43.23	77.32	18.18	4.50
	LB	17.68	14.83	43.17	75.68	20.00	4.32
	C	21.67	16.01	41.32	79.00	15.24	5.76

All these are sandy loams except 88 C and 174 C, which are sands.

Table 7 shows that of the pine plots, six per cent were gravelly sandy loams and ninety-four per cent stony sandy loams; of the hardwoods three per cent and ninety-seven per cent respectively. The hardwood plots contained more boulders than the pine. Such land was earlier abandoned, with consequent earlier occupation by pine, which in turn

TABLE 6

AVERAGE SOIL TEXTURES

By Per Cents

Type	Horizon	Sand 2-.05 mm		Silt .05-.005 mm.		Clay .005 mm and under	
		Average	Range	Average	Range	Average	Range
Pine	DB	71.7	61–79	23.0	17–32	2.3	2.8–10
Hardwood	DB	70.7	63–78	23.8	15–32	5.9	3.8–9.5
Pine	LB	73.4	58–81	20.9	13–32	5.7	3.6–10
Hardwood	LB	70.7	60–80	21.2	15–31	8.1	4.6–11.5
Pine	C	83.2	79–89	12.9	6–16	5.9	1.8–5.8
Hardwood	C	79.2	75–83	16.9	15–19	3.9	0.6–5.8

TABLE 7

RELATIVE ABUNDANCE OF STONES AND GRAVEL IN SIXTY-TWO PLOTS ON EACH FOREST TYPE

	Boulders		Cobbles		Gravel or pebbles	
	Pine	Hardwood	Pine	Hardwood	Pine	Hardwood
Free	19 %	10 %	14 %	16 %	5 %	11 %
Few	57	53	37	39	29	45
Many	18	31	39	39	37	26
Plentiful	6	6	10	6	29	18

was earlier harvested and followed by hardwood stands. The content of stones of cobble size is equal in the two types.

The second purpose of the textural data was to compare the content of colloids (fine particles) with moisture-holding capacity, organic matter, buffer, and nitrogen contents.

Inorganic and organic colloids determine the capacity of the soil for absorption and retention of water. More organic matter means more colloids, and hence improves this capacity. Bouyoucos (1929) has shown that the *water retention* capacity of the soil, which he terms the "moisture equivalent," is represented reasonably well by 0.6224 times the value of the 0.020 mm. colloids as obtained by his hydrometer method. Since 0.6224 is a constant, the comparisons of the moisture equivalent values will be as those for the contents of fine particles. The moisture equivalent values were used in studying the moisture-retaining capacities.

From half-saturated air, moisture-free soils absorb to about half of their moisture-holding capacity; but from one-quarter saturated air, they take somewhat more than one quarter of their capacity (Hilgard, 1914). The loss of weight from the air-dry to an oven-dry condition was used as a measure of the moisture-holding capacity of the soil. This loss was compared with the moisture equivalent as obtained by the hydrometer method.

The relation between moisture-holding capacity (hygroscopic moisture) and the content of fine particles (Table 8) is so indefinite that the use of the moisture equivalent appears to be an unsatisfactory measure of the water-retaining capacity of soil. In the dark brown horizons of the pine and hardwood stands the relations between moisture-holding capacity and content of fine particles are practically equivalent. It is therefore probable that variations in the nature of organic colloids due to their origin from different types of vegetative matter do not affect the moisture-holding quality of the soil. The equivalence of the finer particle content in the dark brown horizons of the pine and hardwood, 15.02 per cent and 15.24 per cent respectively (Table 11), supports the idea that water-holding capacity may be more dependent on colloidal surfaces than upon the composition of the colloids concerned. The organic colloids of the hardwood soils here studied may be more nearly of the composition of those of the pine stands than under hardwoods not following pine.

Table 9 presents the relation of the hygroscopic moisture to the organic contents. The relations of the values of the pine and hardwood groups are similar, indicating that the effect of the organic contents of the dark brown horizons under these stands on moisture retention is equivalent. With

TABLE 8

RELATION OF HYGROSCOPIC MOISTURE TO CONTENT OF FINE PARTICLES LESS THAN 0.020 MM. IN SIZE EXPRESSED AS THE MOISTURE EQUIVALENT *

MOISTURE EQUIVALENT (0.6224 × PER CENT OF 0.020 MM. PARTICLES)

Per cent of moisture Air to oven dry	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17
6–7							1					
5–6			1			3			1			
4–5		2	2		1	1	1					1
3–4	1	1	1	4	7	1	2	1				
2–3			5	6	7	2	1	1				

* Pine and hardwood samples combined.

TABLE 9

RELATION OF HYGROSCOPIC MOISTURE TO CONTENT OF ORGANIC MATTER *

ORGANIC MATTER CONTENT IN PER CENT

Per cent of moisture Air to oven dry	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18
6–7										1				
5–6				1		1	1	1						
4–5		1	2	1	1				1		1		1	1
3–4	1	1		1	3	4	1	2	1	4				1
2–3		2	5	3	2	3	2	1	1	1	1			

* Pine and hardwood samples combined.

greater organic content there is a trend toward increased moisture-holding capacity.

No relation was found between the soil colloids and the nitrogen contents in either the pine or hardwood dark brown horizons, nor was there any relation with age of the stand.

Organic Matter

Identification of the horizons in the profiles is based on color, which is due to organic matter plus colored minerals and deepens with increased organic or moisture content. The content of the organic matter may be determined by the ignition loss, since there is practically no carbonate material present in the soils studied. This determination was used to demonstrate whether or not the separation by color was parallel with other qualities of the horizons.

Method of Determination

The larger pieces of organic matter were removed in preparing the 5–15 gram samples of oven-dried soil for ignition. This was done by sieving through the 1 mm. and .5 mm. soil sieves and jarring the residues down an inclined plane while gently fanning them, then mixing the three separates. Thus the ignition loss represented the organic matter in the more important fine textured system. The samples were then ignited in an open crucible at dull red heat without fusion.

In the field the color of the dark brown zone was described as very dark, dark, or light. Of the dark brown horizons under pine, eighty-nine per cent were dark and the remainder light; under the hardwoods, sixty per cent were dark and the remainder very dark. That color serves well as a field criterion of horizon differences is evident in the colloid, buffer, and nitrogen relations as well as in the organic contents given below, where only one value in each light brown series is higher than the lowest value of the dark brown series. No relationship between species composition of hardwood stands and content of organic matter in the dark brown layer was observed among the samples analyzed.

TABLE 10

ORGANIC CONTENTS IN PER CENT BY PROFILES AND HORIZONS

Pine Horizons				Hardwood Horizons			
Plot	DB	LB	C	Plot	DB	LB	C
88	5.66	2.99	0.85	83	9.94	7.02	2.19
99	6.86	3.44	1.91	131	7.32	3.87	1.50
174	6.82	6.42	2.53	132	8.90 * 6.39 †	3.26	2.31
44	7.96	4.63	2.66	86	13.51	4.34	1.80
..	.	.	.	149	7.89	4.78	2.52
Averages 6.82		4.37	1.99		8.99	4.65	2.06
Hardwood averages exceed by					2.17	0.28	0.07

* Upper † Lower

The average contents of organic matter in soils of the United States given by Waksman (1927) are 2.06 per cent for surface and 0.83 per cent for subsoils. The large farm and prairie area lying south and west of the region here considered greatly affects these averages. The average values found in this study (Table 11) are: for pines, dark brown zone, 9.10

TABLE 11

AVERAGE AND RANGE IN PERCENTAGE OF THE CONTENTS OF ORGANIC MATTER AND FINE PARTICLES FOR VARIOUS HORIZONS

	Pine						Hardwood					
	Dark brown		Light brown		C		Dark brown		Light brown		C	
Number of horizons	30		31		5		44		40		6	
	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range
Organic content	9.10	17.42–4.34	5.35	10.29–2.18	2.05	4.33–.85	10.26	21.96–2.96	5.95	14.62–0.92	2.01	2.52–1.50
Difference between range extremes		13.08		8.11		3.48		19.00		13.70		1.02
Number of horizons	25		23		4		32		27		5	
	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range
Fine particles under 0.020 mm.	15.02	25.82–8.18	14.24	21.32–6.45	11.66	12.32–5.68	15.24	21.50–9.82	16.36	20.50–9.25	11.10	14.00–8.05
Difference between range extremes		17.64		14.87		6.64		11.68		11.25		5.95
Number of horizons	26		18		1		25		10		4	
	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range	Avge.	Range
Fine particles under 0.008 mm.	7.66	12.82–3.00	7.82	12.00–5.00	6.50	...	8.51	13.32–5.32	10.35	14.50–7.50	7.12	8.68–5.00
Difference between range extremes		9.82		7.00		...		8.00		7.00		3.68

per cent, light brown zone, 5.35 per cent, subsoil (C horizon). 2.05 per cent; for hardwoods, dark brown zone, 10.26 per cent, light brown zone, 5.95 per cent, subsoil (C horizon), 2.01 per cent.

