PHYSICAL CHARACTERISTICS AND SILVICULTURAL IMPORTANCE OF PODSOL SOIL

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Introduction

Forestry and agriculture have much in common. The crop production of plant life in various forms is the primary object of both sciences. In no way is the common relationship between forestry and agriculture more fully demonstrated than by the dependence of their crops upon the condition and health of the soil for existence and growth.

Although forest soil science can be said to have been initiated in 1893 when Ramann published his masterly work on " Forstliche Bodenkunde und Standortslehre," it has not kept pace with similar developments in agricultural soil science. The catastrophies which in recent years have overtaken spruce forests in Saxony have stimulated the interest in forest soil studies. The resulting decrease in site quality has manifested the need for a more rational use of forest soil. In Saxony, since 1850 (Anonymous, '23), forest management has been based chiefly upon a financial rotation, no effort being made to maintain the soil fertility through the introduction of hardwood species. Clear-cutting and replanting of pure Norway spruce have been the outstanding features of the system, and until recently the results apparently have been excellent. However, at present the annual cut is but 40 cubic feet per acre, whereas before the war it was 69 cubic feet. This represents a falling off in yearly growth of almost 45 per cent. Among the several reasons alleged for this reduction is the development of podsol soil, a soil formation characteristic only of wooded land. In Saxony, it was found (Anonymous, '23) that " pure stands of spruce fail to maintain the fertility of the soil. The soil loses its life; *it turns a blue-gray color;* there are no rainworms, no microbes, no insects in it; it is littered by a sort of peat ' Trockentorf,' which seems to cover the soil in an air-proof and moisture-proof layer. During the first generation of pure spruce, these changes and these drawbacks do not seem to enter an appearance. In the second and third, they become evident, particularly during dry seasons. The result is utter stagnation of growth." In the words of Dr. C. A. Schenck, the forest soils of Saxony are " sick," and their former productiveness can be restored only after many years of careful work.

The Podsol Soil Profile

The term podsol or podzol, as it is more correctly spelled, is of Russian derivation. It is synonymous with the German " Grauerde," " Bleicherde," or " Aschenerde," and means ash- or cinder-colored. The term describes very appropriately the degenerated forest soil in which the characteristic leached-out gray horizon has been formed. Originally, the term podsol applied more specificially to the gray-colored zone, though now it is commonly used to describe the entire profile or any process or processes which culminate in lowering the soil quality.

In general it can be said that podsol soils occur under two very distinct conditions: first as the result of the natural environmental factors, and secondly where the forest produces conditions favoring the podsol process In the former case, the presence of this soil type may or may not indicate poor soil conditions. In the latter, it does show that serious harmful changes have taken place in the soil. Thus for example, as Hesselmann ('25) points out, while a soil type with raw humus and leached soil is normal for Swedish forests, such conditions in Middle Europe are regarded as signs of the beginning of degeneration. Where the podsol process is simply a part of the natural environment, as is the case with the Cherry Mountain soils, such soils may have humus in the form of " northern mull " and not in the raw state. Notwithstanding the podsol formation found under such humus, this soil can be considered favorable for that particular climatic region.

European forest soil literature contains numerous references to podsol soil. Ramann ('11) gives an excellent description of its formation and distribution in Europe. Glinka ('24) and Niklas ('24) have both investigated the podsol formation in Russia. Recently Hesselman ('25), in his prodigious research on humus layers in coniferous forests and their dependence upon silviculture, has described it as found in Sweden and Germany. In this country McCool, Veatch, and Spurway ('23), in their soil profile studies in Michigan, distinguished and reported the gray forest soil common to the northern part of the peninsula as contrasted with the brown soil found farther south. Bray ('15) has found the leached soil very common to the sand beds of the Adirondack Mountains in New York. Edgington and Adams ('25) have worked on the nitrogen distribution of samples taken from a podsol profile at Cherry Mountain, New Hampshire.

