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Studies of the
HUMUS LAYERS OF CONIFEROUS FORESTS
their Peculiarities, and
THEIR DEPENDENCE UPON SILVICULTURE

by

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INTRODUCTION

When I began to study the Swedish forest soils several years ago to obtain possible clues to their peculiarities and their peculiar dependence on our silvicultural methods of procedure, there was a special indication that my studies were tied up with the humus layers. Forest burning was of outstanding importance not only for the creation but also for the growth of the northern forests. Forest fires have often, if not always, favored reproduction; also the growing stands started upon burned soil often showed an astonishingly vigorous growth, which appeared the more noteworthy when compared with the weak growth of stands on soils long protected from fire, but otherwise — geologically and physically — alike. This phenomenon was partially explained when the importance of burning for nitrification was demonstrated, but the problem was not thereby solved. After the nitrification had stopped the good growth on the burned soils continued. Therefore the question broadened into a more general problem connected with the peculiarities of the various acid non-nitrifying kinds of humus and their silvicultural significance. The kinds of humus mentioned have usually the noteworthy physical peculiarities of a raw humus layer. The studies were thereby transferred into a sphere which constitutes perhaps the most important of the northern forest soil investigations, and established as a research on the various forms of raw humus of our coniferous forests and the significance of their peculiarities for silviculture.

In the course of the investigations it was soon shown that it is important to compare the conclusions obtained in Sweden with those in Middle Europe, especially in the regions with well-recognized soil problems, such as certain districts in Wurttemberg and Barenthoren in Anhalt. Therefore in June, 1921, I made a trip subsidized by the Forest Science Research Fund through Central Germany and Czechoslovakia. The Calmbach and Langenbrand regions in the Schwarzwald, the Prince Schwarzenberger forests near Winterberg (Vimperk) in Bohmerwald, the Rittergut Barenthoren in Anhalt, and the Everswald in Prussia were visited. It is a pleasure to record the friendliness and accommodating spirit which was my portion everywhere. I feel myself especially indebted to Dr. Ramm (Calmbach), Dr. Eberhard (Langenbrand), Dr. Karel Domin (Prag), Dr. Budinsky (Winterberg), Forest Director Wenhard (Winterberg), Dr. von Kalitsch (Anhalt, Barenthoren). Among those gentlemen-colleagues who aided me on my trip, my thanks can no longer reach Prof. Albert Moller in Eberswalde, with whom I had an opportunity to analyze pertinent questions. I visited him on a late summer's day at his home in Eberswalde and discussed the "humus question" and the "Dauerwald" with him in the Research Garden. In the late fall of 1922 Prof. Moller, as the result of an operation usually free from danger, suddenly ended a noble research career. To my mind he was one of the masterly students in the field of forest biology in Germany.

In the fall of 1924 Prof. Wiedemann of Tharandt corresponded with me about my visit in Barenthoren. Prof. Wiedemann was at that time busy with the problem of the "Dauerwald." My researches in the summer of 1921 into the humus problem were supplemented by those completed by Prof. Wiedemann and sent to the Swedish Forest Institute. Last summer I published an article in Wiedemann's "The Practical Results of the Pine Dauerwald." The conclusions are also given in the following sections.

Section I.

The Importance of Middle European Forest Soil Studies for our own Forest Soil Science Problems.

It can be said without contradiction that the European foresters' earliest knowledge of the peculiarities which good forest soils show is founded upon the classical and, so far unsurpassed studies of P. E. Muller on the humus and peat formations in the oak and beech forests and heaths of Denmark. Nevertheless only to a limited degree can Muller's studies throw light upon the problems which the northern coniferous forest soils offer. This is especially due to the fact that the climate and its influence upon the soil in Denmark is of a distinctly different sort from that in Sweden, and especially north Sweden. In Denmark, with the exception of West Jutland, the climatically determined soil type is the "brown earth." The same is also true of the greater part of Germany. In Sweden, on the other hand, the "podsol" is the prevalent soil type. In the "brown soil" there naturally results a type of humus which is called "mull" (mold); just as in the podsol in a like manner "rohhumus" (raw humus) results. Because of the different soil conditions determined by nature, silviculture has different effects in Sweden than in Germany or Denmark, the home of forest soil investigations. The type of soil and humus which is normal for the Swedish forests presents to the Danish and Middle European foresters an abnormal appearance, an indication of an unhealthy condition in the soil, and a reduced productivity.

Section II.

The Soil Conditions in Middle and Northern European Virgin Forests.

There are not many virgin forests left in Middle Europe— for the most part only in the eastern region, as in the Carpathians, Lithuania, and in northwestern Russia. The best known and at the same time most accessible is the preserve managed by Count Adolph von Schwarzenberg on Mount Kubani in Bohmerwald, not far from the Bavarian boundaries, which was first and most thoroughly described by Goppert in 1868. I had the opportunity, during a few days in

June 1921, to study the Kubani virgin forest. The presence of deep thick humus layer is associated with the term virgin forest, a forest, therefore, from which nothing is taken away, but everything that is produced returns to the soil. One would think that such must have taken hundreds or thousands of years to form because of and thanks to the canopy must remain forever. The Kubani virgin forest, however, shows an entirely different picture. Where beech is admixed in the stand the soil is covered with a thin layer of dried brown beech leaves, which are mixed with the coniferous needles when they fall. In June 1921 the litter was composed only of two-year beech leaves. The lower leaves had been thoroughly rotted into a network (lit. a scaffolding) of dry leaf veins. Over this lay the following year's leaves in an unbroken but aerated layer. This layer of litter, thin and only a few cm. thick, was only loosely laid upon the soil; it was not woven together by fungal hyphae or rootlets. Under the litter layer was found a mull layer of 5-6 cm. thickness, which gradually merged into a brown earth layer slightly mixed with mull. Of "bleached" earth there was not a visible trace. Both the quick decomposition of the dead leaves and the relatively thin layer of mull indicate, therefore, that in a virgin forest there is almost an equilibrium between the production of tree destritus and decomposition of the same into nutrients taken up by the vegetation: carbonic acid, water, salts. Among the decomposition products is nitrate. The rather rich weed and grass flora shows as a rule a high saltpeter content in the tissues. Only where the tree trunks had accumulated on the ground was there found a larger quantity of dead organic remains. On the other hand the yearly leaf and needle fall was quickly rotted. In this fact, not in the presence of a great mull accumulation, must be sought the reason for the good soil condition in the virgin forest.

But in Kubani is a smaller area of another sort. In an area slightly less than a hectare (2.47 acres) beech is lacking in the stand. The mull is here replaced by a typical raw humus. The living soil cover is of mixed Holycomium proliferum, Polytrichum commune, beds of sphagnum, and bilberry bushes (Vaccinium Myrtillus). Under the living ground cover there is a rather thick peat-like layer of duff (Vermoderungsgeshicht, Formultningsskiktet, see. nomcl.) and under this a more strongly decomposed humus layer (Humusstoffschicht, Homasamneskiktet). The whole mass reminds one very strikingly of the raw humus layer which we are accustomed to find in our old northern spruce forests. In the virgin forest of Kubani, therefore, the formation of mull is associated with the occurrence of beech. Where this is lacking there is a raw humus layer of the northern type. The significance of the beech in forming a favorable mull is definitely recognized in the silviculture of the domains of Count von Schwarzenberg. Beech equal to ten per cent of the stem count, is looked upon as sufficient in order to assure a good humus condition.

The Middle European forester has come to conceive the idea that under the virgin forest is found an ideal soil condition, and that it is therefore a forest type easy to reproduce. Compare L. Cermak (1910, p. 368), Engler (1904), Christ (1902), Schottler (1919 p. 335) and also the descriptions of Cajander (1903, 1904) of the vegetation of the virgin forests of the Lena River in Siberia.

In sharp contrast to these virgin forests in Middle Europe or Eastern Siberia, with good soil condition, are our Swedish virgin forests of pine and spruce. The dominant vegetation is moss and dwarf weeds, which can create a strong raw humus layer, especially in the climatically poorer sections, which hinders the development of the forest and makes reproduction more difficult. Climate and vegetation both contribute, so to speak, towards the formation of raw humus. In the virgin forest preserve Hamra, where the stand has never been disturbed by the axe, and where for a long time no fire has influenced the development, the raw humus layer is a decimeter (3.9 inches) thick, and as tough as in many a northern spruce forest unwisely handled on a selection basis. In the lower part of the Stor-Uman, where the spruce forest has in many places the character of a virgin forest, the raw humus layer often reaches a depth of as much as 40 cm. (15.6 inches) and renders difficult the reproduction of the forest to any great extent. (Compare fig. 74, p. 489).

In general a soil type with a raw humus layer and under it a leached layer (Bleicherde) and under it a rust-brown layer (Rosterde, Burnt Sienna) is normal for Swedish woods, while in Middle Europe this soil is regarded as a sign of the beginning of degeneration. Only where the soil is especially rich in easily available lime is the soil type different. The raw humus can, however, be of a very different character, depending not only upon the changing type of the mineral soil, but also upon the climate, mixture, age and treatment of the stand.

Section III.

The Influence of Silvicultural Treatment upon Soil Formation According to Middle European Conceptions.