The number of observations on the organic, fine particle, and nitrogen contents in per cent by weight were too few to warrant more than an outline of trends. Table 11 shows that the percentage of soil organic matter by weight is slightly greater in both the dark brown and light brown horizons of the hardwood profiles than in the pine. The 1.16 per cent and 0.65 per cent greater organic content in the hardwood dark and light brown horizons arise from the more active decomposition under the hardwood type. It is interesting that the organic matter values in the light brown horizons have a third less range than those of the dark brown.

The two classes of fine particles, each being partly organic matter, are greater in the light brown than in the dark brown horizons, except in the pine 0.020 mm. class. This may show that downward transportation of a part of the more minute mineral particles has occurred. The average contents of fine particles agree more closely in the dark and light brown horizons of the pine than of the hardwood types. This again may indicate the greater ease of water percolation and temperature change in these horizons under hardwood than under pine stands. The exception in particle content relations in the pine 0.020 mm. class hints that the downward transportation decreases as the particle size limit increases; also, that, as organic content increases and tougher consistency develops, the removal of finer particles to lower layers tends to decrease, as compared to hardwood stands. This downward transportation is discussed for the Worcester County soils by Latimer, Martin, and Lanphear (1927), who show that in regions with similar original soil material this feature of soil development is much greater than found in this study. The contrasts here between pine and hardwood forest types suggest that the vegetative cover may be important in this soil process and that such differences as described for other regions may reflect time under broad-leaved rather than coniferous cover. Since the hardwood stands tested followed pine and were mostly twenty-five to forty years old, fine particle content is a possible criterion of forest type influence on soil. It is another measure of the more open structure, loose consistency, and good tilth of the hardwood soils.

It is significant to consider variations in percentage of organic matter in the dark brown horizons, the depths of which under pine decrease with age, as shown previously. Two tests in the pine ten- to twenty-year age class give an average organic content of 9.81 per cent with a depth of 10.4 inches. These high values are carried over from the old field horizons. The twenty to forty class in the pines shows a decrease in these values to 7.54 per cent organic matter and 6.2 inches. In the forty to sixty class the organic matter increases to 9.2 per cent and the depth decreases to 3.7 inches. These processes continue with time, resulting for the pine sixty to eighty class in a 10.03 per cent organic content and a 3.3 inch depth.

The discussion of horizon depths has shown that organic layers 2.3 inches thick under sixty and eighty year old pine diminished to 0.9 inches under ten-year-old hardwoods which followed the clear cutting of the pine. The depth, 4.2 inches, and organic content, 11.66 per cent, of the dark brown horizon under the ten-year-old hardwoods reflect a disintegration of 1.40 inches or about sixty per cent of the pine organic layers in ten years. Both depth and organic content of the dark brown horizon increased. The total organic matter in the dark brown horizon increased more than the differences in depth and per cent suggest. The products of horizon depth and per cent of organic matter are for the old pine 33 and for the ten-year-old hardwoods 49, or about fifty per cent increase of organic content in the dark brown horizon. The hardwood twenty to forty age class shows a decrease to 7.85

per cent organic matter with the depth remaining at 4.3 inches; but in the forty to sixty class the organic matter increases to 9.46 per cent, while the depth decreases to 3.0 inches. These changes mirror the volume production of litter materials as the stands age. The three tests in the sixty-to-eighty age class, representing culled woodlots rather than occupation of the land after pine stands, show a much greater organic content, 18.39 per cent, with an increase in depth to 3.8 inches. It is notable that the consistency, flocculation, and tilth in these older hardwood stands are much better than in the older pine stands.

The drops in the organic content from the ten-to-twenty age class to the twenty-to-forty age class are paralleled by the lower buffer contents of the plots twenty to thirty years of age. After this age the buffering activity and organic contents increase. The decrease in depth and increase in organic matter with age in the dark brown horizon of the pine stands agree with the tendency to change in consistency of the dark brown horizons from a loose towards a tough condition.

The stands following the clear cutting of pure pine were composed of various species of hardwood. In the discussion of horizon depths it was found significant to classify species and plots by composition groups. This classification and a division according to moisture conditions were applied to the data on depth and organic content for the hardwood dark brown horizons. The depth/organic matter products for plots classed as dry or wet represent moisture conditions somewhat extreme. The averages of these products for the remainder of the hardwood sites are shown in the following tabulation.

	Species Group					
	A		B		C	
Age class	No. of plots	Product	No. of plots	Product	No. of plots	Product
5–20	4	74	8	38	5	31
20–40	.	.	6	32	.	. .
40–60	. .	. .	9	25	2	30

The data suggest, although they do not prove, that the Group A species have twice the effect of the B species in producing organic content in the dark brown horizon beneath them, and that the B species produce about twenty per cent more organic content than the C species. But this presentation does indicate that the species as segregated into A, B, and C groups have a decreasing tendency to improve the soil organic content. The graph of horizon depths (Figure 2), shows much the same relation between the A, B, and C groups as does this table of organic contents.

That the product values for the few plots classed as wet or dry align with the averages for the moist sites may be significant. It indicates that site variations in total soil moisture may have little influence on the total organic content of the dark brown horizon, except as this moisture tends to control the species and thus the nature of the litter. It also shows that the depths of the dark brown may be less dependent on moisture than on composition of the stand.

Similar depth-organic content products for the pine plots were segregated by dry and moist sites. The products decrease with age and mark the influence of shrinkage in the dark brown horizon, since the concentrations increase with age. The moist plots in the twenty to forty and forty to sixty age classes show 166 per cent of the organic content in the dry plots. In the two plots of the sixty to eighty class this relation is 125 per cent. Thus under pine stands the transformation of organic matter and the infiltration of humus into the dark brown horizon are more complete on moist than on dry sites. The litter accumulation under pine tends to aggravate dryness; its more rapid decomposition under hardwoods does the opposite.

Hydrogen-ion Concentration and Buffer Content

The hydrogen-ion concentration, or the reaction of the soil, is very important to plant growth. Apparently different plant communities are limited to areas having a defi-

TABLE 12

HARDWOOD TYPE

PRODUCTS OF PERCENTAGE ORGANIC MATTER AND DEPTH FOR DARK BROWN HORIZON

Age class years	Plot	Zone	Age years	Canopy closed years	Horizon Characters: Depth inches	Organic matter content	Depth × organic content Products by composition classes		
						Per cent	A	B	C
5–20	94	DB	5	3	2.9	13.20		*38.3**	
	73	DB	2		6.7	8.89	59.6		
	74	DB	13	11	8.2	12.03	98.6		
	78	DB	13		4.3	11.99		51.6	
	81	DB	13		4.8	9.95		47.6	
	131	DB	6	4	4.8	7.32			35.1
	132	UDB 1&2	11	9	1.5	8.90		13.3	
		LDB 1&2	11	9	3.0	6.39		19.2	
	106	UDB	19	17	3.0	24.04			
	79	DB	13	10	4.5	9.94		44.7	
	85	DB	13	8	4.5	8.44		38.0	
	116	UDB 3	12	9	3.5	20.63	72.2		
		LDB 3	12	9	6.5	10.08	65.5		
	149	DB	19	13	4.3	7.89		33.9	
	107	UDB 2	18	17	2.0	25.92	*51.8**		
	105	UDB 1	19	17	4.0	7.21			28.8
		LDB 1	19	17	3.3	2.25			7.4
		UDB 2	19	17	3.0	16.02			48.1
		LDB 2	19	17	4.0	8.53			34.1
	86	DB	16	12	3.9	13.51		52.7	
Averages			14	12	4.2 ×	11.66 =	49.0		
20–40	139	DB 1	23	12	5.0	9.99		49.9	
		DB 2	23	12	1.3	10.28		13.4	
		DB 3	23	12	4.0	11.30		45.2	
	141	UDB 2	20	10	6.4	7.28		46.6	
		LDB 2	20	10	6.0	2.96		17.8	
	142	DB 2&3	20	10	3.4	5.32		18.1	
Averages			21	11	4.3 ×	7.85 =	33.7		
40–60	148	DB	43	35	2.6	17.74			*46.1*†
	124	DB	35	25	6.0	6.60			*36.6*†
	95	DB 2 & 3	35	18	3.7	5.72			*21.2*†
(*Under Lycopodium*)		DB 1	35	18	3.0	5.08			*15.2*†
	62	DB 1	30		2.5	9.36		23.4	
	111	DB	35	30	2.8	13.60			38.1
	155	DB	40	25	4.0	8.86		35.4	
	113	UDB 2&3	35		3.6	6.74		24.3	
		LDB	35		1.2	8.71		10.5	
	91	DB	33	23	0.9	12.08		10.1	
	127	DB	28	18	2.8	10.49		29.4	
	125	DB	27	22	2.6	11.21		29.1	
	126	DB	30	20	2.6	10.13		26.3	
	101	DB	35	30	2.7	7.43			20.1
	97	DB	38	30	4.0	8.22		32.9	
Averages			34	24	3.0 ×	9.46 =	28.4		
60–80	135	UDB 2&3	70	63	1.0	20.13	20.1**		
	136	DB	80		6.0	21.96		*131.8**	
	145	DB	70	60	4.4	13.08			57.6
Averages			73	61	3.8 ×	18.39 =	69.9		

UDB = upper dark brown; LDB = lower dark brown.