Ramann ('11) limits the boundaries of the podsol soil distribution in Europe to the regions of cool temperatures where there is abundant rainfall and severe winters. In the United States it is generally believed that this soil formation is coexistent with the spruce-fir-northern hardwood region of the Northeast and Lake States—a region of humid climate and other climatic conditions similar to those outlined by Ramann. It is found also in the white pine region of New England, but in a much less clearly defined area. Probably this soil type extends north through the wooded areas of northeastern Canada. Podsol soil can likewise result, as has been previously mentioned, from a one-sided silvicultural system which produces pure stands, especially of conifers. This will be discussed at some length later.

Physiognomy and Floristic Composition of the Cherry Mountain Forests

During the late summer and early fall of 1924, the Northeastern Forest Experiment Station established a series of permanent sample plots at Cherry Mountain, New Hampshire. The forests in the vicinity of the plots are typical stands of mixed spruce-fir-northern hardwoods. The area has good drainage conditions, moderate to steep slopes, and a general east to southeast exposure. The overwood, though mature and presenting a virgin forest appearance, was lightly culled for large spruce timbers some fifty years ago. At the time the plots were established, the dominant red spruce trees had reached an age of between 180 and 250 years. The tallest tree on the plots, a red spruce, had a height of 83 feet with a diameter at breast height of 20.7 inches. The diameters of the species at breast height varied from 1 inch to 26 inches. A tally of all trees one inch and over in diameter on a half-acre plot gave the following distribution per acre:

Table I. *Percentage distribution and basal area of tree species per acre*

Species	Number	Percentage	Basal Area*	Percentage
Red spruce (*Picea rubens*)	162	35.8	62.730	41.71
Balsam fir (*Abies balsamea*)	76	16.8	13.026	8.66
Yellow birch (*Betula lutea*)	138	30.5	58.812	39.11
Sugar maple (*Acer saccharum*)	6	1.4	5.372	3.57
Beech (*Fagus grandifolia*)	26	5.8	5.814	3.87
Others †	44	9.7	4.636	3.08
Per acre	452	100.0	150.390	100.0

* Basal area is the area section of a tree, usually expressed in square feet, and usually referring to the section at breast height. The sum of the basal areas of trees in a stand is the basal area of the stand and is usually expressed in square feet per acre.

† Others comprised the following species—red maple (*Acer rubrum*), striped maple (*Acer pennsylvanicum*), mountain maple (*Acer spicatum*), and pin cherry (*Prunus pennsylvanica*).

The underwood and herbaceous growth, as is typical of our northern mixed softwood-hardwood forests, was very prolific both in number of species and area distribution. It consisted for the most part of sapling and seedling growth of overwood species with a preponderance of the three maples—red, mountain, and striped—pin cherry, and witch hobble (*Viburnum alnifolium*).

The frequency distribution of herbaceous growth was as follows:

TABLE II. *Distribution of herbaceous growth*

ABUNDANT	COMMON
Witch Hobble (*Viburnum alnifolium*)	Star Flower (*Trientalis americana*)
Clintonia (*Clintonia borealis*)	Twisted-stalk (*Streptopos amplexifolius*)
Wood Sorrel (*Oxalis Acetosella*)	Miterwort (*Mitella nuda*)
Wild Sarsaparilla (*Aralia nudicaulis*)	False Miterwort (*Tiarella cordifolia*)
Bunchberry (*Cornus canadensis*)	Violet (*Viola* sp.)
Canadian Mayflower (*Maianthemum canadense*)	Indian Pipe (*Monotropa uniflora*)
Aster (*Aster acuminatus*)	SCARCE
Spiney-shield Fern (*Aspidium spinulosum*)	Rattlesnake Plaintain (*Epipactis pubescens*)
Common Club Moss (*Lycopodium clavatum*)	White Trillium (*Trillium erectum*)
Groundpine (*Lycopodium complanatum* var. *flabelliforme*)	Painted Trillium (*Trillium undulatum*)
Lycopodium lucidulum	Orchis (*Habenania* sp.)
Lycopodium obscurum var. *dendroideum*	Sweet-scented Bedstraw (*Galium triflorum*)
	Rough Bedstraw (*Galium asprellum*)
	Dwarf Raspberry (*Rubus triflorus*)

PHYSICAL PROPERTIES OF PODSOL SOIL

Excellent examples of strongly leached soil were abundant on the areas selected for the permanent sample plots. The appearance of soil profile is given below (see also Figs. 1 and 2). The numbers represent the average of a series of twelve soil well measurements. The Swedish (Swd.) and German (Ger.) terms are given whenever possible.