Starting with the good soil condition which is believed to have been ensured by the virgin forest, German foresters have above all placed to the debit account of modern silviculture these facts: that the managed forest is often overcharged with raw humus formation, that the ground condition is often less good, and that reproduction is rendered more difficult. The reason for the superiority of the virgin forest over the planted forest is usually sought in the clear cutting system and in its - actually or ostensibly - unprofitable effect upon the soil. I am opposed to attributing the good condition of the virgin forests of Middle Europe to the fact that they contain a larger number of tree species, and among them hardwoods as a natural and constant part of the stand. The virgin forests from which people have drawn their observations as to the soil condition of the virgin forest have been mostly mixed forests, in which the hardwoods have played an important part; as the few remains of virgin forests in Hasli-Tal and Obwalden (Christ 1902), the virgin forest of Bialowics (in spite of the increase in the number of coniferous trees through the virgin area, cf. Lautenschlager 1917, pp. 88, 89), the Bosnian virgin forest (Cermak, 1910); there seem to occur here to a greater extent pure spruce forests with tall bilberry bushes. (Beck von Mannagetta 1901, p. 346). If hardwoods are lacking, raw humus is formed where climate and soil are such that a raw humus can exist, (Kubani, cf. with above). The lack of raw humus formation in the pure pine forests in Bialowics is to be attributed to the special climatic and soil conditions. The ground vegetation of these pine forests is composed of an array of plants fond of warmth and limestone (examples, p. 182 at the bottom and cf. also Graebner, 1918, p. 233). Therefore on a limestone soil and in a continental climate, the pure coniferous virgin forest can be free of raw humus.

Of more questionable significance for the soil condition are several other characteristics of the virgin forest: its uneven age, the continuous shading of the soil, characteristics which are also common to the selection (Plenter) forest. For these reasons selection cutting was considered by many German authors to insure a good soil condition in contrast to the similarly-aged, planted clear-cut forest (Kulturwald Kahlschlagbetrieb). In very few cases this conception is supported by well considered investigations, as for example, those of Ehrenberg (1922, pp. 74-92) and Burger (1922, pp. 72-218). Well known is the cessation of growth in Saxony, which in the last few years has occasioned tremendous discussion (cf. Deiche, 1912, Bernhard, 1914, Martin, 1920, Vater, 1920 and especially Wiedemann, 1923). As a remedy for the damage resulting from a one-sided silvicultural system the introduction of hardwoods, especially beech, is generally considered effective. The research-workers who look upon the clear-cutting system as detrimental to the soil, consider as the chief cause thereof the fact that it hardens the soil and causes it to lose its penetrability for air and water. Thereupon in the case of heavy rainfall, especially in winter, the water becomes stagnant and acids accumulate in the soil. This may result both in the destruction of the mull layer, and the formation of raw humus. With the formation of raw humus there ensues an increased leaching of the upper layers into the soil, which can lead to the establishment of a bleached layer (Bleicherde) and hardpan (Ortstein). Against this idea many serious objections have been raised by the foresters, for example, von Schwappach (1921) and Trebeljahr (1920, 1921), and on the botanical side by Kastner (1921) who conclusively argued that the clear-cutting itself caused raw humus formation. The opposite may be true at first, because the vegetation of the clear cut consists for the most part of plants which Kastner, in conjunction with Ramann (1911, p. 49) and P. E. Muller (1887, p. 49), regard as direct humus-destroyers.

According to Kastner, the formation of the raw humus might rather be a result of the character of the stand and of the special conditions of the plant detritus.

To sum up, it may be said that although raw humus sometimes exists the mull represents the normal forest soil type climatically determined in Middle Europe. It is an open question to what extent, through inexpedient silviculture, the latter more favorable form of humus can be changed into the former.

Section IV.

Research Methods.

1. DESCRIPTION OF THE LOCALITY. Since the whole experiment has a strongly ecological character, I have considered it expedient to characterize by a description of its vegetation the locality from which a given humus sample was taken. The plant detritus is the chief material from which humus is formed and for the most part determines its character. At the same time the humus layer influences the vegetation. There exists therefore between the vegetation and the plant material layer an intimate reciprocal effect, the examination and proper understanding of which is of great importance for rational silviculture. The classical example of such experimental work is P. E. Muller's studies of the natural forms of humus in the oak and beech forests of Denmark.

The descriptions of vegetation in Section XV form therefore an important part of the presentation of this treatise. To a great extent the statistical method of Raunkiaer has been used as an analytical method. The sample plots of 1/10 square meter were laid out by means of a simplified Raunkiaer (1918 p. 60) instrument fastened to a staff. In addition to frequency percentage the covering was also determined by the area percentage covered, which was done by dividing the individual sample plots into tenths. The division was made easier by the fixed graduations (co-ordinates on the instrument). In addition to this method that of Hult-Sernanders was often used in order to save time.

2. COLLECTION AND PRESERVATION OF THE SOIL SAMPLES. The soil samples were collected in clean linen sacks in which they were kept as far as possible at the same moisture content as in nature. As a rule a month more or less elapsed before they were studied. This circumstance is however of but slight importance, since the humus samples, while they were stored, changed their peculiar qualities very little or not at all. Thus, for example, the acidity changed very slowly, as the humus samples are very rich in buffer substances. Storage in tin boxes for one year altered the reaction value of the raw humus inappreciably.

3. INVESTIGATION OF THE ACIDITY AND ALKALINITY OF THE HUMUS LAYER. The apparatus used (cf. Fig. 2, p. 194) is that of Sorensen, with the exception that in place of the 0.1 N calomel electrode of Sorensen, there was used the saturated calomel electrode of Michaelis. In order to get the determined E. M. F. in millivolts converted into pH valves, the table of Ylppo (1917) was used. To complete the electrical circuit between the hydrogen electrode and the calomel electrode a saturated calcium chloride solution was used. The apparatus was checked now and then with a known standard solution (Sorensen, 1909, p. 38).

Often on account of the low content of electrolyte in the humus extract, it was necessary, in order to secure a sufficiently sharp determination, to raise the conductivity by the addition of a drop of a 1.0 N KCl solution for each 10 ml. of humus extract. Table 1, p. 195 shows that the pH was not changed to any appreciable extent by this addition. (N.B. Extract referred to below).

In addition to the actual pH of the expressed extract the potential acidity was also determined by electrical titration after Bjerrum and Gjaldbeck (1919). A quantity of the humus sample equivalent to 5.0 g. of the dried substance (at 98°C) was weighed out and puddled in 200 ml. 0.1 N KCl solution. This solution was allowed to remain standing for 24 hours and the titration was then made with 0.1 N NaOH and 0.1 N HCl. The titrating solution was added in portions of 1 ml., thoroughly stirred with a glass rod after each addition and the pH determined by the use of Hildebrand's electrode (Michaelis, 1914, p. 168). In this way, while the KCl solution reacted upon the whole sample, it caused a lowering of the acidity (pH), which substantiated the findings of Christensen and Jensen (1923).

The electrical titration shows the effect of the content of acid and alkaline buffer substances in the humus sample. If the acidity (the degree of reaction, pH) changes very slowly with the intermittent (gestafftlen = echelon) addition of the titration solution, the content of the corresponding buffer substances is high; with a rapid change in the degree of reaction (pH), the content of buffer substances is small. The titration with alkali shows the content of acid buffer substances, that with acid shows the content of alkaline (basic) buffers.

4. MOISTURE DETERMINATION. The necessary moisture determinations were made on approximately 15 cubic cm. samples. They were dried out at a temperature between 95 and 98°C.

5. HUMUS DETERMINATIONS. The humus content was mostly determined by the ignition of samples dried at 98°C. For these determinations 5-20 g. samples were used. Mull soils which were poor in humus were burned in an ignition tube, the Co_2 which was formed was collected by Vesterberg's method, the amount determined, and from it the amount of humus determined by multiplying by the factor 0.471 (cf. Tamm, 1917, pp. 252, 253).

6. LIME DETERMINATION. The lime determination is of especial interest because of the relation between lime content and pH. The greatest importance is attached to the easily dissolved so-called assimilable (assimilerbare) lime. In order to determine the amount I used the method of absorption displacement with chlor-ammonium solution. In the tables are given the values determined as Ca^{O}ass. For these determinations were used 12.5 or 25.0 g. samples, which were extracted with 150 or 250 ml. samples of 10% chlor-ammonium solution, in some cases also with 350 ml., when — with raw humus samples — it was necessary in order to secure an amount of solution which could be filtered. The extract was placed in the waterbath and remained there for three hours. The lime was precipitated as oxalate and either gravimetrically determined as CaO or titrated.

The lime content given as CaO_{tot} was obtained by extractions of the ash with 10% HCl.

7. NITROGEN DETERMINATION. The total nitrogen determination (N_{tot} in the tables) was determined by Kjeldahl's method, reducing the saltpeter with phenol (see Svensk Fortfattningssamling 1906, Bih. (vol. 37, Sec. 17h*). For each determination approximately one gram of soil was used.

8. AMMONIA DETERMINATION. The determination of ammonia in the soil sample is difficult, since in the first place the ammonia is strongly absorbed and secondly destruction products and NH_3 are evolved from the albumins or their destruction products by the stronger agencies which are necessary for freeing the absorbed ammonia. Since the suggested complicated methods of avoiding these difficulties give, according to the view of Barthel and Bengtsson (1918, p. 354-58), no better results than the earlier and simpler methods, I have used only the methods of Boussingault and Schlosing.

For the determination a 10 g. sample was used. The sample was shaken for an hour with 100 ml. 0.1 N HCl, the filtrate boiled with MgO, the freed ammonia caught in an 0.1 N sulphuric acid solution and its amount determined by titration with 0.1 N sodium hydroxide. Duplicate determinations in general gave me good checks.