* Wet. † Dry. ** No analysis of lower dark brown averaging 17 inches.

TABLE 13

PINE TYPE

Products of Percentage Organic Matter and Depth for Dark Brown Horizon

					Horizon Characters				
Age class years	Plot	Zone	Age years	Canopy closed years	Depth inches	Organic matter content	Depth × organic content Product for plots on Dry sites		Moist sites
						Per cent			
10–20	80	DB	15	8	4.3	10.59			45.54
	63	DB	13		16.6	9.06			150.40
Averages			14	8	10.4	9.81			97.97
20–40	181	DB	27	17	10.4	4.34	45.14		
	99	DB	33	28	3.3	6.86	22.64		
	152	DB	29	20	4.2	6.95	29.19		
	164	DB	32	15	3.6	8.90			32.04
	174	DB	32	15	7.9	6.82			53.88
	88	DB	20	10	9.9	5.66			56.03
	55	DB	23		4.4	13.25			58.30
Averages			28	17	6.2	7.54	32.32	42.46	50.06
40–60	118	DB	57	47	2.9	7.45	21.60		
	57	DB	50		2.3	12.66	29.12		
	65	DB	55		3.0	5.49	16.47		
	166	DB	55	40	3.2	11.26	36.03		
	150	DB	50		6.5	10.52			68.38
	157	DB	52	33	3.8	7.78			29.56
	163	DB	40	25	4.2	7.19			30.20
	180	DB	42	34	3.4	14.35			48.79
	153	DB	45	25	4.4	7.84			34.40
	44	DB	40		3.8	7.96			30.25
Averages			49	34	3.7	9.25	24.80	34.48	40.26
60–80	129	UDB 3	65	55	2.0	11.66	23.32		
		LDB 3	65	55	11.0	6.35	69.85		
		UDB 1 & 2	65	55	1.1	9.38	10.32		
		LDB 1 & 2	65	55	3.7	5.22	19.31		
	130	DB	65	55	3.7	6.81	25.20		
	50	DB	62		1.9	12.23	23.24		
	156	DB	65	50	2.0	9.20			18.40
	179	DB	65	55	4.3	12.03			51.73
	46	DB	80		0.3	17.42			5.23*
Averages			66	54	3.3	10.03	28.54	27.40	25.12†
									35.06**

* Not an average condition † All three. ** Only two.

nite and rather narrow range of reaction which is characteristic for each association (Arrhenius, 1920; Atkins, 1922; Christophersen, 1925; Comber, 1921; Kelley, 1923; Wherry, 1923; and many others). The litter from European tree species has differing hydrogen-ion concentrations and varies widely in the amounts of acid and basic buffers, as has been shown by Hesselman (1925). He has shown that the presence in a forest stand of species rich in basic buffers often determines the character of the soil profile, as to whether it will become a mull or a raw humus profile. Larch, for instance, has a good effect on the humus layer; for although its litter is acid and is rich in acid buffers, it is much richer in basic buffers than either pine or spruce litter. For the same reason European beech, among the hardwoods, is also a good soil improver. While the reaction is important in determining the development of an association, there is some question as to whether the influence is direct or indirect. Apparently the reaction does not seriously affect the growth of the higher plants (Duggar, 1920). Indeed the reaction of the soil and the presence of buffers may be mainly important in their direct effect on the soil microörganisms, which, by decomposition of the litter and humus, determine the amount and character of the nutrients available for the higher plants.

Method of Determination

There are two electrometric methods for determining hydrogen-ion concentration: the hydrogen gas chain method and the quinhydrone. The majority of soil workers now prefer the quinhydrone method for the reason that equilibrium is much more readily attained with it and there is much less "drift" in potential with time. With the hydrogen gas chain it was found that the drift with time was considerable, which causes some error and inconsistent results when titrating a soil suspension, a process that may take several hours to complete. At present it is not clearly understood what causes this drift in potential with the gas chain, but it is possibly due to a catalytic reduction by the platinum black (Clark, 1928). The following table shows the amount of drift in a soil suspension with the hydrogen gas and quinhydrone methods.

Time	Hydrogen gas	Quinhydrone
0	pH 5.90	pH 5.92
15 min.	5.80	5.94
30 "	5.62	5.97
45 "	5.55	6.00
1 hr.	5.45	6.08
2 "	5.10	...
3 "	...	6.17*

* After shaking the soil suspension for two minutes and then taking another reading, the pH was 6.03; in the hydrogen gas there was no change in pH after shaking for a few minutes at the end of the three-hour period.

Zero time in the above table is taken after hydrogen gas has been bubbled through the soil suspension for about half an hour, at which time equilibrium has become relatively stable. Zero time for the quinhydrone is only two or three minutes after the quinhydrone has been added to the soil suspension.

The hydrogen-ion concentration of a number of soils was determined by both the electrometric methods and gave good agreement; but with the quinhydrone method equilibrium was reached in a few minutes, whereas with the hydrogen gas it took very much longer to establish an equilibrium (one-half to two hours).

The hydrogen-ion concentration and the buffer content of the soil samples were determined by the quinhydrone method as described by Snyder (1928). Only air-dried soil samples were used; and since they all gave an acid reaction, the hydrogen-ion concentration was very little affected by air drying (Baver, 1927). A soil/water ratio of 1 to 2 was used throughout. Five grams of the air-dried soil which had previously been passed through a 2 mm. sieve and 10 cc. of distilled water were shaken together in a special pyrex vessel (Bovie, 1922). To this 1 to 2 soil/water suspension was added approximately 0.2 grams of quinhydrone, and the mixture thoroughly agitated for several minutes. The length of this time depended upon the soil, since some soils came to an equilibrium in one minute while others took as long as five to ten minutes. The gold wire electrode and the KCl saturated agar bridge were then placed in the suspension, and the potential read half a minute after the vessel had come to rest, which was ample time for the settling of the soil suspension.

After the initial potential of the soil suspension had been taken, the suspension was titrated with a N/10 HCl solution, additions being added in from 0.25 to 2.00 cc. portions. The amounts added at each interval depended upon the rate of change in potential of the solution. Where the change was great, the amount of acid added was small; and where small, the amount added was great. The acid was added until the soil suspension gave a hydrogen-ion reaction of pH 2.00. The potential was recorded after each addition of the acid. A duplicate suspension was similarly titrated with a N/10 solution of NaOH, until it was brought to pH 9.00. After each addition of acid or alkali, the suspension was stirred thoroughly for several minutes to prevent a localized equilibrium around the electrodes; and the readings were taken half a minute after the vessel had come to rest. In some cases the solution had to be stirred several times before equilibrium was attained. The potentials were checked frequently against standard buffer solutions so as to insure correct potential readings of the soil suspensions. The calomel half cell was immersed in a water bath and kept at a constant temperature during the titration.

Biilmann and Krarup (1924) have found that the potential temperature curve of the quinhydrone electrode over a range of temperatures from 0 to 37° C. is practically a straight line. Clark and Collins (1927) give the following equation for obtaining the pH from the potential readings for a saturated calomel half cell:

$$pH = \frac{0.4538 - 0.00009\ (T - 18) - \pi}{0.0577 - 0.0002\ (T - 18)}$$

where T equals the temperature and π the observed potential. It was found convenient to use a graph obtained from the above equation for the temperatures used, instead of the equation itself, in converting the potential readings into the pH scale.

After the titration curves were obtained from the soil samples, buffer curves were derived from them by plotting the amount of tenth normal acid or alkaline solution necessary to cause a pH change of 0.2 at all points along the titration curve, that is, between a pH range of 2.0 and 9.0.

One hundred and forty soil samples were titrated, of which seventy were from pine and seventy from hardwood stands. The samples were about equally divided between dark brown and light brown horizons, and a few were taken also from the C layer.

From Table 14 it is seen that the acidity of the soils decreases with depth; the dark brown horizons of the pines ranging from pH 3.3 to 5.1, the light browns from pH 4.3 to 5.7, and the C horizons from pH 4.8 to 5.8. Under the hardwoods the dark brown horizons vary from pH 3.8 to 5.4, the light browns from pH 4.3 to 5.2, and the C horizons from pH 5.1 to 5.6. No relation was found between the composition of the hardwood stands and the acidity of the soil.