A_0—ORGANIC HORIZON.

Horizon of pure organic matter; depth 1.0 to 4.0 inches, with an average of 2.6 inches.

A_0^1—*Litter Zone* [Förnerskiktet (Swd.); Streuschicht (Ger.)]. "The unaltered total dead remains or detritus of plants or animals." No decomposition other than weathering is found in this zone, which consists primarily of the more recently fallen leaves, twigs, and small branches. On account of the physical state of the organic matter, aeration is excellent.

A_0^2—*Duff Zone* [Förmultningskiktet (Swd.); Vermoderungschicht (Ger.)]. The region intermediate between the litter zone and the humus zone, and consisting of organic matter in the process of decomposition whose structure is still plainly visible. Aeration is moderately good and fungal hyphae or mycelial threads are generally lacking. This is the so-called F-layer of Hesselman ('25).

A_0^3—*Humus Zone* [Humusamneskiktet (Swd.); Humusstoffschicht (Ger.)] "The sum total of organic remains of plants or animals which have become part of the soil and have been therefore subjected to an alteration process." The decomposition in this layer has gone so far that the plant structures are no longer distinguishable. Aeration is very poor, and, where raw humus [Råhumus (Swd.); Rohhumus (Ger.)] is found, the layer is always felt-like and interwoven with fungal hyphae and mycelial threads. This is the layer designated as H by Hesselman.

A—Leached Horizon.

Horizon from which the organic matter and inorganic colloids have been washed out into the next lower horizon, and from which the soil formation derives its name. Depth 0.5 to 7.0 inches; averaging 2.9 inches.

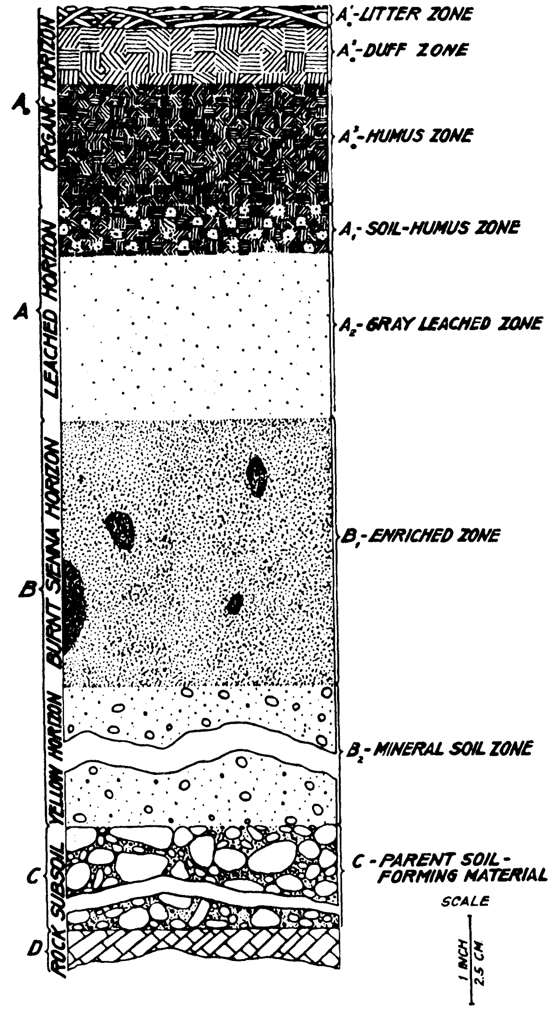


Fig. 1. Profile of podsol horizons at Cherry Mountain, New Hampshire.