The adaptability of the method of removing from the soil the absorbed ammonia I attempted to investigate in the same manner as Bartel and Bengtsson (1918, 1924) and others by adding to the soil an ammonia salt and then determining how much of the added ammonia could be recovered by the analysis. Table 2, p. 202 shows that one must always count upon a loss of ammonia. In general this loss amounts to several per cent; in one case it was greater than 10%. In spite of this the method appeared adequate for my purpose; since the method was utilized in a similar investigation, and particularly in one dealing with the possibilities of ammonia formation. In this experiment the ammonia content before and after the storage (three months in an Erlenmeyer flask at room temperature) was determined by this same method. From the results of this method will be drawn conclusions concerning only large differences in the possibilities of ammonia formation.

9. SALTPETER DETERMINATION. The saltpeter content of the soil was determined colorimetrically after Grandval, Lajoux, and Reitmair (Consult Hesselmann 1917, p. 323). The discoloration of the humus extract by soluble humus material could always be overcome through the aid of milk of lime. At the same time several drops of $KMnO_4$ were added. As was the case with ammoniac nitrogen, these studies are also of value for demonstrating the speed of formation by saltpeter determinations made in the described manner before and after three months storage. For a description of the method see Hesselman 1917, p.p. 321-323.

The lack of nitrifying ability may be accounted for by the absence of nitrification organisms, lack of necessary materials for the process or the organisms which accomplish it, or the unfavorable chemical constitution of the nitrogeneous raw materials. In order to test these different possibilities, studies were made with the introduction partly of nitrification organisms, partly of various materials, and partly of both at the same time. The nitrifying organisms were not only added as pure cultures, but also inoculation material was used from a strongly nitrifying humus from a clear-cutting in Jonakers "haradsallmanning" in the province of Sodermanland. The nitrifying ability of the inoculation earth was determined individually at the beginning of each series, so that the corresponding nitrifying value could be subtracted from the value found in the test with the inoculated earth. The ratio between inoculum and the inoculated earth was in general 1:9, calculated by weight.

10. THE PRESENTATION OF THE ANALYTICAL RESULTS. The analytical data are calculated partly on the dry weight (defined above) of the soil sample, partly on the humus content. The first values are called "direct," the second "calculated."

The contents of ammoniacal and nitrate nitrogen are given in mg. nitrogen per kg. of the dry material of the soil sample, and per kg. of humus, respectively.

The various percentages of the total nitrogen which are presented as ammoniacal or nitrate nitrogen are called the ammoniacal or nitrate coefficients respectively.

The following designations are used in the tables giving the analyses.

Total Nitrogen	(cf. 7. above)	Totalstickstoff	N_{tot}
Available Lime	(cf. 6)	Assimilerbarer Kalk	CaO_{ass}
Total Lime	(cf. 6)	Totaler Kalkgehalt	CaO_{ass}
Ammoniacal Nitrogen	(cf. 8)	Ammoniakstickstoff	Am-N
Nitrate Nitrogen	(cf. 9)	Saltpeterstickstoff	S-N
NO_s-N. after inoculation	(cf. 9)	D:o nach Infektion	S-N_{inf}
Ammoniacal Coefficient		Ammoniakoefficient	Am-N_{koe}
NO_3 Nitrogen Coefficient		Saltpeter koefficient	S-N_{koe}
Inoculation earth		Infektionserde	Inf.jord
3 Months Storage	(cf.8 and 9)	3 Monate aufbewahrt	3 mån. lagr.
Loss by Ignition		Gluhverlust	Glodf.
Per cent on Dry Weight of soil sample			dir.
Per cent on Humus Weight of sample			omr.

Section V. Nomenclature.

Since the translation of terminology is frequently difficult, in the following review the Swedish term is given, and only occasionally the German translation in parenthesis. The nomenclature used by me accords for the most part, but not wholly, with the decisions of a committee which deliberated on the occasion of the Northern Agricultural Congress in Gothenburg in 1923.

Jord (Boden)	Soil	A loose mass of mixed organic or inorganic particles which has been formed on the earth's surface.
	(Antonym	(Gestein) Blocks of stone, boulders).
Jordart		Geological bed with loose structure.
	(Antonym	(Gestein) Rocks.
Jordmån		The part of the earth's crust which thru the direct and indirect operation of the climate has been so altered that it can be distinguished chemically and physically from the underlying rock. In the indirect operation of climate that of vegetation is to be considered before all others.
Mark		The part of a rock or soil formation in the earth's crust adjoining directly the atmosphere or hydrosphere of which vegetation does or can form a constituent.

Forna Litter	The unaltered total dead remains or detritus of the plant or animal kingdom.
Humus Humus	The sum total of the organic remains of plants and animals which have become a part of the soil and have been there subjected to alteration processes.
Humussamnen (Humusstoffe) Humus materials	Yellow to dark brown materials (of unknown constitution) which result from the breaking down of organic substances (in nature or in the laboratory). They have a great affinity with water and show a marked swelling if they are not dissolved or dispersed in the water. The water absorbed can only be partly lost by evaporation. (See especially Oden, 1919).
Humussyror Humussauren Humic Acids	Humus materials which liberate hydrogen ions and with strong bases form salts also giving rise to water.
Humuslagret Humus level Humusschicht Humusstacket Humusdecke	The more or less loose layer in the upper part of the soil profile which contains humus in such quantities that this in the final analysis determines its character.
Formultningsskiktet Vermoderungschicht Duff(horizon)	The layer in the humus-covering which consists for the most part of plant remains in the process of decomposition.
Humusamneskiktet (Humussoffschicht) Humus horizon	The layer of the humus covering in which the humus consists principally of completely disintegrated amorphous humus materials. In distinguishing mold (Mull), moor (Mor), and raw humus (Rohhumus) profiles one is concerned with the two horizons mentioned (the duff (Formultningskiktet) and the humus (Humusamneskiktet). I have found no grounds for distinguishing between rotting (Verwesung) and decomposition (Verfaulen) in Mull, Mor and Rohhumus. In the tables the duff horizon is designated by F, and the humus horizon by H.
Rahumus (Rohhumus) Raw Humus	The feltlike humus covering woven through with fungal hyphae, mycelial threads, or higher plants (e.g. dwarf bushes), which can be clearly distinguished from the mineral earth. The duff horizon is frequently thick, and always felt-like, the humus horizon is only to a small extent mixed with the mineral earth.

Mar	Mor	Moor	(After the Danish Mor, frequently so called in the text). Lighter humus layer only slightly interwoven by funga hyphae. The duff horizon is thin and always of rather light structure, the humus horizon is ordinarily thin and only to a small extent mixed with mineral earth.
Mull	Mull	Mold	Humus layer of a definite crumb structure, duff horizon mostly thin, alway light and often crumby, the humus horizon varying in thickness, always crumby and more or less mixed with mineral earth.

Section VI. The Geographical Distribution of the Experimental Material.

See the map, Fig. 3, p. 209, and the review p.p. 210-211.

Section VII. The pH Reaction of the Humus Layers of Different Forest Types, and their Dependence upon the Composition of the Stand.

1. THE REACTION OF THE DIFFERENT LAYERS OF THE SOIL PROFILE.

As in all soil science investigations, so here, it is very necessary to differentiate between the various layers that can be distinguished in every natural soil. Characteristic divergences in the reaction between different horizons in the soil profile have been shown to exist. Thus in the humus covering the duff horizon has usually shown a higher reaction value (more alkaline, pH = larger) than the humus horizon, (cf. Table in text, p. 212). That is, the top horizon in the humus layer of the coniferous woods is usually less acid than the lower. Apparently this holds true in the mixed stands also, altho the difference given in the table cited is entirely untrustworthy. This rule holds good as well for the planted forest of the Schwarzwald (spruce Picea excelsa) and (Abies alba) as for the spruce, pine, and mixed forests of central Sweden and Noreland.

The mineral soil under the humus covering has a different reaction value from these (cf. Table, p. 213). The typical condition in a normal podsol profile is that the humus horizon is the most acid of all horizons, and that it (the acidity) diminishes from this upwards to the duff horizon, as well as downwards to the mineral earth. In the mineral earth the acidity decreases downwards from layer to layer so that the bottom has almost a neutral reaction. Deviations from these rules seem to be correlated with water seeping through from higher levels and with the admixture of broad-leaf trees in the stand (by means of which the pH value of the humus covering is raised.) Reproduction areas are also often exceptions.

2. THE REACTION OF THE HUMUS LAYER IN DIFFERENT FOREST TYPES.

The principal material available from the pH determinations of the humus layers is summarized in Table 3, p.p. 216-219, arranged according to forest types. Each vertical stroke is a tally indicating a determination. The table also gives directly the frequency distribution of the pH values in the various horizons found in a given forest type. Determinations in reproduction areas are denoted by a star instead of a tally stroke. The experimental limits of the forest type agree with those used by Malmstrom (1926). The Swedish terms in the table are explained in the tables on pages 332-342. Since all the data is in the tables, a condensed abstract will be given of the Swedish text, more complete only where Middle European localities are concerned. PINE HEATH. pH 3.5 - 4.3; characteristic value about 4. Lowest value 3.6-3.7 in Barenthoren, in some parts of fairly productive heaths of Vasterbotten (North Sweden) near Vindeln, and a very poor heath with raw humus formed by Calluna in Alvadalen (Dalecarlia). Manuring with brushwood (Barenthoren), (northern heaths) appears to have a certain, though meagre influence, a high percentage of birch can raise the pH to 4.4 without changing the soil vegetation appreciably (Fagerheden, Norrbotten.) SPRUCE FOREST OF VACCINIUM TYPE WITH MUCH MOSS. This type borders upon the type rich in herbs. Humus layer in Scandinavia generally of the raw humus type. Variation in acidity 3.6 to 4.4, generally 3.9 to 4.0. In a smaller pure stand of spruce in the Kubani forest (Bohmerwald) with a pronounced raw humus a pH of 4.1 was found, in other words almost exactly like the northern spruce stands found on soils poor in lime.