There was a slight increase in acidity w th age in the pine stands, the pH in the younger stands (ten to forty years) being from pH 5.1 to 4.2, and in the older age classes (forty to eighty years) from pH 4.6 to 3.3. The hardwood stands which followed the logging of the mature pine stands have not changed the soil reaction very much in forty years.

In all the dark brown horizons titrated there was a great deal of buffer material present, which was at a maximum

TABLE 14

SOIL ACIDITY IN PINE AND HARDWOOD FORESTS OF DIFFERENT AGES

THE ACIDITY IS EXPRESSED AS pH.

Horizon	Age Class in Years								
	5	10	20	30	40	50	60	70	80
				Pine					
DB		4.2	4.7	4.3	4.2	4.6 (2)*	3.3		4.0
		4.4	4.9	4.4	4.6		3.4		
				4.5			3.8		
				5.1 (2)			4.0		
							4.3		
LB		4.7	5.1	4.5	4.7	4.5 (2)	4.4	4.5	4.3
			5.7	4.9 (3)	4.9	4.7	4.6		4.6
				5.0		5.2	4.7 (2)		
				5.4			4.8		
							4.8		
C			5.3	5.3	4.8				
			5.8	5.4					
				Hardwoods					
DB	3.8	3.9 (2)	3.9	4.0	3.8		4.8	4.1	4.6
	4.2	4.0	4.0	4.1 (2)					
		4.3 (3)	4.2	4.3					
		4.4 (2)	4.3	4.6					
		4.5	4.4	4.7					
		4.6 (2)	4.5	5.4					
		4.8	4.9						
		5.0	5.0						
LB	4.4	4.5	4.4 (2)	4.5	4.3		5.2	4.6	
	4.8	4.6	4.7 (2)	4.8					
		4.7	4.8 (4)	4.9					
		4.8 (2)	5.0	5.0					
		5.0	5.1	5.2					
C		5.1	5.1						
		5.5	5.4						
			5.6						

* If a given pH occurs for any age class more than once, the number of times it occurs is given in parenthesis after the pH figure.

from pH 2.0 to 4.5 and from pH 6.5 to 9.0, and at a minimum from around pH 4.5 to 6.0. The amount of buffer material decreases with depth, there being very little buffering in C horizons (Figure 4). This decrease in buffer material with depth is closely related to the decrease in acidity and to the decrease in percentage of organic colloids, since the organic matter decreases in pines from an average of 9.1 per cent in the dark brown horizons to 5.4 per cent in the light browns; and under hardwoods, from 10.3 per cent in the dark browns to 5.9 per cent in the light browns. Gaarder and Hagem (1921) have shown that soils rich in humus are strong buffers, while mineral soils are comparatively weak. This is due probably to the colloidal nature of the humus colloids acting as strong buffers and to the presence of weak organic acids with buffer action.

There is considerable variation in the amount of buffer material in forest soils in the same age class, as shown in Figure 5. This variation in buffer material cannot be explained entirely on the basis of variations in the percentage of organic content of the soils or the organic matter/nitrogen ratio, since soils differing widely in their buffer content have the same amounts of organic matter and the same organic matter/nitrogen ratios. In the hardwood stands this variation could not be related to the composition of the stands.

When the amount of buffer material was averaged for each age class, there was seen to be a relation between the buffer content and the age of the stand. The buffer is high in the ten-year-old pine stands, but falls off rapidly in stands from ten to thirty years, and then begins to build up again, reaching a maximum in the mature eighty-year-old stands (Figure 6). In the young age classes of the hardwoods following the cutting of the mature pine stands, the amount of buffer material is at a minimum at ten years and then begins to build up again, reaching a maximum in the oldest age classes (Figure 7). This falling off in buffer material after the logging of the pine and the continuation until the hardwood

