

from 45 to 55, the range being due largely to differences in slope and exposure. The unfavorable features of this soil are its shallow A horizon and hard and compact B horizon, high in colloid.

There is an obvious relationship between rate of height growth of trees and recognizable quantitative group combinations of factors, such as are summarized, for instance, in a specific soil type of specific slope and exposure. There is even more evident relationship between rate of height growth and specific soil profile characteristics. It has been pos-

sible to determine some of these profile characteristics as they are related to good, bad, or indifferent growth rate. These have been briefly described in the foregoing discussion.

Summarily speaking, soil features influencing available water seem to be more influential than any others in determining the rate of growth of pine trees. These factors are, of course, degree of slope and its effect on drainage, exposure as affecting surface losses, and the depth, or spatial relationship and physical structure of the horizons.

## CONTRASTS BETWEEN THE SOIL PROFILES DEVELOPED UNDER PINES AND HARDWOODS

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SPECIFIC types of vegetation have long been recognized as associated with the qualities of the site. By the terms "piney soil", "white oak land", and "hickory bottoms" the pioneers described land available for settlement (8). Herbaceous and shrubby plants are now used more or less successfully as "indicators" of site fertility in the northern spruce and pine forests—Sweden (13), Finland (2), Canada (9, 4). The presence and development of these plants reflect partly, but not completely, the qualities of climate, water, and soil which enter into site productivity. These site conditions are thus considered to be the controlling factors of which the vegetation is the resultant.

The first two factors, climate and water, may be altered by interference with the vegetation. Alterations in the micro-

climate under a forest canopy and the moisture-retaining capacity of the forest floor follow woods operations forthwith. But the soil-building process is ordinarily regarded as slowly moving. In the humid forest regions it consists of the physical and chemical weathering of the mineral particles and the slow transport downward of colloidal humus, silica, iron, and alumina. Stratification characteristic of the podzol and the podzolic profiles results. The effect of vegetation on the soil climate and on the chemical nature of the contribution of the vegetation to the soil are stressed in detailed descriptions of the physical and chemical changes (14, 10). It is apparent that quick, drastic changes in the rates of these processes as the result of vegetational differences are not expected.

Hence the interest aroused by descrip-

tions of the soil variations under various forest covers. This interest dates from the studies by P. E. Müller (15) on the differences under beech forests, coniferous forests, and heather in Denmark. More recently Tamm (18) and Lundblad (12) have made notable contributions to our knowledge of the alternations of soil types under beech, oak, spruce, and pine. The significant differences are in the relative distribution of organic matter in the soil profile from the top downward, and the various intermediate and end products in the disintegration of the organic matter.

Under the coniferous stand at one extreme is the tendency to produce the podzol profile. The greater part of the organic matter is found above the mineral soil with a lower minor concentration in the mineral soil. This soil enrichment results from the coagulation of organic material transported downward in the disperse state of minute particles suspended in water.

The profile at the other extreme is found under certain hardwoods. By July or August the total leaf fall of the preceding autumn disappears, leaving no organic matter on the surface. In the soil there is no concentration of organic material in horizontal zones at various depths. From the top downward there is a uniform decrease in humus content which sometimes does not disappear until a depth of thirty inches is reached. Between these two extremes various intermediate profiles are recognized.

Recognition of the agencies involved in the formation of these different profiles is essential if the highest soil fertility is to be attained by treatment of the forest. Further observations by Bornebusch (1) in Denmark verify the earlier conclusions of P. E. Müller that the soil fauna are of great importance in determining the course of disintegration of the annual fall of leaves and needles. In a penetrating review of present information, Romell (16) advances an hypothesis to

account for the formation of profiles differing as widely as those just cited. It is suggested that an adequate explanation is not to be found in the individual effects of any of three agencies working alone—acidic or basic substances, fungi, and soil invertebrates. Rather, the effect on the profile is brought about principally by the action of the biological agencies, including interaction between them. It is therefore interesting to determine how the vegetation may bring about changes in soil flora and fauna.

As might be surmised, greater contrasts between the vegetational effects on the soil are found where there is the possibility of alternate occupation by the floras of two regions. Such is the situation of the Harvard Forest in the tension belt between the coniferous types of the North and the hardwoods of the central states (6). It follows that the forest is in the region of gray-brown podzolic soils in which the true podzols are formed under coniferous stands in certain sites. Furthermore, the land history lends itself to the study (7) of the influence on the soil of the succession, (a) tillage or pasturage, (b) old field white pine, (c) hardwood.