A_1—*Soil-Humus Zone.* A rather thin band of black concentrated admixture of humus and soil; "nut"-like in structure, and characterized by the presence of white quartz flour on the surface of the organic matter. A transition zone between the organic horizon and the leached horizon.*

* This transition zone may be so thin in the undisturbed podsol profile as to be almost indistinct, and in some cases it may be entirely lacking. The soil-humus zone is however very characteristic of the podsol profiles of old pasture spruce stands and of second growth white pine forests.

A_2—*Leached Zone* [Blekjordskiktet (Swd.); Bleichschicht, Aschenerde or Grauerde (Ger.)]. A zone of almost pure white to blue-gray sand, with scarcity of organic matter.

B—Burnt Sienna and Yellow Horizons.

B_1—*Burnt Sienna Horizon.*

Enriched zone, burnt sienna in color (sometimes spoken of as *coffee brown*). Horizon of rather uniform texture with small concretions of very dark brown to almost black particles. Depth 1.0 to 10.0 inches; averaging 4.0 inches.

B_2—*Yellow Horizon.*

Mineral soil zone, yellow to rust-colored, in which there is a concentration of iron compounds; depth undetermined.

C—Subsoil Horizon.

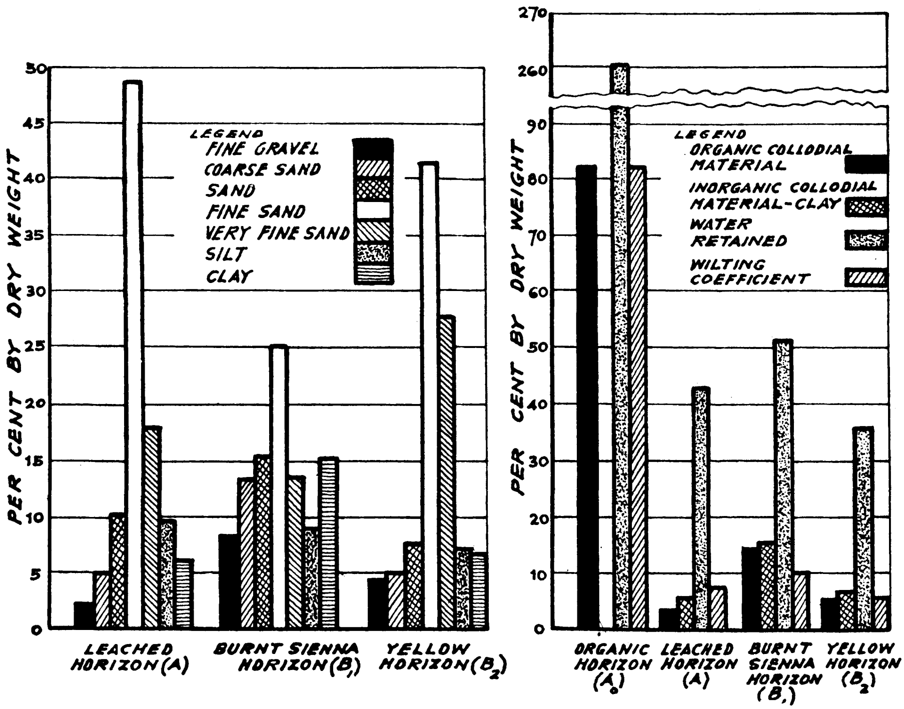
Zone of parent, soil-forming materials; glacial origin; depth undetermined.

D—Rock Horizon.

Parent bed-rock; composed mainly of granite and gneiss.

Fig. 2. Soil well in podsol soil at Cherry Mountain, New Hampshire.

It should be remembered that the above terms and definitions are morphological. All of the zones distinguished may or may not be present in every forest soil, depending upon climatic as well as upon forest floor conditions. Thus, for example, in the best type of mull soil, humus is present, but in a much different quality and quantity than in the less favorable forest soils. In the former, ecological conditions produce rapid oxidation and decomposition of the detritus materials, resulting in a very thin, loose organic horizon. In the latter, on the contrary, the site factors lead to the formation of a dense felt-like layer of organic matter which we term raw humus.