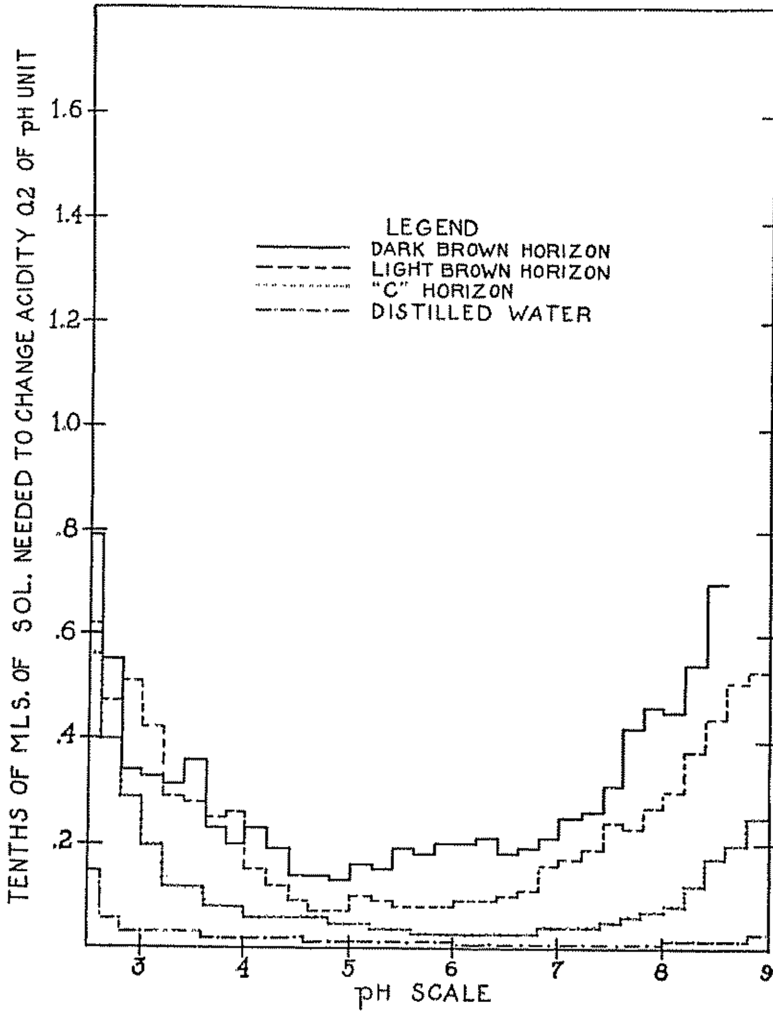

Fig. 4. AVERAGE BUFFER CURVES FOR THREE HORIZONS OF A THIRTY-YEAR-OLD PINE STAND

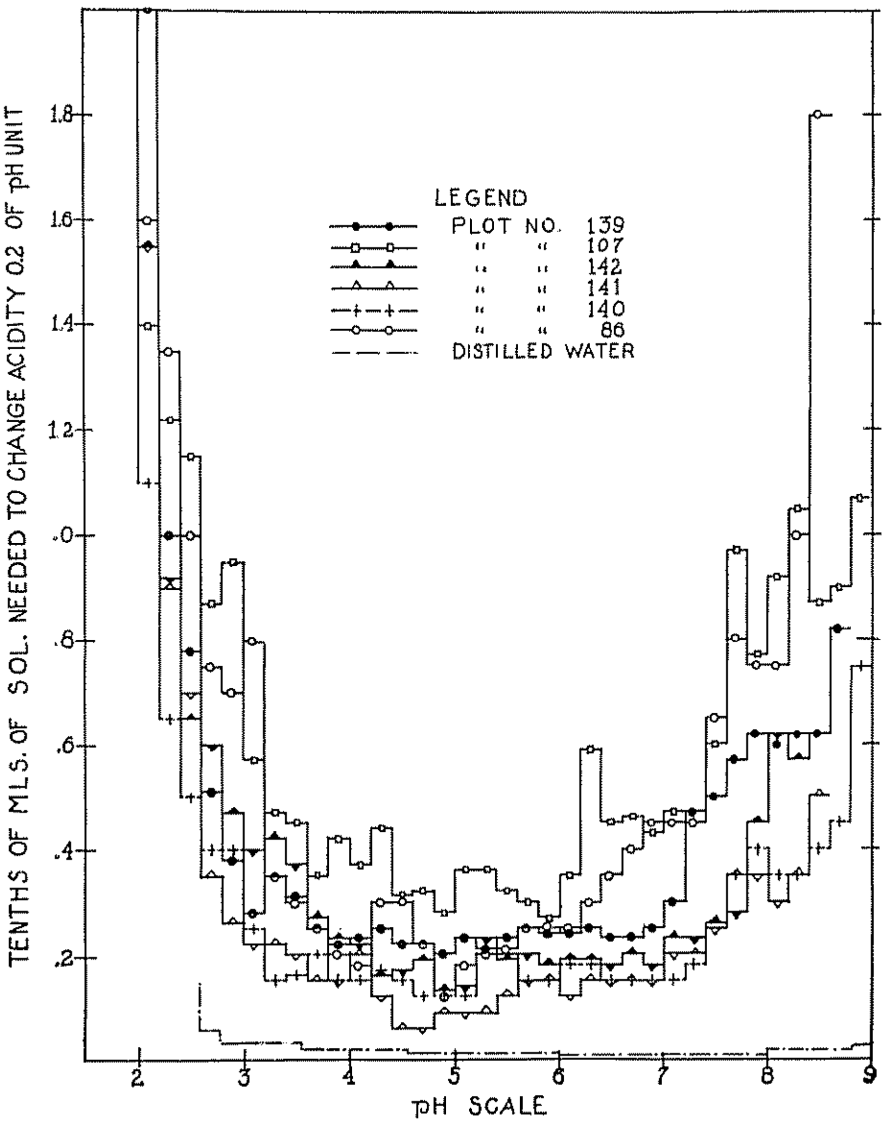

FIG. 5. VARIATION OF BUFFER MATERIAL IN DARK BROWN HORIZONS FOR TWENTY-YEAR-OLD HARDWOOD

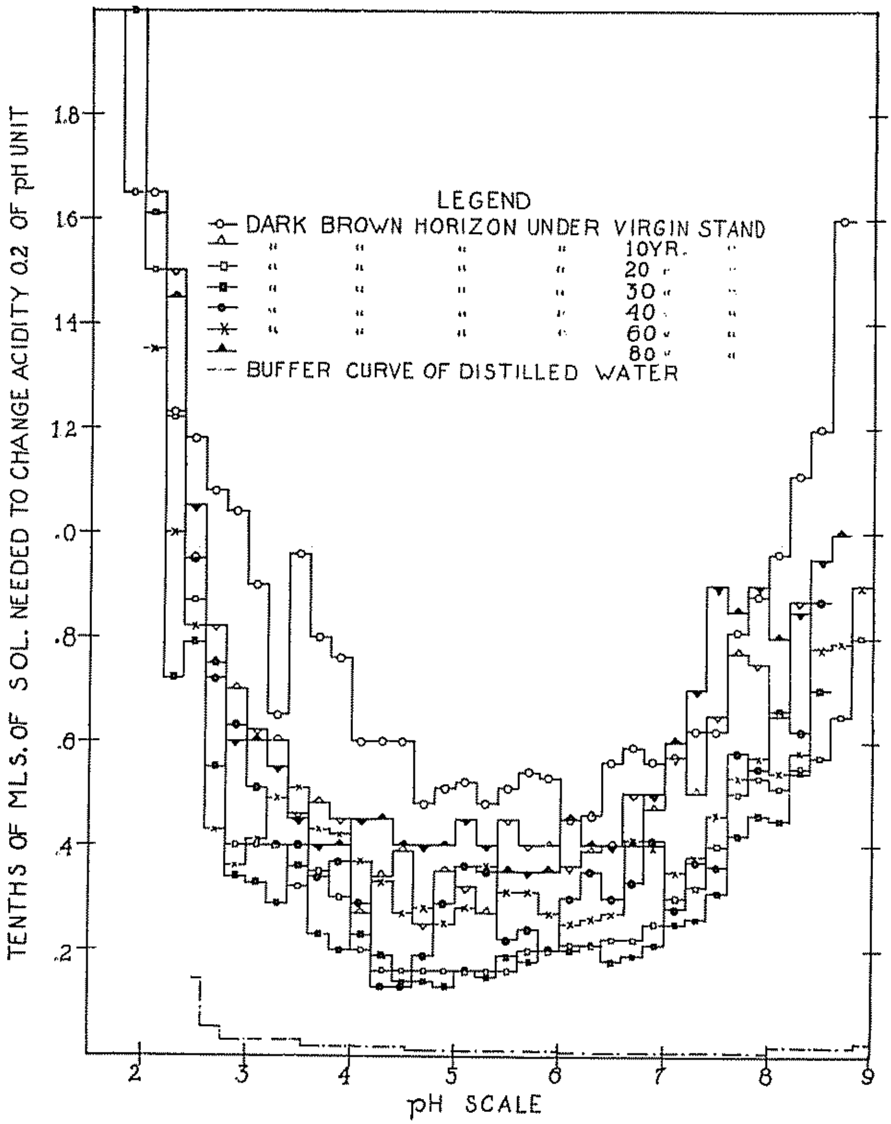

FIG 6 AVERAGE BUFFER CURVES FOR DARK BROWN HORIZONS UNDER DIFFERENT AGE CLASSES OF PINE

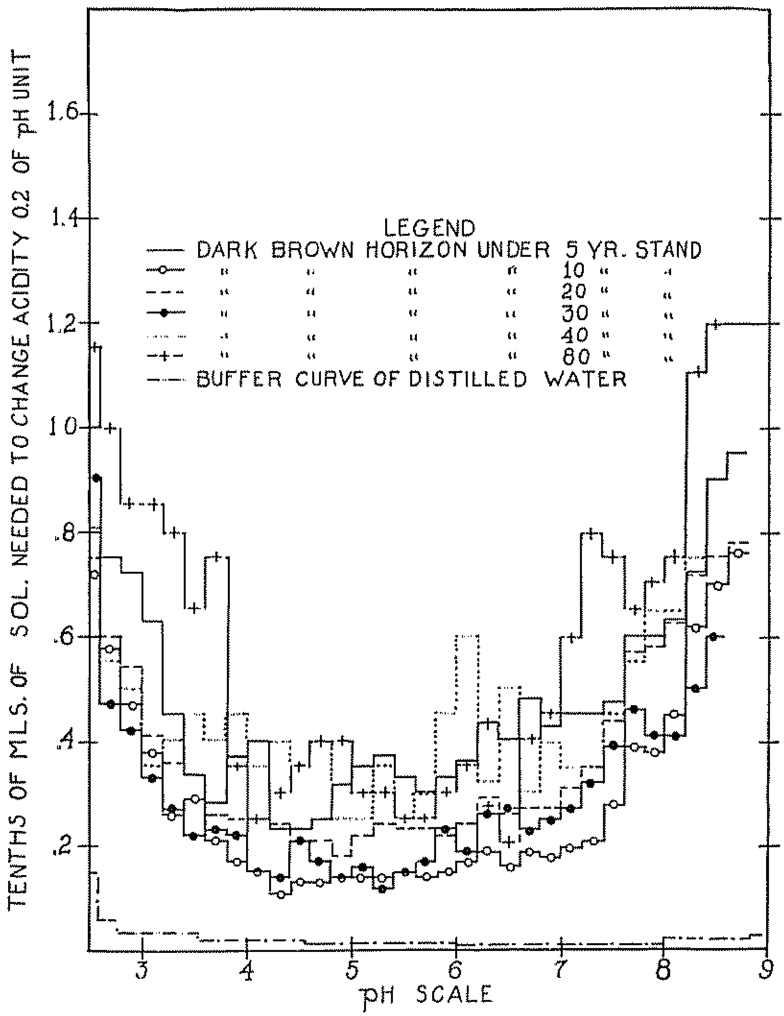

FIG. 7. AVERAGE BUFFER CURVES FOR DARK BROWN HORIZONS UNDER DIFFERENT AGE CLASSES OF HARDWOOD

stand is established is accompanied by a narrowing of the organic matter/nitrogen ratio and by an increase in total nitrogen. This indicates a more rapid metabolism of the soil microörganisms; and it is to be recalled that the thick, undecomposed organic layer which is characteristic of the older pine stands entirely disappears in a few years after logging. With increased radiation and an increased rate of metabolism of the soil microörganisms, the organic matter is more completely broken down than under conditions of lower radiation and slow metabolism. Thus by oxidation and by energetic metabolism there will be a lowering of the amount of weak humic acids present in the soil, with a corresponding lowering of the buffer content.

In conclusion it is to be noted that there is very little difference in the buffer curves of pine and mixed hardwood stands which followed the logging of mature pine stands.

Nitrogen

The present information on the nitrogen of forest soils may be summarized by reference to a few of the important contributions.