CONIFEROUS FORESTS WITH PURE MOSS COVER OR WITHOUT LIVING GROUND COVER.

A division of such forests into types characterized by dwarf bushes and one characterized by herbs, although these characteristic plants are absent, appears to me to be incorrect and impossible. The planted forests of middle Europe often belong to this type as well as the well cultivated spruce forests in the region Calmach and Langenbrand (Schwarzwald). The humus layer is loose, little or not at all matted together by fungal hyphae (Moorlike) (refer above to section 5). Distinct duff and humus layers, the first with pH 3.8, the second 3.6. Like values (3.9 in both layers) in the so-called virgin forest Fiby in Uppland (Middle Sweden), considerably higher in other Swedish forests. The pure fir forests found on the New Red Sandstone in the Schwarzwald approach the pure spruce stand. In two stands investigated with loose humus layers the duff layers gave me pH values of 3.7 and 4.1 respectively, the humus layer 3.6 and 4.0 respectively. CONIFEROUS FORESTS WITH ABUNDANT MOSS COVER, DWARF BUSHES, AND HERBS. The boundary of this type is not distinct from that of the above types rich in dwarf bushes, (the spruce forest with Vaccinium?) and is determined by the frequency and percentage area covered by the characteristic plants. Several subtypes will be distinguished in the following material: I. Fir and mixed coniferous forest rich in dwarf bushes with low herbs, as for example, Oxalis acetseli, Dryopteris Linnaeana, Anemone nemorosa. This subtype can be compared best to the Oxalis-type of Cajander. I have distinguished two further sub-types: Ia. The Dryopteris type characterized by plants such as Oxalis acetosella, Dryopteris Linnaeana, Anemone nemorosa, and an abundance of Maianthemum bifolium, Trientalis europea, etc. Ib. The Hepatica type characterized by Anemone hepatica, and other plants requiring mull such as Fragaria vesca, Lathryus vernus, Veronica officinalis, Vicia sepium. 2. Fir and mixed coniferous forest rich in dwarf bushes with tall herbs, for example Geranium silvaticum, Mulgedium alpinum, Aconitum septrionale. Also this type can appropriately be divided into two subtypes: The one larger in area and apparently less exacting characterized by Geranium silvaticum, ferns such as Athyrium Felix femina, Drypoteris spinulosa, and austriaca, in the north, Mulgedium alpinum; and the other more exacting type with Aconitum septrionale and the above named plants in high, elevated localities. The last type reaches its highest development in Silurian Jamtland. The humus layer is often mull-like, the moss layer loose and, in parts at least, composed of mull-requiring species. The types rich in herbs are favored by the seepage of water, and this fact determines the nature of the habitat. The enriching of the soil cover by the increase of weeds is in the northern coniferous forest accompanied by a change in acidity in an alkaline direction. The determinations for the Dryopteris type lay around 4.4, those for the Hepatica type in Siljansfors around 5.0. In the regions rich in lime still higher values were obtained up to 6.9.---

THE PINE FORESTS RICH IN HERBS is, at least in Sweden, commonly found principally on soils strongly enriched by lime. In Barenthoren on ground manured by faggots years before appear such types, in which in addition to the heath are met herbs such as Galium rotundifolium, Fragaria vesca, Dactylis glomerata, Filipendula hexapetala. The pH values obtained, 4.1 and 4.3, show a change of approximately 0.6 in the alkaline direction as compared with those of adjacent pine stands influenced by the removal of the litter. In the Swedish pine forests enriched by herbs which appear upon soils rich in lime, pH values up to 7.9 were found.

PURE CONIFEROUS FORESTS RICH IN HERBS, WITHOUT LOW SHRUBS, were seldom the object of my investigations; among these, was a highly productive fir stand in the Schwarzwald with a well-characterized mold (Mull) humus layer and a pH of 4.0 and therefore distinctly acid, but nevertheless a less highly acid humus than in the stands without herbs in the Schwarzwald. - - - BROAD LEAVED TREES ADMIXED WITH CONIFEROUS FORESTS generally influence very distinctly the degree of acidity of the humus layer, as has already been said. Under the crown of a windblown though still living alder in Kulbacksliden (Vasterbotten) the humus layer has a pH of 5.0, outside of the crown projection the pH is 4.0. In the coniferous forests of middle Europe the admixture of beech produces often, though not always, the formation of mold (Mull) and is generally accompanied by a change in the pH in an alkaline direction. In the coniferous forests of Schwarzwald with a pH 3.6 to 3.8 a small admixture of beech in the older stands may not have a very distinct influence, as for example in a mixed stand on the Hengstberg at Calmbach. Other coniferous forests with beech mixtures show, on the other hand, a distinct change in an alkaline direction as for example on the Hirschkopf in the region Langenbrand where the pH is 4.8. In the Kubani forest the raw humus of the parts of the forest which are pure coniferous have a pH of 4.1, the mull with a part mixture of beech has a pH of 4.2 to 4.5. A mixture of larch can have a like influence and result in a mull with pH 4.7. In Barenthoren a mixture of oak in a pine forest leads to a "Mull" humus with a pH of 4.7, instead of 3.6 found in the pure pine forests. The beech has had a transforming influence; under the planted beeches there is sometimes found a mold (Mull) of 4.3, sometimes a beech-turf with pH 3.5 to 3.8. More significant is the influence of an admixture of hardwoods into the northern coniferous forests. --- COPPICE HOLLOWS. Here the influence of the movement of water and the admixture of hardwoods are supplementary, and a characteristic mull humus with continuous nitrification results, which is less acid than the humus of the surrounding stands. --- HARDWOOD FORESTS in the ordinary sense lie outside the scope of the investigation. Only random determinations from some Swedish alder and oak forests are given, pH 4.9 to 7.9. --- REGENERATION AREAS. The alterations in the conditions in the soil produced in areas opened up for reproduction have already been dealt with by me before (1917 b.) Generally there is a change in the pH in the alkaline direction. Compare Sec. XIII and Table 38, p.p. 332-343.

The results can be summarized as follows: Upon soils built from rocks poor in lime (gneiss, granite, porphyry, and sandstones deficient in lime the humus layer of the coniferous forests has an outstandingly acid reaction. Where water does not seep through a soil from the surrounding country, and where the soil cover is composed largely of dwarf plants and moss the pH value of the Humus cover varies between the rather narrow limits of 3.6 and 4.3. The upper horizon of the humus cover, the duff horizon, is slightly less acid than the lower, the humus horizon. A thin loose easily decomposed humus horizon can have the same pH as, or in fact a lower pH (i.e. be more acid) than a thick, tough layer, unhealthful to the forest (Schwarzwald, Lappland.) Where the water seeps through the soil from the surrounding country the living soil cover is more or less rich in herbs, and the acidity is moved in an alkaline direction (Dryopteris-type, approximately 4.4, Hepatica-type, approximately 5.0). The admixture of hardwoods in coniferous stands (birch, aspen, alder, willow, mountain ash, oak, beech) generally effect a change of the pH in the alkaline direction, the extent of which depends among other things upon the amount of the leaf fall. In areas rich in lime the pH value is greater (more alkaline condition), though the reaction of the humus cover of the coniferous forests in such places is generally acid. Opening of the stand through cuttings for reproduction produces in the coniferous forests a change in the pH in the alkaline direction. The "Mull" of hardwood forests can show a distinct acid reaction, whereas in regions rich in lime the reaction can be neutral and even weakly.

3. REVIEW OF PREVIOUS INVESTIGATIONS INTO THE ACIDITY OF FOREST SOILS.

A review of the literature shows that my conclusions above agree with those of other investigators: the maximum acidity in the humus layer (Salisbury); the corresponding determinations of the greater acidity in the coniferous forest humus as compared with that found in the hardwood forest humus (Raunkiaer); the lowering of the acidity through the admixture of hardwoods (Nemec and Kvapil); the discovery of an acid reaction upon the lime soil (Chodat, Salisbury) although the lime content influences the acid reaction (Adamson), slight variations in the pH of coniferous forest humus on soils poor in lime and not leached by water, in spite of large variations in the structure of the humus covering; the change of the acid reaction through the opening of the stand (Olsen, 1921, p. 84, Raunkiaer, 1922, p.p. 52-54, Nemec and Kvapil; by analogy - soils upon which grass grows are less acid than forest soils Chodat, Raunkiaer.)

The acidity of the forest soils appears therefore to be an important factor, nevertheless it is by no means always of outstanding importance. "Mull" and raw humus can have the same pH, and a good highly productive beech forest soil can be distinctly acid (pH approximately 4.0). Such acidity is consequently of itself no hindrance to good production or to a healthy condition of the soil; on the contrary, for many highly productive soils it is characteristic. A change in acidity in an alkaline direction is nevertheless in general favorable, although a marked acid reaction, as has been observed, has a detrimental effect, not in itself, but in conjunction with other factors.

Section VIII. THE DEPENDENCE OF ACIDITY UPON HUMUS AND LIME CONTENT.

The correlations obtained from the material are easily seen from Fig. 4 - 12, p.p. 234-242. The values which form the basis of the figures are contained in tables 4-7, p.p. 243-246.

In assembling a large amount of material from various forest types and various localities, as the figures show, these conclusions follow. In general, the acidity increases with decrease in humus content. The relationship is nevertheless not marked, and with respect to the large variations, indeterminate. The alkalinity increases also with the content of available lime. In contrast to the previous conclusion, although here also the variations in the same region are large, the relationship is strongly marked.