FIGS. 3 AND 4. Fig. 3 (left). Percentages of soil fractions in the various horizons of a podsol profile. Fig. 4 (right). Relationship between the amount of colloidal materials in the horizons of a podsol profile and the retentive capacity for water and the wilting coefficient.

Samples were collected from each of the first four horizons. In the laboratory, specimens of each of the above were subjected to the regular mechanical analyses as used by the Bureau of Soils, the ignition test for estimation of organic matter, and the Hilgard method of determining the maximum water-holding capacity. All tests were done in duplicate. Edgington and Adams ('25), working with samples from these identical horizons, determined the nitrogen content, acidity, and moisture equivalent.

a. Mechanical Analyses of the Horizons

Table III and figure 3 show the percentage of the various soil fractions in the three soil horizons. It was not possible to make such a determination for the humus or soil-humus layers, because of the presence of excessively large amounts of organic matter. Ten-gram samples were used.

TABLE III. *Distribution of soil fractions in horizons of the Cherry Mountain podsol profile*

Separate	Size of particles mm.	Horizons		
		Leached per cent	Burnt sienna per cent	Yellow per cent
Fine gravel	2.0 –1.0	2.19	8.34	4.29
Coarse sand	1.0 –0.5	5.07	13.26	5.01
Sand	0.5 –0.25	10.24	15.62	7.67
Fine sand	0.25 –0.10	48.91	25.12	41.39
Very fine sand	0.10 –0.05	17.92	13.35	27.76
Silt	0.05 –0.005	9.69	8.95	7.23
Clay	0.005–0.0001	5.98	15.36	6.65
Totals		100.00	100.00	100.00
Classification		Fine sand	Sandy loam	Fine Sand

b. Estimation of Organic Matter

Oven-dried samples were placed in heat-resistant crucibles and ignited at a low red heat until all the organic matter had been oxidized. The cold mass was then moistened with ammonium carbonate and reheated to a temperature of approximately 150° C. to drive off all the ammonia and replace the carbon dioxide. When no further loss in weight could be detected, the samples were finally weighed, and the loss in weight was taken as the amount of organic matter present. The results were as follows:

TABLE IV. *Organic matter in horizons of the Cherry Mountain podsol profile*

Horizon	Percentage of organic matter
Organic	83.17
Leached	2.96
Burnt Sienna	15.12
Yellow	4.86

c. Maximum Water-Holding Capacity and Wilting Coefficient

The maximum water-holding capacity was determined with the usual perforated brass cup holding a column of soil one centimeter thick in accordance with the Hilgard ('12) method. The wilting coefficient was calculated, using the data in Table V with the formula (Lyon and Buckman, '22):

$$\text{Wilting coefficient} = \frac{\text{water-holding capacity} - 21}{2.9}:$$

TABLE V. *Maximum water-holding capacity and calculated wilting coefficients of horizons of the Cherry Mountain podsol profile*

Horizon	Maximum water-holding capacity	Calculated wilting coefficient
	Percentage of dry weight of soil	
Organic	260.69	82.7
Leached	43.49	7.8
Burnt Sienna	51.90	10.7
Yellow	36.00	5.2

The relations between the colloidal materials in these four layers, the amounts of water retained, and the calculated wilting coefficients are graphically presented in figure 4.

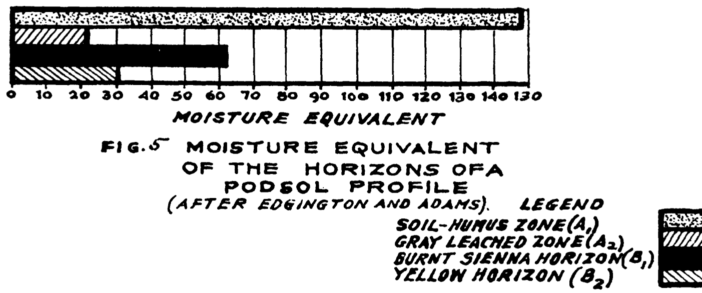


FIG. 5 MOISTURE EQUIVALENT OF THE HORIZONS OF A PODSOL PROFILE (AFTER EDGINGTON AND ADAMS).