Clarke (1924) found that nitrate is present in measurable quantities in very acid soils; that the accumulation of ammonia is greater in very acid soils than it is in slightly acid and neutral soils; that the ammonia of a very acid soil is liable to rapid fluctuation; and that the soil shows a great retentive power for ammonia when in certain conditions of moisture content. In soils with a pH range of from 3.5 to 5.0, he found nitrogen present as ammonia with an average content of about ten parts per million for the seasonal range, and present as nitrate with an average seasonal content of about two parts per million. Kutriavtseva (1924) confirmed Clarke's results in finding fixed differences in the forms of nitrogen in soils of different acidities. In the less acid soils, they are more stable in character, less easily leached out, and tend to accumulate; while those in the more acid soils are more mobile, more easily hydrolyzed, and more soluble in acids. From observations of the luxuriant herbaceous and seedling growth on areas where the canopy had been opened, Hesselman (1925) was led into the study of the nitrogen metabolism of humus. Climate, variation in the species of tree composing the stand, and geological conditions were found to exert an effect on the relations of the humus layers and nitrification. His investigations showed that the abundance of available nitrogen is one of the factors which most strongly influence the growth of forests. Ilvessalo (1923) drew the same conclusions. Both these results are in accord with the work of Falkenstein (1912), who found that in the sandy lands of northern Germany there is a closer correlation between the nitrogen content of the humus and the site class than any other single chemical factor. Hesselman showed that in general the coniferous types in northern climates tend to produce heavy humus layers with slow nitrogen turnover; and broad-leaved types in less northerly climates tend to produce loose soils of the brown earth type with rapid nitrogen release. He also showed that on limestone soils under Continental climates, even pure coniferous stands could be free of raw humus and have a rapid nitrogen transformation. This evidence agreed with the findings of Valmari (1921), who showed that there is a very good correlation between tree growth and the lime and nitrogen content of the soil under pine stands. The work of Weis (1929) in Denmark has also brought out the importance of lime in connection with nitrification.

Since the soils studied in this investigation were formed from disintegration of rocks which are extremely low in lime content, the quantitative determination for calcium was omitted. The qualitative hydrochloric acid test showed none.

In studying the nitrogen contents of the soils investigated, twenty-six plots were selected from the pine type, and thirty-five plots were chosen from the hardwood type. These were distributed through the different age classes in order to expose any possible changes in the nitrogen content with age. For each of these plots total nitrogen was determined for both the dark brown and light brown zones of the enriched horizon. The unenriched horizon was tested in seven of the plots in each type. Zones of leaching were also analyzed whenever they occurred in the profile.

Method of Determination

The laboratory determination which was used is a modification of the Kjeldahl Method given in the Official Methods (1925):

Five grams of soil were placed in a Kjeldahl digestion flask and 30 cc. of sulphuric acid containing 1 gram of salicylic acid were added. This was shaken until thoroughly mixed, allowed to stand for at least 30 minutes with frequent shaking or until complete solution resulted; and then 5 grams of sodium thiosulphate were added. This was digested as follows: It was heated over a low flame until all danger from frothing had passed. Then the heat was increased until the acid boiled briskly and the boiling continued until white fumes no longer escaped from the flask (five to ten minutes). Approximately 0.7 gram of mercuric oxide or its equivalent in metallic mercury was added and the boiling continued until the liquid in the flask was colorless or nearly so. In case the contents of the flask looked as if they might solidify before this point was reached, 10 cc. more of sulphuric acid were added.

The contents of the flask were allowed to cool and then were diluted with about 200 cc. of water. A few pieces of the zinc were added to prevent bumping and 25 cc. of potassium sulphide with shaking. Next was added sufficient sodium hydroxide solution to make the solution strongly alkaline (100 cc.). The solution of sodium hydroxide was poured down the side of the flask so that it did not mix at once with the acid solution. The flask was then connected to the condenser, the tip of which extended below the standard acid in the receiver. The contents were mixed by shaking and distilled until all the ammonia had passed over into a measured quantity of the standard acid. The first 150 cc. of the distillate generally contained all the ammonia. This was then titrated with the standard alkali solution using methyl red or cochineal indicator.

All samples were run in duplicate. The analytical data were calculated on air-dry weight and then converted to an oven-dry basis.

The following table shows how the total nitrogen decreases with depth in eight representative plots from each of the types. The table also includes the maximum and minimum values of all the plots for each of the mineral horizons and the average values for the dark brown and light brown zones in each type.

The analyses for several leached layers gave in each instance a lower nitrogen content than either the dark brown or light brown zones, and in one case lower than that of the C horizon.

There is no direct relation between total nitrogen per cent and age of stand. There is, however, a relation between the organic matter per cent and the total nitrogen per cent. The organic matter in the dark brown horizons plotted against total nitrogen content shows that in the hardwood type one varies directly with the other. In the pine type the scatter is wider and the increase in nitrogen is not proportionate to the increase in organic matter in the higher organic matter contents.

In the older age classes of the pines the diminished depth of the dark brown horizon is accompanied by an increased organic matter content by weight. This causes the product of organic matter times depth to remain more or less constant. But since the organic matter content has a proportionately smaller nitrogen content, the organic matter/nitrogen (OM/N) ratio widens. Therefore, the product of nitrogen content times depth decreases in the dark brown horizon of the pine type, although the organic matter content times depth is more or less constant. This suggests that there may be a direct relation between the organic matter/nitrogen ratio and age of stand.

The carbon nitrogen (C/N) ratio has been used by several investigators as the index to the course of the nitrogen metab-

TABLE 15

PER CENT OF NITROGEN CONTENT BY WEIGHT

Horizon	Plot	Pine								Data for 26 plots		
		88	55	99	174	44	57	46	181	Max.	Min.	Avge.
DB		.1636	.3494	.1213	.2132	.1681	.3051	.4929*	.1019†	.4929	.1019	.2320
LB		.0399	.1649	.0392	.1263	.0650	.0409	.0941	.0464	.1649	.0386	.0729
C		.0023	.0778	.0125	.0435	.0308	.0153	...	...	.0778	.0023	...

Horizon	Plot	Hardwood								Data for 35 plots		
		131	86	83	132	149	141	136	142	Max.	Min.	Avge.
DB		.1535	.3365	.2582	.2014	.1708	.2090	.6572*	.1436†	.6572	.1436	.2525
LB		.0809	.0912	.1298	.0693	.0721	.0523	.1368	.0759	.2134	.0523	.0900
C		.0184	.0257	.0370	.0245	.0257	.0097	...	...	.0370	.0008	...

* Plot with maximum per cent nitrogen in dark brown.
† Plot with minimum per cent nitrogen in dark brown.

olism in the soil. However, the organic content of the soil bears a definite relation to the carbon content, so the organic matter/nitrogen ratio can be used for the same purpose.

The normal C/N ratio for the average agricultural soil is 11.4, according to Hutin (1913). Russell and McRuer (1927) in their study of the relations of organic matter and nitrogen content in virgin grasslands determined the OM/N ratio for a number of soil types in Nebraska and obtained an average OM/N ratio of 20.8. This is comparable to the C/N ratio of 11.4 reported by Hutin as normal for average agricultural soils, since carbon composes forty to fifty per cent of the soil organic matter (Dvorak, 1912).

The explanation of the constancy of the C/N or OM/N ratio in soils is to be found in the nitrogen content of microbial protoplasm. The transformation of the organic matter is due to the activity of bacteria and fungi working together or separately. In acid soils a hydrogen-ion concentration of pH 3.0 to 5.0 precludes the importance of bacterial activity as the bacterial optima are above this range.

Since the hydrogen-ion concentration of the soils investigated, pH 3.5 to 5.0, lies well within the acid range, it can be stated that nitrification is due principally to the activity of fungi which have optimum conditions at about pH 4.0.

According to Waksman (1927) it is the soil fungi which decompose practically all the constituents of the organic matter, with the possible exception of the lignins. In so doing they consume as much as thirty to fifty per cent of the carbon for the building of cell structure. The fungal protoplasm itself contains about five per cent nitrogen. So when organic matter added to the soil is low in nitrogen and rich in carbon, the fungi may consume the available nitrogen to the diasadvantage of the higher plants. This condition of nitrogen availability is expressed by the OM/N or C/N ratio. If it is wider than normal, it indicates that there is a deficiency of nitrogen in the soil.

TABLE 16

ORGANIC MATTER/NITROGEN RATIOS

Age Classes															
10		20		30		40		50		60		70		80	
Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N
Pine — dark brown															
80	31.6	88	34.6	99	56.6	163	45.8	57	41.4	118	54.2	171	49.2	46	35.4
63	25.5	55	37.9	152	41.4	180	41.3	65	19.5	129U	42.8				
133U	48.5			137	35.8	153	36.7	166	56.7	129L	59.7				
133L	45.8			164	42.9	44	47.3	150	44.3	129U	45.9				
				174	32.0			170	51.4	129L	58.5				
				182	43.0			157	37.5	130	46.3				
				181	42.6			64	39.0	50	45.4				
										156	60.0				
										179	38.4				
Hardwood — dark brown															
73	39.2	149	46.2	124	41.8	148	38.3					135U	52.1	136	33.4
94	32.0	140	39.3	95	37.2	97	38.2					135L	49.2	144	46.7
74	43.4	139	51.7	62	49.4							145	38.3		
78	41.9	139	42.3	111	40.7										
81	39.5	139	44.3	155	47.8										
82	40.9	105U	45.9	113	38.2										
131	47.7	105L	34.7	91	47.0										
132U	36.7	105U	37.6	127	46.9										
132L	39.4	105L	36.3	125	55.9										
79	31.8	86	40.2	126	40.7										
85	33.5	141U	35.0	101	49.0										
116U	41.3	141L	26.7												
116L	37.5	142	34.8												
83	38.5	142	37.1												