Section IX. INVESTIGATIONS OF THE INITIAL MATERIALS OF HUMUS FORMATION. (der Forna, Litter).

The research material consists of the autumnal yellowed leaves, about to fall, or even fallen. They had therefore undergone the usual autumnal changes on the mother plant, although they had not been subjected to any one of the decomposing processes taking place in the soil. Only the moss material consisted of branches still green, because in nature the mosses after withering are almost immediately taken possession of by fungi. The ash content, the lime (calcium oxide) content, the acidity of a water extract of the pulverized substance, the content of acid and basic buffer substances (obtained through electrical titration of a concoction of pulverized leaf in KCl solution) were determined. In order to get comparable values from the pH determinations and the electrometric titrations, the same proportions were used between dry substance and water and dry substance and KCl solution respectively as in the corresponding humus tests.

1. REACTION AND LIME CONTENT OF VARIOUS KINDS OF LITTER.

The analytical results are assembled in table 8, p.p. 250-251. The correlations between the available lime content and pH obtainable from the material are given in the grouped Table 11, p. 263 and the corresponding graphs Figures 13 and 14, p. 249. Table 8 shows that characteristic differences exist between various plants and groups of plants. Distinctly acid is the litter (needles) of coniferous trees and that of the dwarf shrubs; somewhat less acid were the moss materials examined, while the litter of the broadleaf trees and the herbs had in general a reaction which lay significantly nearer the neutral point. Two kinds, maple and Geranium silvaticum, were notable exceptions. On the other hand the reaction of one and the same litter from even the same collecting place can vary, in the case of birch between 5.3 and 6.1, in the case of beech 5.3 to 6.6. The litter from a region rich in lime may be less acid than the corresponding litter from a region poor in lime; nevertheless the acidity value of a litter material appears to be aspecific characteristic of the plants concerned.

2. THE CONTENT OF ACID AND BASIC BUFFERS OF VARIOUS TYPES OF LITTER MATERIAL.

The analytical data are collected in Tables 12-15, p.p. 263-266, and in Figures 15-20, p.p. 253-257. For comparison are given in Table 16, p. 266 the results of an electrometric titration of a pure KCl solution. The titration curves corresponding to these values are shown in Figs. 15-20 as smooth, gently-rounding curves without special characteristics. From the results we can profitably distinguish between five different types;

1. A high content of acid and a low content of basic buffers. To this belongs the litter of our conifers, also that of the juniper forest as well as of several dwarf weeds (Calluna, Empetrum, Vaccinium

idaea and the forest mosses (*Hylocomia*). 2. A very high content of acid and a fairly high content of basic buffers. To this belongs the litter of most of our broadleaf trees, birch, alder, aspen, willow (*Salix caprea*), also beech and ash, as well as a number of herbs, especially those which are characteristic of our coniferous forest; 3. With a very small content of acid and a large content of basic buffers. To this belongs the hazel and especially the elm litter, as well as that of *Mulgedium alpinum* and *Stachys silvatica*; 4. With a high content in acid and at the same time a high content in basic buffers. This is a heterogeneous group to which belong, among the kinds of litter investigated, that of maple, *Geranium silvaticum*, oak and larch; 5. With an especially low content of buffers - *Deschampsia flexuosa*. The content of buffers, like acidity, varies with the locality (Fig. 20, p. 257); nevertheless the individual peculiarity of a litter may generally be considered a specific character.

Thus the initial material for humus formation in coniferous forests has an acid character. The actual acidity of the litter of the coniferous forests (spruce and pine forests) the dwarf bushes and also (approximately) the mosses in the coniferous forests, has a value approximating that of the humus covering (around pH 4.) In addition, the content of acid buffers is large. The litter from the hardwood trees and the herbs differs through a lower acidity and a smaller acid, but larger basic buffer content.

3. THE NATURE OF THE BUFFER SUBSTANCES.

The method used for the determination of the degree of humification (Humifizierungsgrades) of peat (leaching with NaOH or NH_4OH and comparison of the color of the extract with a standard solution of "humic acids" or "synthetic humus" from pyragallol, cf. Oden 1919, Melin and Oden 1916 and 1920) showed experimentally a surprising content of "humus substances" (Humusstoffen) in the litter which are the initial materials of humus formation (Table 9, p. 259, the determination for peat may be compared, Table 10, p. 261). The content of "humus materials" so determined shows however no relation to the pH value or to the content of acid buffers. Other acid substances must therefore be thought of. The nature of these must remain for the present uncertain. Oxalic acid, other organic acids, tanning materials may be considered. Among the basic buffer materials lime may play an important role. Apparently in rotting leaves one must also reckon upon the presence of ampholytes, which according to the conditions can act as acid or basic buffers.

Section X. THE CONTENT OF ACID AND BASIC BUFFERS IN THE HUMUS LAYER, AND THEIR DEPENDENCE UPON THE PECULIARITIES OF THE LITTER, OF THE DEGREE OF DECOMPOSITION AND OTHER FACTORS.

The extracts of humus are very poor in buffers, as the titration curves show, Figures 21 and 22, p.p. 268-9. The extracts were prepared by leaching a 10g. sample with 100 ml. 1.0 N HCl. The extract, as shown by the titration curve, consists of a weak solution of a rather strongly dissociated acid.

Wholly different titration curves were obtained when, instead of a filtered solution, an unfiltered concoction of the humus was investigated. Such curves are presented in Fig. 23-36, p.p. 270-284. The data for the curves are found in Tables 13-28, p.p. 289-295.

A review of the material shows next that the titration curves of the humus layer of the coniferous forest on soils poor in lime, especially that of the duff horizon, strongly resemble those of the corresponding debris (spruce, pine, moss).

The differences between the various samples which results have proved to be as follows;

The duff horizon of a raw humus layer, when treated with a KCl solution generally shows a smaller change of the reaction (pH) toward the acid direction than the humus horizon treated in the same way. The first horizon is also generally or with few exceptions richer in alkaline or basic buffer substances than the second horizon. The content of acid buffer substances is variable (see below).

The kinds of raw humus which were collected are differentiated through characteristic contents of acid buffers. Many are also rich in alkaline buffer substances. From the forestry viewpoint the favorable kinds of raw humus are distinguished from the unfavorable by the higher content of alkaline buffer substances. The content of acid substances varies in such an irregular manner that it is of less significance from this viewpoint.

Of great influence on the content of buffer substances is the nature of the debris, as has already been shown by the similiarity of the titration curves of the duff layer and the most important kinds of debris of the coniferous forests. An admixture of deciduous litter in the raw humus layer has at least in the majority of cases resulted in an increase of alkaline buffer substances, and a decrease in the content of acid buffers.

Distinct "Mull" forms with small humus content (little loss on ignition) are indicated by insignificant content of acid buffers as well as basic buffers. "Mull" forms with high humus content are often, though not always, (see below), rich in basic buffers.

The discussion therefore indicates that the process of humus formation is essentially a continuation and an intensification of the process which is already taking place in the dead plant remains, though it must also be conceded that the admixture of mineral earth can lead the process in other directions. A comparison of samples with the same loss through ignition shows that while "Humification" increases the content of acid buffers, the content of basic buffer substances decreases. Generally however the ignition-loss of the humus horizon is smaller than that of the duff horizon, as is its content of acid buffer substances.

The decrease is greater than would correspond to the admixture of mineral earth. In spite of this diminution in acid substances, the humus horizon gives, as has already been indicated, an acid water extract, and especially with KCl a more acid solution than the duff horizon. A more exact analysis of the chemical differences which would explain this lies outside the scope of this work. Table 17, p. 287 shows that the content of acid substances is not parallel with the colorimetrically determined content of alkali-soluble humus materials (Humusstoffen). Important, and one to be reckoned with, is the role played by basic buffer substances, the amount of which, as has already been pointed out, in raw humus parallels the good condition of the soil. The conclusion is that they, among others, are necessary to neutralize the simultaneous acidification which accompanies the process. It is noteworthy also that I never found a lower pH value than 3.5. This appears to be the extreme limit below which humification ceases. The value of the limiting pH nevertheless varies very much according to the climate. With a pH of approximately 4, in a favorable climate, mull can be formed, while in north Sweden such is only met with in the true raw humus (see Section 7). The same is also true for the content of basic substances. The humus samples collected in the Schwarzwald and in Barenthoren, in comparison with the better north Swedish humus forms, are poor in basic substances but show nevertheless a fairly rapid decomposition.

Striking is the small content of buffer substances in the "Mull"-forms. This is also characteristic of certain mull-forms rich in humus, like that from Hemson (Angermanland, North Sweden, Fig. 33, Table 24), with an ignition of approximately 90%. This seems to indicate that the chemistry of "Mull" formation is in many cases entirely different from raw humus building.

The distinguishing peculiarities of the humus which have just been discussed appear most markedly after changes in the soil climate through the opening up of the stand. Further discussion of this point follows in later sections (Sections 13 - 14).

Section XI. THE NITROGEN CONTENT AND NITROGEN TRANSFORMATION IN THE UNDECOMPOSED FOREST LITTER (THE DETRITUS).

1. NITROGEN CONTENT OF THE DETRITUS. The qualities of organic nitrogen contained in the detritus probably play an important role in the nitrogen balance in the humus layers, although it is hard to judge the relative importance of these quantities of nitrogen, as compared with the nitrogen fixation of nitrogen assimilating organisms whose activity was first clearly demonstrated by Henry (1897). The text tables, p.p. 296-297, which show the total content of nitrogen in various forms of detritus, give an idea of the amounts of nitrogen introduced into the soil by the detritus. For comparison, two analyses were made of fresh needles of pine and spruce which were collected in the winter. It is noteworthy that of the various forms of tree litter the alder is richest in nitrogen, possibly because of the ability of the alder to fix nitrogen.