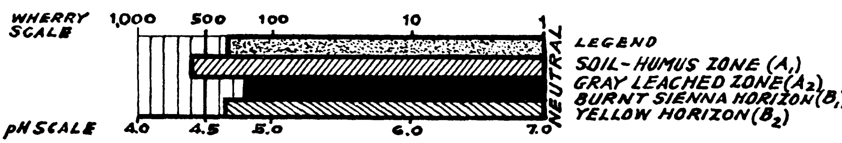


FIG. 6 ACIDITY OF THE HORIZONS OF A PODSOL PROFILE (AFTER EDGINGTON AND ADAMS)

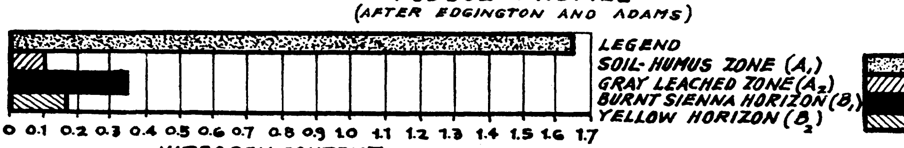


FIG. 7 PERCENTAGE OF NITROGEN IN THE HORIZONS OF A PODSOL PROFILE (AFTER EDGINGTON AND ADAMS)

FIGS. 5, 6 AND 7. See captions under each figure.

d. Moisture Equivalent, Acidity, and Nitrogen Distribution

The determination of the moisture equivalent, acidity, and nitrogen distribution by Edgington and Adams ('25), using samples of the podsol soil from Cherry Mountain, New Hampshire, are presented herewith. The graphical presententaticn will be found in figures 5, 6, and 7.

TABLE VI. *Moisture equivalent, acidity, and nitrogen content of horizons of the Cherry Mountain podsol profile (after Edgington and Adams, '25)*

Horizon	Moisture equivalent percentage by dry weight of soil	Acidity pH	Nitrogen content percentage
Soil-Humus	148.9	4.66	1.660
Leached	21.9	4.40	0.099
Burnt Sienna	62.7	4.80	0.348
Yellow	30.6	4.65	0.164

e. Chemical Analyses

No chemical determinations, other than for nitrogen and hydrogen ion concentration, were made with samples taken from these profiles. It is of interest to record the findings of Niklas ('24) in this connection. This investigator, working with bleached sand and soil formed in situ (the burnt sienna horizon soil), found that the enriched layer, as contrasted with the leached layer, contained five times as much iron, twice as much aluminum oxide and phosphoric acid, and one and a half times as much soluble silicon oxide. These results agree closely with the work of McCool, Veatch and Spurway ('23), who, in their chemical analyses of the podsol horizons of northern Michigan, found that there was three and a half times as much nitrogen, three times as much iron oxide, two and a half times as much aluminum oxide, twice as much phosphoric acid and sodium oxide, and half again as much calcium oxide, magnesium oxide, and potassium oxide.

The Podsolization and its Silvicultural Importance

The data presented show that the amount of organic matter, inorganic colloids (the clay fraction), and chemical elements found in the burnt sienna and yellow horizons is greater than in the leached layer. Likewise, it is evident that these zones are distinctly acid, with the lowest pH in the leached zone, and an upward trend for the soil humus zone and also for the burnt sienna and yellow soils. This factor is of outstanding importance in the explanation of the leaching process. The organic acids are believed to play an important rôle in the removal of the soil salts from the first soil zone and their redeposition in the lower soil layers. In a cool forest floor, an acid condition reduces the activities of fungi and micro-örganisms, resulting in incomplete oxidation and decomposition of the organic detritus. These colloidal humic materials, acid in nature, percolate through the first soil zone, where they leach out the bases to form a colloidal suspension. Coming to the second soil zone, the burnt sienna horizon, the presence of more basic materials precipitates these colloidal particles. The dissolved humus substances thus protect the soil colloids from loss, and there is a diminution of bases, especially iron and aluminum, from the leached layer, with their subsequent accretion in the burnt sienna horizon.