Age Classes															
10		20		30		40		50		60		70		80	
Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N	Plot	OM/N
								Pine — light brown							
80	56.4	88	74.9	181	74.7	163	73.2	57	83.2	118	72.0	151	59.5	109	79.7
133	86.0	55	52.1	99	87.8	180	49.8	57	68.8	129	72.0	171	73.9	46	107.0
				152	59.4	153	54.8	57	66.1	50U	76.9				
				172	55.4	44	71.3	166U	92.7	50L	78.6				
				137	73.9			166L	122.0	120	71.1				
				164	57.0			150	82.0	156	74.7				
				174	50.8			170	48.7	179	73.0				
				182	65.6			157	34.9						
								Hardwood — light brown							
94	46.7	149	66.5	124	66.8	148	55.8					135	47.2	136	57.5
73	56.9	140	50.4	95	59.5	97	68.8					145	121.4	144	48.1
47	68.9	107	48.6	62	61.6										
74	46.8	107	71.6	111	49.9										
78	47.8	139	59.0	155	50.7										
81	58.0	105	43.3	113	59.6										
131	47.9	86	47.6	91	68.6										
132	47.1	141	37.2	127	70.5										
79	59.7	141	76.7	125	64.2										
85	49.7	141	64.0	126	55.6										
83	54.1	142	107.7	101	71.5										
		142	77.0												

The average OM/N ratio in the dark brown zone of the pine profiles for the 10 to12 year age classes is comparatively narrow, 37.0, and widens with increasing age (Table 16). The average ratio for the 30 to 50 year age classes in the same zone is 42; and that for the 60 to 70 year age classes, 50. The narrowest single ratio recorded is 25.5 at thirteen years, and the widest is 60 at sixty-five years. The comparatively narrow ratios in the youngest age class probably reflect the influence of the cultivated fields upon which the pine stands have developed. These fields would contain an average OM/N ratio of about 21 for the old culture horizon.

The dark brown zone of the hardwoods following pine contains an average OM/N ratio of 42.1 for the 0 to 20 age class. The widest single ratio in this group is 46 and the narrowest 32. The ratios widen somewhat in the next age class, 20 to 40, the group having an average ratio of 41.5, with a maximum of 56 and a minimum of 35. However, with the exception of the one ratio at 56, all fall within the range of 35 and 49. There is a slight increase with age. The oldest age class, 70 to 80 years, has an average OM/N ratio of 43.3 and a range of from 33 to 52. The range in the youngest age class of the hardwoods is considerably narrower than the range in the oldest age class of the pines which preceded the hardwoods. This is undoubtedly due to the increased radiation following the cutting of the pine and the resulting increase in the nitrogen metabolism.

The differences between the OM/N ratios of the pines and hardwoods are more apparent in the light brown zones than in the dark brown.

The hardwood ratios for the light brown zone range from 43 to 121; but with the exception of two profiles, all fall within the range of 43 to 71, and the ratios do not widen with increasing age. The pine profiles range from 35 to 107; but with only one profile, that at 35, below 50, and with sixty per cent of the profiles above 70. There is also an apparent tendency for the OM/N ratios in the pines to widen with increasing age. These tendencies are more apparent when the ratios are plotted on the age of closure of the stand instead of on actual age.

Under the conditions of wide OM/N ratios, mycorrhizal activity becomes increasingly important: first, on account of the ability of mycorrhiza to furnish the trees with nitrogen; and second, because they belong to one of the few groups which are apparently capable of decomposing lignins (Melin, 1925; Rudan, 1917; and Herbert, 1924).

Lignins are present in the soil organic matter in amounts ranging from ten to forty per cent (Ritter, 1924); and whereas other constituents are decomposed more or less rapidly, lignins are not, and thus gradually accumulate. Since lignin contains from sixty-two to sixty-four per cent carbon (Waksman, 1927), it contributes heavily toward widening the OM/N ratio and at the same time is relatively unavailable.

There is evidence of wider OM/N ratios under the pines than under the hardwoods; and in spite of the scatter, it is believed that trends are discernible. However, further study on a larger number of plots will be necessary to prove this point, and more knowledge must be sought in connection with the organisms affecting decomposition and the nature of the organic matter itself before the data can be fully and properly interpreted.

VIRGIN FOREST

THE following observations and analyses of soil profiles under virgin forest are from the Pisgah Forest in southern New Hampshire, a portion of which is owned by the Harvard Forest. They represent not only conditions preceding the farming era and the subsequent development of the transition types considered in this study, but also conditions to which the present types (if undisturbed) would in time revert.

Fifty-four profiles were taken under the white pine–hemlock type, six under the spruce–hemlock type, three under pure hemlock, and forty-one under the mixed hardwoods. The depth measurements give the following composite profiles for the different types.

Horizon	White pine–hemlock (54 profiles)	Spruce–hemlock (6 profiles)	Pure hemlock (3 profiles)	Mixed hardwoods (41 profiles)
Litter	0.5	0.7	0.5	0.1
Duff	1.3	1.1	1.3	0.7
Humus	1.6	3.6	2.5	0.9
Leached	1.3	2.1	1.4	0.8
Dark brown	1.1	2.0	1.6	0.4

In spite of the range of composition from hemlock and spruce to hardwood, these profiles show but small differences. Thus, under the hardwoods is a leached layer four tenths as deep as that under the markedly podsolizing species, spruce and hemlock. The explanation may be the overlapping phases of succession, the stagnation of the whole physiology of over-mature forests, and the infrequency of the more soil-improving species.

Tilth

Notes on consistency and structure were taken on fifty pine-hemlock profiles and on forty-five mixed hardwood profiles. The results of these notes are shown in the following table.

Horizon	No. of profiles	Consistency in per cent of profiles				Structure in per cent of profiles			
		Loose	Friable	Tenacious	Tough	Grainy	Granular	Crummy	Columnar
				Pine-hemlock					
DB	50	5	28	65	2	5	35	55	5
LB	50	2	60	36	2	2	56	42	. .
				Mixed hardwoods					
DB	45	. .	60	40	. .	. .	40	60	.
LB	45	15	74	11		4	76	20	.

The soil under the hardwood stands is more friable and slightly more crummy than that under the pines, but in neither case is it as good as that of the younger age classes of the second growth. The soil of the light brown horizons is much looser than that of the dark browns, but is much more granular in structure.

Texture

It is to be observed from the following analyses of texture (Table 17) that the soils are much the same as those in Petersham. The high content of clay in the leached horizon is of interest, since its grainy structure is so marked. The rôle of organic material in flocculating the fine material of the soil is thus strikingly evidenced.

Hydrogen-ion Concentration and Buffer Content

The hydrogen-ion concentration and the buffer content were determined for three pine-hemlock profiles and for two mixed hardwood profiles. Both the hardwood and pine-hemlock profiles were distinctly acid, the leached horizons being especially so. The leached horizon under the pine-hemlock stands had an acidity of pH 2.9, and the mixed hardwoods an acidity of 3.1. Table 17 gives the acidity of the different horizons under the two types of forest stand.

From Figure 8 it is seen that there is a great amount of buffer material present in the dark brown horizons of the pine-hemlock stands, much more than there was in the dark brown horizons of the old field pine type. The amount of buffer decreases with depth. The three buffer curves for the leached horizons, unlike those of the light and dark brown horizons, were exactly alike.

The profiles under the mixed hardwood forest (Figure 9) had a much lower buffer content than those of the pine-hemlock forest, and was generally lower even than the mixed hardwood stands of the older age classes which followed old field pine.

TABLE 17

TEXTURE VARIATION BY ZONES

Plot	Zone	Sand 2–.05	Silt .05–.005	Clay .005 and under	Soil name
		Hardwood			
36	leached	68.32 %	26.62 %	5.00 %	sandy loam
	DB	61.05	31.63	7.32	sandy loam
	ULB	61.55	30.13	8.32	sandy loam
	LLB	68.05	25.13	6.82	sandy loam
27	DB	57.32	38.68	4.00	loam
	LB	58.32	37.86	3.82	loam
		White pine, hemlock, and hardwood			
9	leached	62.18 %	32.00 %	5.82 %	sandy loam
	DB	56.68	35.50	7.82	sandy loam
	ULB	64.82	30.18	5.00	sandy loam
15	leached	64.50	29.50	6.00	sandy loam
	DB (W)	69.37	23.45	7.18	sandy loam
	DB (E)	58.82	35.18	6.00	sandy loam
	ULB	62.25	37.07	0.68	sandy loam
	LLB	75.00	21.32	3.68	sandy loam
		Hemlock			
28	leached	64.58 %	29.69 %	5.63 %	sandy loam
	DB	61.00	30.18	8.82	sandy loam
	ULB	63.18	29.69	7.13	sandy loam
	LLB	58.63	34.37	7.00	sandy loam

ORGANIC CONTENT IN PER CENTS BY PROFILES AND ZONES

Plot number	Leached	DB	ULB	LB	LLB
		Hardwood			
36	5.93	9.66	7.36	...	3.96
27	...	18.26		11.69	...
37	9.59	...		...	...
		White pine, hemlock, and hardwood			
9	4.63	14.68	8.39	...	...
15	...	...	...	...	...
13	4.33	18.22	13.60	...	9.77
		Hemlock			
28	3.14	13.54	12.72	...	15.20

Soil Acidity

Horizon	Pine-hemlock Acidity in pH	Mixed hardwoods Acidity in pH
Leached layer	2.9, 2.9, 2.9	3.1, 3.1
DB	3.4, 3.5, 4.2	3.8, 4.8
LB	3.5, 4.3, 4.7	4.7, 4.9
C	4.1, 4.8, 4.8	4.6, 4.6

Nitrogen

Total nitrogen was determined for the mineral horizons of three white pine-hemlock profiles, for one of the hemlock, and one of the hardwood profiles. The following table gives the total nitrogen contents for these mineral horizons and also the organic matter/nitrogen ratios.