2. TRANSFORMATIONS OF NITROGEN IN THE DETRITUS. To investigate this question the litter samples obtained were air dried, pulverized, mixed with inoculation earth, moistened and placed in Erlenmeyer flasks. For one part of the inoculation earth humus from the clear-cutting at Jonaker was used; for a second, a strongly nitrified mull from the Dalby coppice in Schonen, and for a third, a strongly ammonifying raw humus from Kulbackslidden in Vasterbotten. The humus from the clear-cutting at Jonaker was used for the corresponding humus study (see above Section IV). The mixture of pulverized detritus and inoculation earth was in the ratio of 9:1, as was the case in the investigation of humus already referred to, but in another the ratio was 1:9. The quantities of ammoniac and nitrate nitrogen obtained after a three months storage are given in Table 29, p. 300. The first column of the table contains amounts of ammonic nitrogen found in the litter at the beginning before storage; this determination was not made in all cases. The third column shows the experimental results, using the ratio: nine parts of pulverized detritus and one part inoculation earth, the fourth column, the experimental results with nine parts of inoculation earth and one part of detritus material. The bracketed figures in these columns give the amounts of nitrate nitrogen which must have been formed, as calculated from controls run on inoculation earth alone in the absence of litter material.

It follows accordingly that in general the ammoniac formation as well as nitrate nitrogen formation are depressed to a minimum by the addition of detritus material. It appears that in addition the ammoniacal nitrogen present in the material at the beginning is used up either completely or until but a small quantity remains. Only certain forms of detritus rich in nitrogen (with about 2% nitrogen) are exceptions to this rule.

The lowering of the nitrification can be caused by the activity of the denitrifying agents which live on the carbohydrates of the litter. Filter paper has a similar effect as litter material on the nitrification when added to a nitrifying earth in ratio of 1:9 (Text table p. 299). The absorption of the ammoniac nitrogen cannot however be cleared up in this way. I agree with an investigation of Waksman (1924), that the amount of nitrogen found is fixed in the microorganisms which develop.

Section XII. THE NITROGEN CONTENT OF THE HUMUS COVERING.

In general the content lies between rather narrow boundaries, 1.5 to about 3.0%. The extreme limits found were 0.6% and 4.3%. But the nitrogen content of the humus is on an average generally greater than that of the detritus, and in the various soil samples on the average it is the greater, the smaller the ignition loss of the sample. (Table 30, p. 304, Fig. 37, p. 302). Both are foreseen as automatic results of the progressive "humification" process, in case this consists first in the oxidation of the carbohydrates and other materials free from nitrogen. In a comparison of the duff and the humus horizons, there was found, however, only in the "Mull" humus profile whose initial material consists to a larger extent of deciduous leaves, an average higher content of nitrogen in the humus layer (the average difference in eleven cases was 0.4%). For the raw humus tests was found an average difference in a diminished direction of 0.007% (average of 27 cases); there exists then no average difference in the same direction as in the case of the "Mull", rather the opposite, especially in the pure coniferous forests. Besides a relative resistance of the nitrogenous materials to decomposition, the nitrogen content of the "Mull" can be attributed to nitrogen fixation, which is lacking or weak in the raw humus profile.

Because of the relations between pH and ignition loss on the one hand, nitrogen content and ignition loss on the other hand, there was to be anticipated a relation between pH and nitrogen content, which as a matter of fact exists (Fig. 38, p. 303, Table 31, p.p. 305-306). On the whole therefore, the nitrogen content of the humus rises with a rising pH.

Section XIII. TRANSFORMATION OF THE NITROGEN (Ammonia and nitrate Formation) IN THE HUMUS LAYER AND THE FACTORS INFLUENCING IT.

In the raw humus layer of the coniferous forest, as I have previously shown (1917), the destruction of the nitrogen groupings proceeds only as far as the formation of ammonia, while in the "Mull" soils in general a nitrification of the ammonia thus formed takes place (compare among others Gaarder and Hagem 1921, Carsten Olsen, 1921). The factors affecting the speed of decomposition are of many kinds, as pH, content in buffer materials, and available calcium, the nature of the nitrogenous material, climate, soil temperature, and soil moisture. The composition and density of the stand, and so on, also have an effect in a complicated manner.

1. NITROGEN TRANSFORMATION AND REACTION (pH). All the material from the tests for which the total nitrogen content was determined so that from the storage experiments the ammonia and nitrate coefficients (cf. Sec. Vi) could be calculated, is assembled in Table 32, p.p. 312-315, arranged according to pH groups. The coefficients obtained are grouped in the detailed summary in classes separated by 0.1 of a pH unit. The values within a pH group in the same horizontal row are from the same sample. It will be seen that the samples are arranged within the pH groups according to the rising values of the ammonia coefficient. In the summarizing review, p. 315, at the bottom, the same material is arranged in groups of 0.5 of a pH unit, the bracketed figures giving the number of determinations on which the average values of the coefficients are based. The result of the last summary is also given again graphically in Fig. 39, p. 309.

Table 33, p. 316 contains the summary of the quantities of ammoniacal and nitrate nitrogen per kg. of humus respectively found in the storage experiments grouped according to pH, and not therefore given as in the previous table, in total nitrogen. Here the whole material can easily be seen, also the samples for which total nitrogen has been determined. The material was divided into two groups, namely the samples which came from the Research Forest at Siljanfors (the upper row of figures) and the others. The bracketed figures are the totals of the determinations in both groups; the figures above are the averages. The values in the table are also represented graphically in Figs. 40 and 41, p.p. 310-311.

The summaries show that in individual cases no definite relation exists between pH and nitrogen transformation, but that the total material arranged in rather large pH groups shows a very beautiful and regular correlation between the pH values and nitrogen transformation, with an optimum for ammonia formation between 4.5 and 5.0, for nitrate formation by inoculation between 5.5 and 6.0, and for nitrate formation without innoculation above 6.0.

2. NITROGEN TRANSFORMATION AND CONTENT OF AVAILABLE LIME. On account of the relation between CaO_{ass} and pH on the one hand, and on account of the relation between nitrogen transformation and pH (the previous subsection 1) on the other hand, a relation between CaO_{ass} and nitrogen transformation was expected. However, as Table 34, p. 317 shows, it is weak with the exception of the total nitrogen formation after inoculation, which shows an optimum in the group with lime content of between 2.0 and 2.5%.

3. COMPARISON OF THE NITROGEN TRANSFORMATIONS IN THE DUFF AND THE HUMUS HORIZONS. The material is summarized in tables 35-37, p.p. 320-324 (German explanation at the end of Table 37 p. 324). The tables contain the calculated values for N_{tot} and the transformation coefficients Am-n, S-N (compare above under Sect. I, as well as Sect. IV_{10}). The two latter values are calculated upon humus content.

As is seen, with few exceptions a much stronger nitrogen transformation is to be found in the duff layer than in the humus layer, a noteworthy result, among others, on account of the diminishing content of detritus (Compare above). From this point of view an explanation of the differences between the unaltered litter and that in the early stages of decomposition can only be obtained by further investigation. Several possible explanations offer themselves.

The difference between the duff horizon and the humus horizon is especially marked in the humus layers of a raw humus character, less so in the "Mull" humus layers. The differences occur in the ammonia coefficient as well as in the speed of nitrification with or without inoculation. It appears as if during the "humification" process, especially that of raw humus building, the nitrogen became more firmly bound, becoming more difficult of access to the rotting organisms. The transformation coefficient can fall to zero or nearly zero in the humus horizon of a well-marked raw humus. The same is true for the duff horizon of raw humus-forms in old stands. The length of the period of raw humus building appears accordingly to be of some influence.

An exception to the rule of a marked decrease in the transformation coefficient during raw humus formation is found in the stands with mixed hardwoods, where the transformation does not seem to be diminished in the humus horizon. The admixture of hardwood leaves with the raw humus layer seems to be able to counteract the unfavorable changes which have been remarked. In coniferous forests with dwarf shrubs and herbs,(Dryopteris-type) the humus layer has a less strongly marked raw humus character and takes an intermediate position between the raw humus and "Mull" forms with respect to the question under discussion.

4. THE NITROGEN TRANSFORMATION IN THE DIFFERENT FOREST TYPES. A summary of the material according to forest types is found in Table 38, p.p. 332-343. From the analysis of the differences are obtained the following general viewpoints.

Independently of the pH the nitrogen transformations and the nitrification of the humus nitrogen respectively are favored through;

a. Favorable Summer Temperature. In middle Europe and south Sweden is to be found nitrification in the coniferous forests at pH values which in north Sweden are met with only in raw humus with little transformation.

b. Favorable Water Supply. Seeping water containing oxygen favors nitrification very greatly; also ammonification is favored by good water supply.

c. Favorable Nature of the Initial Organic Materials of the Process. Deciduous leaves in the duff stage increase the transformation and favor nitrification also without changing the reaction (pH). The same is also true to a still greater degree of freshly rotting branches of spruce and pine.

d. Well-closed Stand. In well-closed stands with a pure moss cover or without living ground-cover the transformation is often strikingly great. Nitrification often occurs when there is an acid reaction. The susceptibility to inoculation with nitrifying earth is strikingly great.

e. Young Stands. The transformation as well as the susceptibility to inoculation is generally greater in younger stands.