Under the pine there is a tendency for the organic needle remains to accumulate on the surface of the soil. Before the occupation by pines the top nine inches of mineral soil in the abandoned fields is colored by organic matter of which the soil contains more than 5 per cent by weight. This dark brown horizon becomes progressively more shallow the older the pine stand. After clearcutting, the pines on loam soils are succeeded by hardwoods originating as natural advance growth. Under certain hardwoods the tendency of organic leaf remains to accumulate on the surface of the mineral soil is minimized and the depth to which organic matter enriches the mineral soil increases.

An attempt was made to arrange the species found on the area sampled in the

course of the study according to their apparent contribution of organic matter to the soil (7, Table 2). Since hardwood stands containing only a single species were not available the rating was obtained by comparison between stands of varying composition. A tentative and approximate order of decreasing contribution was ventured: white ash, elm, basswood, paper birch, aspen, gray birch, black cherry, pin cherry, hornbeam, chestnut, white pine, beech, white oak, and red oak.

Although corroborated by depths of the dark brown soil found in the profiles, the order in the above series was based partly on observation of the amount of relics of leaves of various species remaining on the surface of the ground at different times during the summer. If the stand is composed mostly of the first species in the list, the mineral soil is visible early in the summer through a thin covering of trash consisting of twigs, ash petioles, and fibrous plant remains (5). Much of this material is piled in middens around the openings into the burrows of angleworms. Their presence accounts for much of the rapid changes in the soil under hardwoods following pine.

In studies on the invertebrates of these soils, Johnston (11) made observations on the activity of the large angleworms *Lumbricus terrestris* (L.) Müller. Reaffirmed are the assertions of Charles Darwin concerning the tremendous importance of earthworms in the soil-building process, a conclusion he first stated in 1837, and further substantiated by evidence collected during the subsequent forty years (3). Of importance here are the observations by Johnston on the food preferences of the angleworm. He found that of six species studied in laboratory feeding experiments, the large-toothed aspen, white ash, and basswood were accepted immediately in that order. Sugar maple and red maple were taken less avidly; the latter was not entirely

consumed. Red oak was not eaten. Field feeding plots were also established. In a site under white ash containing a numerous angleworm population the rates of decomposition were as follows: "... white ash and paper birch completely decomposed after one active season, red maple completely decomposed after two active seasons, red oak almost completely decomposed after two seasons, and white pine about thirty per cent decomposed after two seasons."

These notes were taken on plots containing pure samples of leaves. The leaves were collected immediately after they fell in the autumn and were distributed to form a layer two inches deep on areas five by two feet from which the trash had been removed leaving a clean mineral-soil surface. They were covered by a screen attached to a wooden frame, in order to prevent the addition of falling leaves and the loss of leaves by blowing. By August of the following summer, of the two inches of ash leaves nothing remained on the surface of the soil except the fibrous petioles and midribs of the leaflets collected around the middens. Dissection of the burrows showed that the rapid disappearance of leaves from the surface was the result not only of surface feeding but of the introduction of whole leaves into the burrows as was described by Darwin (3, pp. 55-112).

The admixture of whole leaves into the mineral soil in this manner must be of extraordinary importance. There is a reciprocal beneficial effect on the course of the decomposition of the organic material and on the chemical weathering of the mineral particles. The addition of sand to humus in storage experiments increases the bacterial action as shown by increased nitrate formation. It has long been known that the products of biological decomposition are among the chemical agents responsible for the chemical attack on the soil minerals. Car-

bonate, nitrate, and sulfate ions are assigned a role in the disintegration of the mineral particles.

It happens that the mineral ash content of the various species of leaves more or less parallels their apparent attractiveness to the angleworm as food. The "more demanding" hardwoods, whose leaves are a favored food of angleworms, are "heavy feeders". It is believed that they "pump" the basic nutrient elements, potassium and calcium, from the deeper soil levels. Possibly the parallelism between preference and mineral content is not fortuitous, and the worms do recognize the higher mineral content of the favored food. (Differences in textures of the leaves had been suggested as the reason for the preferences by R. T. Fisher).

Yet it would appear that it is the first step, the carrying down of the whole leaf into the soil, which should be stressed. The leaves drawn into the burrows are used as food and intimately mixed with mineral particles in the gizzards of the angleworms. The feces apparently form a substrate promoting bacterial activity. Since the ejecta dry into crumbs there results a loose, porous, permeable soil. Furthermore, by trituration in the digestive tract the mineral particles are physically made more susceptible to the action of chemical agents.