Plots	White pine-hemlock						Hemlock		Mixed hardwood	
	15		9		13		28		36	
	Tot.N	OM/N	Tot.N	OM/N	Tot.N	OM/N	Tot.N	OM/N	Tot.N	OM/N
Horizons										
Leached	.0552	74	.0927	50	.0741	59	.0524	60	.1582	37
Dark brown	.1590	69	.2384	62	.2236	81	.2309	59	.2270	43
Light brown	.0684	98	.1482	66	.1482	83	.2217	63	.0859	65

In general, these profiles indicate that the favorable and unfavorable influences which appear so clearly segregated in the studies of second growth stands are, to a considerable extent, merged and obscured in the virgin forest. The apparent discrepancy between the profiles under the younger hardwood stands succeeding old field pine and those examined under the hardwood phases of virgin forest is probably to be explained, as indicated in the Introduction, in terms of differing life history and composition. In the second growth hardwood we have an initial period of exposure following the cutting, rapidly changing phases of herbaceous and shrubby vegetation, and a final leaf canopy which for a number of years is comparatively low and shallow. All of this makes for a wider annual range of climatic action, particularly temperature and radiation, as applied to the forest floor. On the other hand with the virgin forest there has been no recent nor wholesale exposure of the ground. The forest canopy has developed to a far greater depth, and there is commonly a large accumulation of subordinate elements in the stand, underbrush, suppressed and intermediate trees, together with the apparent tendency over long periods toward alternation of hardwood and softwood predominance. These conditions would certainly have a tendency to offset the more favorable influence of hardwood associations as compared with those of softwood on soil metabolism. In fact, even in second growth hardwood stands those which have reached an age of eighty years or more and in which no cutting has occurred often show a slowing down of decomposition in the humus layers and consequent accumulation of organic material, which suggests progress toward the profiles characteristic of the virgin forest. It would appear that even the most favorable influences of forest composition upon soils must be to some extent regulated by periodic cuttings and suitable rotations.

CONCLUSION

In agriculture the qualities of a fertile soil and the operations by which it is maintained are already well understood.

A farm soil is kept in the best possible condition for plant growth by crop rotation, by the addition of fertilizer, by ploughing under a cover crop, by liming, and by tilling. The results of these operations are threefold: the supply and use of the nutrients is thus adjusted, the activity of the microflora is aided, and the physical properties of the soil are controlled. In ploughing under a cover crop the addition of organic matter furnishes a source of nutrients which are slowly released by the action of fungi and bacteria. The supply is increased by the more readily available nutrients in the commercial fertilizer. The rotation of crops equalizes the withdrawal of the nutrient elements. The humus residue from the organic matter helps to flocculate the soils, which increases the aeration, the ease with which the roots penetrate the soil, and the equalization of moisture content. The periodic ploughing and harrowing also improve the tilth by exposing the clods to the effects of wider variations in water content and temperature. A better physical condition is also obtained by the addition of lime, which acts as a coagulator of the fine colloidal particles. It also serves to neutralize the acidity which may result from the nature of the parent soil material and from the decomposition products of decaying organic material. Better conditions for the activity of fungi and bacteria result, and with the improvement of tilth there is a decreased likelihood of the soil water removing the more soluble nutrient elements from the vicinity of the feeding roots of the plants into the region of ground water.

This study shows that in respect to soil qualities the effects of a pure pine type as contrasted with those of mixed hardwoods are comparable to the effects of poor farming and good farming.

Under the white pine originating on old pastures and tilled areas the arrested decomposition of the organic débris has a marked influence on the previously developed cultural horizons. The extent of the slowing down of the decomposition is attested by the development of a deep duff zone of felted needles. The lack of continued organic additions is reflected in the manner in which the more heavily enriched dark brown layer diminishes markedly in depth with the age of the stand. While this decrease in depth is accompanied by an increase in weight per cent content of organic matter, the result is not beneficial. The organic material added is such that the dark brown zone becomes more compact in structure and more tenacious in consistency. Fungal activity is diminished so that, although the small decrease in total nitrogen per unit of growing space is not alarming, the widening of the organic matter/nitrogen ratio indicates that available nitrogen is probably diminished. It is likely that the considerable increase in mycorrhizal activity in the humus zone evident in the older stands is the result of the reduced availability of nitrogen in other forms.

These poor conditions are mainly due to the narrowing of climatic extremes under the evergreen canopy. Continuous shading of the forest floor so lowers its temperature that decomposition is slowed up, and the slow nitrogen turnover winds in upon itself and the rotting process in a vicious circle. The accumulating raw humus with high absorptive capacity for water prevents anything but extraordinarily heavy rains [1] from reaching the soil.

As the dark brown zone retreats upward, the soil changes into one less heavily enriched with organic matter, the light brown zone. This soil partakes of the nature of a grossly mismanaged agricultural soil, being fine, light, mealy, granular to fine grainy in structure, with no flocculation. Although friable and offering but a minimum resistance to root penetration, the wide organic matter/nitrogen ratio, the apparent infertility and deficiency in moisture explain the lack of root development in this zone and the corresponding concentration in the dark brown. Thus, although the demands of the growing forest for nutrients increase, the depth and fertility of the dark brown zone — the top soil of agriculture — grow steadily less.

Under hardwoods succeeding old field pine more favorable trends are discernible and reveal themselves even more markedly under stands where the soils have never suffered deterioration during occupation by pine. The zones of the organic horizon are always thin; in the extreme case the actual mineral soil is visible (Fisher, 1928). According to the climatic theory of soil evolution, the principal cause appears to be the wider extremes of soil temperature and exposure,

[1] This deep and absorptive duff is seen by Sherman (1928) to be a valuable factor in flood prevention. This may be questioned on two grounds: first, that such a duff should never be very deep in a well-managed forest; and, second, that the more compact soil under such a heavy raw humus zone would increase rather than diminish run-off once the humus were saturated.

especially in spring and autumn, which accompany a deciduous canopy. Although rapid for hardwoods in general, this decomposition varies in rate according to the species whose leaves make up the forest litter. These differ in relative toughness, attractiveness to worms (Walton, 1928) and other soil fauna as food, and susceptibility to fungal attack. Thus ash leaves disappear very quickly, and it is observed that they are exceptionally fragile and often attacked by a fungus while yellowing on the tree.

In contrast to the pine type, this more rapid decomposition in the organic horizon builds up and improves the dark brown zone. While naturally a great portion of the organic material is oxidized to the volatile end product, carbon dioxide, some resistant humus is added to the soil each year. The greater soil transportation and more active metabolism which go on under the hardwood canopy produces a light brown horizon slightly higher in organic content than under the pines. It is also noteworthy that while under pines the zones are sharply defined, under hardwoods they pass very gradually into one another, which is interpreted as further indication of the manner of improvement. A better tilth follows, which, though less in degree, is similar in kind to that in the dark brown zone.

Thus, the influences at work under the hardwood type are analogous to cultivation and fertilizing. The current addition of organic matter to the soil corresponds to manuring. It is possible also that alkaline materials in the leaves take the place of liming; but although this effect has been demonstrated in Europe, it has not yet been discovered with American species. The fluctuations of moisture and temperature improve the physical condition just as does harrowing. Earthworm activity replaces ploughing. Taken together these processes are parallel to those by which the fertility of the soil is maintained in farming.

If the productiveness of forests is to be maintained, forestry must resort to practices which depend upon natural reactions between the soil and the vegetation it supports. Sustained fertility is as indispensable to good forestry as it is to good farming. Silviculture can accomplish this, first, by establishing the species most favorable to soil improvement; and, second, by intensifying or prolonging their beneficial effects through timely and appropriate treatment.

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