Changing the composition of the stand, by the introduction of hardwoods into the coniferous forests, which changes the acidity in an alkaline direction, increases the transformation, makes nitrification easier, and increases the susceptibility to inoculation with nitrified earth. In opening reproduction areas an increase of transformation accompanies the change in reaction. Nitrification is nevertheless frequent at pH values which are found under stands showing little nitrification, and usually ammonia formation. The alterations which are to be found in reproduction areas nevertheless vary according to the kind of humus cover and climate.

In a comparison of different forest types under similar climatic influences we find on the whole an increase in transformation with rising pH (increasing alkalinity). With a pH of approximately 5, nitrification in the northern coniferous forests is frequent; with higher values it is always present.

It must be remarked in discussing the values found for the nitrogen transformation and their significance for higher vegetation, that the ammonia was determined by extraction with 0.1 N HCl, as given above, while the nitrate nitrogen was determined by extraction with water. It is apparent that the amounts of ammonia so determined are not so easily available for the plant as are the amounts of nitrate nitrogen determined. Moreover, there is every indication that nitrates are more favorable sources of nitrogen than ammonium salts. The greatest abundance of vegetation and the highest forest productivity are accordingly not found with pH values of 4.5 to 5.0, where on the whole the largest amounts of nitrogen are found in the storage experiment, but with greater pH values (more alkaline conditions), which are beneficial to nitrification. On the other hand, our forest trees and other mycorrhizal developing plants are a special case as regards the nitrogen supply. The relative nutrition values for nitrate nitrogen and ammoniac nitrogen obtained from water or sand cultures are not applicable to the conditions in nature, as has been contended by P. E. Muller (1924, p. 176) against Carsten Olsen. Among other reasons the mycorrhizal plants, owing to the fact that their roots are strongly penetrated by fungi, are apparently placed in a better position in the struggle for nitrogen in raw humus, as Stahl and later Melin (1925) believe.

5. THE INFLUENCE OF THINNINGS UPON THE TRANSFORMATION OF NITROGEN IN THE HUMUS LAYERS.

Thinnings have an unquestionable significance because the subsequent growth is laid upon a smaller number of larger stems, whereby the economic value of the stand can be increased. Also it is believed that thinnings can increase the total subsequent growth (per hectare)— an idea which was entertained by Schotte (1917) among others, supported by the thinning experiments of the Swedish Forest Research Institute.

The proof of such a fact would be also of greatest interest from a forest biological standpoint. Among other factors it could depend on a lively nitrogen transformation and especially on increased activity in the soil as a result of higher temperature. From this point of view I made a comparative investigation of a thinning series which seemed to corroborate Schotte's conclusions. There was found for the series in Dalby in Scanica (a planted spruce forest, 49 years old) a definite correlation between the transformation of the nitrogen and the increment. The heavily thinned and fastest growing Compartment III (Text Table, p. 345, see also the light values at breast height, in % of light values in the open, Sect. XV, p. 394) had a definitely stronger nitrogen transformation in the soil than the other compartments (Text Table p. 345). In a series at Voxna (Halsingland) in a pine forest with abundant moss, of the Myrtillus-type, the differences between the nitrogen transformation were much less, but were nevertheless in the same direction, while the ammonia formation in the thinned compartment was much stronger (Text Table, lower part of p. 346). In the corresponding series in Bispgarden (Jamtland) the transformation was on the contrary stronger in the opposite direction in the section which was not thinned (ammonia formation; Text Table for the above, p. 346). The difference in growth in both of the last two cases was not marked. Moreover, the amount of current growth, which in the first place is to be compared with a single nitrogen determination (whereas the values of nitrogen may well vary from time to time) is for a shorter period and was unfortunately not determined with satisfactory accuracy. It appears however that a thinning under certain conditions can result in increased nitrogen transformation and also greater general total production in the stand, while, conversely, under other certain circumstances both can be decreased by thinning. The varying results are correlated with differences in soil or humus type.

6. THE POSSIBILITY OF NITROGEN TRANSFORMATION IN VARIOUS RAW HUMUS FORMS.

The various results of the thinnings upon the nitrogen transformation in a "mull" or moor ("mor") soil on the one hand, and in a raw humus soil on the other hand, signify that in the soil of the former the nitrogen is less strongly bound than in the raw humus profile. Also within this last group big differences are met with which, it appears, are independent of pH. As indicated, for example, in the old northern spruce forests, the nitrogen in the humus profile is closely held, or is inaccessible to the rotting organisms. The low content of alkaline buffer substances does not appear to explain fully the condition of the humus layers. In order to follow the matter up further, I tried to adjust the existing differences in pH by the addition of $CaCO_3$, in the form of very fine powder, and thereby introduced an adequate quantity of basic buffer substances at the same time. For each specimen 50 g. of soil was used, to which amount respectively 0.2, 0.4, 0.8, or 4.0 g. $CaCO_3$ was added, in several cases also 1.0 and 7.5 g. were added. These specimens were then, as was the case with the other stored samples, stored at room temperature for three months in Erlenmeyer flasks. In another case the samples, excluding those with increased amounts of calcium, were treated with a constant amount of inoculation earth (nitrifying humus from a clear-cutting), that is 5.0 g. of inoculation earth were added to 45 g. of raw humus. In this discussion are given the results for only five different kinds of raw humus: 1. From a completely closed mixed forest of pine and spruce near Glindran (Sodermanland; consult locality descriptions p. 397, Fig. 52); 2. From an old, weakly-growing, lichen-covered spruce stand of the Vaccinium type in the research forest Kulbacksliden (Vasterbotten; see p. 465); 3. Same as No. 2, but from a different locality; 4. From a younger, about 70-80 year old spruce stand of the Vaccinium-type, with good birch mixture, having arisen after a forest fire in the research forest Kulbacksliden; 5. The same stand as No. 4 in a part of which there was a weak birch mixture.

The results are given in Table 39, p.p. 355-356 and are graphically represented in Figs. 42-46, p.p. 349-353. In the specimens 1, 4 and 5 nitrification resulted with the simple addition of calcium, in the others none or very little; addition of both calcium and inoculation earth produced nitrification in both the other samples; that in 3 was very weak however (never once becoming equal to inoculation-earth control). Among other interesting facts which this investigation disclosed may be stated:-- that differences between the duff horizon and humus horizon were to exist here also; that all samples during their storage had changed their pH in an acid direction except No. 1, where the reverse was the case; and that the two samples, Nos. 4 and 5, having the same pH (5.1), coming from the same stand, (however one was a raw humus heavily mixed with hardwood leaves) show great differences.

The differences between various raw humus forms which the study has shown can be explained in part through the hypothesis of soil microbiological differences. For example, there may be a suppressed nitrification flora in the better humus forms which is lacking in the poorest (see the new soil microbiological investigations of Winogradsky). Partly however, there may be differences in the nitrogen-containing material or the amounts of toxins which are active in the poorer samples. Regarding the first possibility see Suchting (1925); according to this investigator the nitrogen is found in the raw humus primarily in the form of pyridine, chinoline, acridine, and similar compounds, which are poor nitrogen sources for the organisms. In the duff horizon must necessarily be present larger quantities of more easily broken-down (chemically unstable) groupings. Further investigations with a view to throwing more light on these matters, are in progress.

Section XIV. DISCUSSION OF THE RESULTS OF THE INVESTIGATION.*

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* These sections in the German text are direct translations of the corresponding Swedish sections.

1. INFLUENCE OF THE DETRITUS MATERIAL, CLIMATE, AND GEOLOGICAL STRAT UPON HUMUS FORMATION IN THE CONIFEROUS FOREST.

An exhaustive treatment of the above subject is not possible at the present time. Among other things this is because of our all too meagre and uncertain knowledge of the nature of humus materials. We find ourselves here in one of the most difficult and complicated phases of organic chemistry. The above-mentioned material gathered through observation nevertheless gives an opportunity for the discussion of certain results of some considerable importance.

Above all it appears important to point out the large part played in the humus layer by the characteristics of the detritus. The acidity and the content of the detritus in basic and acid buffer substances clearly exercise a very great influence upon the quality of the humus layer. Most strongly does this influence show itself in the northern coniferous forest, where the humus builds a layer or horizon on the soil which only to an insignificant extent is intermixed with the underlying mineral earth through activity of insects and worms. Besides, the direct chemical influence of the soil in these forests is decreased because in the podosol soil the upper horizon of the mineral earth has through the influence of a weathering process become especially poor in soluble alkalis. In fact a mineral soil, rich in alkalis, especially in soluble calcium, can otherwise act as a buffer in that the acid humus materials formed through the decomposition of the detritus are neutralized. In his work on the influence of the sub-soil upon forests, Tamm (1921) classifies the various kinds of soil on the basis of their lime effect, and pointed out beyond doubt that this is a characteristic of the sub-soil which is of the greatest significance in the formation of forest soils in a humid climate. The greater the lime content the greater the possibility that the decomposition products of the acid detritus materials of the coniferous forests will more or less be neutralized. Here however topography plays an important part. The dissolved calcium is carried downward to the base of the slopes and the calcium content of the soil influences more especially the soils with moving ground water. Naturally this phenomenon is most striking in the characteristic lime regions, or where the moraine is mixed with limestone. In eastern Jamtland, in the Parishes of Bodsjo, Bracke and Revsund, the humus layer in the pure coniferous forest in* the neutral point (see p.p. 445, 447, 448). In these regions humus layers which, because of their consistency, are of a somewhat raw humus type, show a proportionately high pH (alkaline). This fact can be explained by an unusually high content of assimilable calcium, in the humus layer (compare for example the pine forest near Bracke, the forests on the heights surrounding Bodsjo). The water which leaches through this forest soil often shows, especially in the deeper hollows, a large content of soluble calcium. In the autumn of 1921 during a visit in this region several water samples were taken from dug holes or small hollows and their lime content subsequently determined at the Institute by Mr. K. Lundblad. One water sample