As Hesselman ('25) has indicated in his study of humus layers in coniferous forests, silviculture can play a part in the development or retardation of the podsol process. This is true both where the podsol soil is the result of climatic conditions and where it is the result of favoring pure coniferous stands. The controlling factor appears to be very largely soil acidity, since strongly acid conditions in the forest floor are conducive to the leaching process in the soil layers. Slow decomposition and strongly acid conditions go hand in hand. Any silvicultural method which will increase the rate of decomposition of the detritus materials will help to combat the tendency toward the formation of a degenerated soil. Since a higher temperature accelerates the action of the micro-örganisms, thinnings and small openings in the stand will hasten oxidization and decomposition by permitting more solar radiation to fall upon the forest floor. Furthermore, the admixture of hardwoods in coniferous forests should be favored, because hardwood leaves produce alkaline buffer substances which react upon the humic acids. The species most valuable for this purpose are ash, birch, maple, and beech. Not only is the soil directly favored by such a mixture of hardwood leaves in the detritus materials, but the nitrogen transformation is much livelier. This last factor is of decided importance in producing higher yields. While it is true that in this country forestry has not yet reached a stage where the liming of the soil is feasible, as is being done in the beech forests of Denmark, nevertheless we have within our means recognized silvicultural measures which can be utilized to increase soil fertility.

Pure white pine stands in New England tend to produce podsol soil. Fisher ('28) has described this development at the Harvard Forest and its subsequent conversion to a good mull soil. This has been done simply by permitting the better hardwoods to come up in young pine stands. In this region a decided decrease in the rate of growth of pure pine stands takes place at an age of between 50 and 60 years. Not only is there a period of stagnation, but also low quality timber is produced because of the slow pruning. Perhaps such poor growth conditions could be postponed to a much later date by the use of judicious thinnings. Accompanying such a period of stagnation, strongly leached layers with raw humus zones several inches in thickness are developed. When such pure pine areas are clear cut and the subsequent stands permitted to develop into mixed stands composed of scattered pines and the better hardwoods, excellent mull soils are formed where degenerated soils once existed. This change is exceedingly rapid. At Petersham, no trace of leached soil could be found in from twelve to fifteen years after the softwood stands had been cut.

The entire question of podsol soil formation where it does not occur naturally as the result of environmental conditions offers a striking proof of the old German forestry axiom, "Beech to ten per cent of the stem count should be maintained to produce good soil conditions and consequently good growth." Although our beech appears to be much less valuable than the European beech as a soil improver, there are a number of other species which can be made to serve the purpose.

Summary

1. In regions of humid climate, where rainfall is abundant, and winters severe, there exists a tendency toward the podsolization of forest soils. Such soil can also be formed in regions with more favorable climatic conditions as the result of producing pure stands, especially conifers. This soil formation

is characterized by a leached layer, gray in color, immediately beneath the organic horizon; and an enriched horizon, burnt sienna in color, below the zone of outwashing.

2. A physical and chemical examination of a typical northern podsol profile shows that more organic matter, clay particles, and chemical elements are present in the enriched zone than in the leached zone.

3. These conditions are reflected in the maximum water-holding capacity and calculated wilting point determinations made with samples from the various horizons.

4. Cool temperatures and acid conditions further the podsolization process because of incomplete oxidation and decomposition. It is believed that the acid humus particles in the form of colloids leach out the basic materials as they pass through the leached layer, to redeposit them in the enriched zone.

5. A tendency toward podsolization can be combatted by opening up the stand and by encouraging the admixture of hardwoods such as ash, birch, maple, and beech. Such silvicultural measures hasten the activities of micro-örganisms and decomposition, produce alkaline buffer substances which react against the unfavorable humic acids, and produce a more lively nitrogen transformation.

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