By the continued action of worms the stratification of the soil into sharply separated horizons is obscured. By carrying to the surface material from the lower layers they neutralize the downward movement of the soil material. When their activity is continued for sufficient time, they work through the layer in which chemical enrichment usually takes place. Yet at the beginning of the transformation the previously found podzol profile may still be evident if examined by chemical tests for mineral colloids—silica, iron, alumina. Hence

separate strata can be identified chemically within the preformed upper depleted stratum. During such transformations the limits of the strata showing differences in color do not coincide with chemically determined limits of the A and B horizons.

The transformations brought about by angleworms illustrate the most drastic change which may be brought about by the soil invertebrates. But the presence of worms does not ensure the transformation described. Some worms do not pass into the mineral soil, but are active only in the superficial organic material. On the other hand, other invertebrates may form mull (17). As yet we know very little about the food preferences and the habits of the prolific soil fauna instrumental in bringing about the dynamic balance apparent in the various types of humus. Worms are frequently but a minor part of the total population. Because of the outstanding results brought about by angleworms they are cited as an extreme case. But these extraordinary transformations are not as yet found over any large part of the forested area in the Northeast.

These considerations, the writer believes, should have an important bearing on the subject of humus classification. The organic material in the angleworm soil is the highest development of the sort designated as *mull*; the unincorporated organic material found on the surface soil above the extreme podzol profile is the sort of humus for which the name *mor* is used.<sup>1</sup> The question arises, to which of these groups should certain intermediate form of humus be assigned? Thus, a type of superficial organic matter showing but a small admixture of mineral soil particles is grouped with the *mulls*. If it is so thin that (a) the amount of increased "biological" weathering brought about in it does not involve any considerable depth of mineral soil, (b) in its

<sup>1</sup>See "Nomenclature of forest humus layers" by S. O. Heiberg in this issue.

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formation there can be no significant neutralization of the processes which result in stratification, then it should be called a *mor* in the opinion of the writer. It will be objected that such criteria call for laboratory determination, and are not recognizable by field inspection or tests. Such criticism is well taken, but is met by the suggestion that increased knowledge and the development of simple field tests will make elaborate tests supplementary to field inspection unnecessary.

A further problem is the extent to which vegetational succession and the associated biological differences can confuse the identification of soils under forest stands as they are re-examined in the course of time. For information on this problem it is important that provision can be made for the periodic investigation of soils in managed forests which have been intensively mapped for soils and cover. This problem bears on a relevant query. To what degree may the formation of "young" profiles or the failure to develop "normal profiles" (14, Plate 6) within the area of the gray-brown podzolic soils be due to the alternation of vegetational types? There is ample evidence that the primeval forest was not static. Of practical as well as philosophical interest, the question has a bearing on how the maximum in forest soil fertility is to be achieved and maintained.

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## PHYSICAL AND CHEMICAL STUDIES OF TWO CONTRASTING CLAY FOREST SOILS<sup>1</sup>

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THE late Dr. C. F. Marbut, when asked how deep the true soil extended, replied, "In most cases eight feet or less". (9).

With this in mind, samples of heavy clay soils were taken to a depth of eight feet for the purpose of comparing the total amount of several important mineral elements present in two contrasting forest soils. The "poor" clay soil chosen is represented by a member of the Flatwoods region, namely, Lufkin clay, while Sharkey clay, a "rich" soil from the Yazoo-Mississippi Delta, is analyzed for comparison. Both soil types may be considered forest soils but for different reasons. Lufkin clay is too impervious for most cultivated crops, giving rise alternately to excessive wetness and to excessive dryness. On the other hand Sharkey clay lies at such a low topographic position that unless it can be economically drained the hazard of damage to crops by flooding renders it better suited on the whole to trees than to corn or cotton.

No contrast exists in either the average annual precipitation or the normal annual temperature in the regions where

these soil samples were taken; the former being about 52 inches and the latter 64" F. Neither does the elevation above sea level vary more than from 100 to 150 feet.

### LOCATION

Lufkin clay is probably the dominant soil type on the area labeled "Flatwoods" in Figure 1. The area occurs as a north-south belt 6 to 12 miles wide across the northeast corner of Mississippi, the extension of which may be found in both Tennessee and Alabama. The Sharkey clay under consideration (Figure 1) is a very common member of the young Delta soils. Its distribution is wide in the first bottom flats lying between the Yazoo River and the Mississippi River.

### NATIVE VEGETATION

The term "Flatwoods" connotes infertility, whereas "Delta" implies fertility. A glance at the forest cover in the Flatwoods is all that is needed to predict that the soil is not "strong" nor produc-

<sup>1</sup>The term "forest soils" as here used refers to any soils that originally supported trees and whose best use at the present time is primarily centered in timber production.