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*Note: In cutting this stencil the following was inadvertently omitted after the word "in": "the deepest hollows is often "Mull"-like, and their acidity approaches" taken near Skurun, in Bodsjo, contained per liter 16.7 mg. of CaO; a sample near Stavre, in Revsund, 45.4 mg. and another in the same region 73.9 mg. These are very high values, compared with the lime content of water in regions poor in lime. According to the investigations of Malmstrom (1923, p. 68) the lime content of the spring-water in the Research Forest of Kulbacksliden varies between 2.8 and 5.0 mg. CaO per liter, and that of the water in streams from 2.0 to 3.0 mg. per liter. According to the investigation of Lundblad (1926) the spring-water in the Research Forest Siljanfors has a lime content of 2.9 - 6.1 mg. per liter, the stream-water a content between 2.4 - 6.8 mg. per liter and the water of the lakes 2.0 + 2.4 mg. per liter. But even when the lime content is so low as in Siljanfors, the conditions of a favorable topography can promote a pronounced calciophil vegetation in certain characteristics, that is, forests of the Anemone hepatica-type. The areas in Siljanfors where this forest type is found are so situated that the upper layers, or the uppermost horizons of the soil are wet by the percolation from higher levels when the water content is high. The humus layer becomes "mull"-like, the acidity rather high, pH 5.0, and the content of assimilable lime reaches an average as high as 1.46% of the ignition loss or humus content. The nitrification is often lively and the forest highly productive. The forests which are influenced by the water of the streams also have a humus rich in lime; in the region of Stickosalsbacken this amounts to 2.74% of the ignition loss. The pH is approximately 5.5, the saltpetre formation reaches very high. Other forest stands in Siljanfors which are influenced by running water are the spruce swamp forests rich in herbs, which appear in regions where the spring water comes to the surface. The pH of the humus layer is 4.9 - 5.5, the content of assimilable lime 1.77 - 3.06%, and the nitrification in the humus horizon considerable.

One of the areas influenced by running water is the most productive in the research forest at Siljanfors, and is the so-called selection area (Plentergebiet) south of the railroad (see p. 426). The acidities lie between pH 4.6 and 4.8. On areas cut for reproduction the nitrification increases strongly, and naturally reproduction is easily obtained. The soil moisture and the actige nitrogen changes make good preliminary conditions for the success of the selection method.

A vegetation map of the Research Forest at Siljanfors affords a good illustration of the influence of topography on the humus formation. It is seen that a plant such as Anemone nemorosa follows definite lines or directions which just coincide with the path of the water in the forest soil. Similarly, though not so well, the Research Forest at Kulbacksliden shows the influence of the topography on humus formation. Areas that are somewhat humid produce forests of the Dryopteris-type; depressions or hollows well percolated by water have forests of Geranium silvaticum. The influence of topography upon humus formation makes itself more strongly felt in northern than in southern or central Sweden. Such species as are important as indicator plants for judging the characteristics of the forest soil, such as Anemone nemorosa, Anemone hepatica, and Oxalis acetosella, are somewhat independent of topography for their existance in southern and central Sweden; indeed they appear even on comparatively dry soils. In northern Sweden, perhaps with the exception of areas very rich in lime, these plants limit themselves to soils moistened by flowing water; this applies especially to the Anemone species. Here one finds what from a plant geographical viewpoint is an interesting and noteworthy difference between the vegetation of northern Sweden on the one hand and that of the southern and central part of the country on the other. The difference may in general depend upon the stronger podsolization of the soil and the costly, marked leaching out of the upper soil layers in northern Sweden. The flowing water, with its content of electrolyte, though it be especially lime salts, produces favorable conditions in the humus layer and results in the north in local forest soil types of southern character.

The role which climate plays in humus formation appears most marked therefore on soils poor in lime, which are not influenced by water percolating along or near the upper layers of the soil; but where the water movement is mostly vertical, there climate and not topography determine the leaching. If the localities of a like character from a topographical viewpoint are compared for these qualities studied in this investigation, for example the forest soils in the Schwarzwald, in Barenthoran, in southern, central, and northern Sweden, there is a remarkable agreement in the case of the acidity of the humus layer, as well as in the content of acid and basic buffer substances, but in respect to the vigor of the nitrogen decomposition there are differences. With regard to acidity and buffer substances, these are dependent upon the nature of the detritus materials, while the nitrogen transformation depends mostly upon the climate, above all the temperature. In the strong, tough, raw humus layers of the old spruce forests of Norrland, and the thin, porous humus layers of the coniferous forests in the Schwarzwald or those of central Sweden, the agreement in the case of acidity and buffer substances is striking; here the peculiarities of the detritus materials are well known. At the beginning of the decomposition the more fragile, loose groupings of nitrogen are broken up, and changed into ammonia or to some extent, saltpeter. When the decomposition has reached a certain stage, as for example in the humus layer, there remain only the more inaccessible nitrogen combinations. (See Section XIII:3).

The whole process gives the impression that humus formation in such humus layers is chiefly a continuation of the alteration process which began in the yellowing leaves, and that the difference between the thin loose humus layers, and the thick, matted, raw humus lies more in the speed with which the decomposition proceeds and less in the chemical divergences. It is naturally impossible to advance a more definite opinion on this question in view of these observations and our present knowledge of the nature of humus. If one believes - as is quite possible and probable - that the detritus materials are acidoids in nature (compare Michaelis, 1922, p. 206-209; Page, 1926 a) one can regard the entire humus-formation in a humus-cover uninfluenced by mineral earth as consisting of the gradual replacement by hydrogen ions of the metallic rations absorbed by the acidoid, a reaction which can occur through water only. Such a theory of the nature of the humus material also allows, as Page (see above) points out, for a consistent explanation of the different forms of soil acidity established by Kappen (1917, 1920). This theory of the nature of humus materials may be applied, according to our conception, in determining the peculiarities of the humus extracts. In the same proportion as the metallic kations absorbed on the complex humus material are replaced by hydrogen ions, they are leached out, and the podsolization of the mineral earth is accelerated. Such a theory does not exclude the belief that the formation of true acids simultaneously occurs during the decomposition. The detritus material is not homogenous from a chemical viewpoint; its component parts have various qualities and can be broken down by chemical action in various ways. In this connection this question cannot be further elaborated. Consult the above-quoted works of Michaelis, Page, and the works of the Russian forester Gedroiz referred to by the latter. I hope soon to have the opportunity to return to this question in other experiments.

Meanwhile my own studies as well as those of Kappen (1917) show that the acid humus floor of the coniferous forest finds its most natural explanation in the character of the detritus material. The theory of a rotting which produces acids, occasioned by lack of air in the raw humus layer, in contrast to the decomposition occasioned by exposure to the air, is to my mind practically unnecessary and not established thru observation. The exact air analyses of Romell (1922) show that generally the raw humus layers in the northern coniferous forests, thick and of great depth as they are, are as well aerated as the "mull" soils, and so also are the soils underneath these raw humus layers. . Romell could not demonstrate a lack of oxygen in normal, unswamped raw humus soils. What therefore determines the character of the raw humus soils is, above all, the speed with which decomposition follows organic breakdown (microbiological attack and assimilation follows the first stages of mechanical and chemical disintegration). Here the climate plays its great role. In the dense spruce and fir forests of the Schwarzwald, the humus layer is thin and loose (see Fig. 48), the decomposition of organic remains is active. In carelessly thinned stands there is formed an unfavorable raw humus exactly as in our northern coniferous forests (see Fig. 47) - and in the open clear-cuttings, bilberry (Vaccinium Myrillus) or heath bushes make vigorous growth. As far as the bilberry is concerned there is a noteworthy difference between the Schwarzwald and the northern part of Sweden. One of the best means to alter the raw humus under the old selection spruce forest of the north is clear cut; the bilberries and the whortleberries (Vaccinium Vitis Idaea) disappear, the moss dies, and the thick raw humus begins to change, From the appearance of the luxuriantly growing bilberries on the clear cuttings in the Schwarzwald it is easily understood why the foresters in south Germany view the clear-cutting as a raw humus builder. Between the Schwarzwald and the north there is indeed a great difference in climate. The Schwarzwald has a climate of an Atlantic variety. To this the vegetation also bears witness (see for example Oltmanns, 1922; Troll, 1925). The precipitation is significant-1,000 to 1,200 m.m. (39 to 47 inches). The climate of the north is more continental, the summer temperature can be rather high, while at the same time the precipitation is sufficient to promote a vigorous decomposition in the cut areas. On northern slopes, especially at some elevation over the sea level, as 300 - 400 m. (1,000, 1300 feet) in upper Angermanland, the temperature does not rise sufficiently to accelerate the decomposition of the raw humus lay in the clear cutting. In such places other measures are required for the transformation of the humus, for example, burning or working the soil. If on the one hand a very rainy climate can contribute to raw humus formation, so on the other hand a very dry climate can have the same effect. The humus layer dries out too much on the surface. If "mull" is so treated the soil fauna disappear or decrease, whereby one of the most valuable requisites for the formation of "mull" is lost. If or when the closed stand already has a raw humus layer, the cut-over area (Hiebflache) can dry out so much that the decomposition process is checked. It is in such cases that the view advanced by Wiedemann (1924) and Ehrenberg (1922) is justified. The reaction of the humus layer of a given silvicultural method must, in the nature of things, assume a different form under different climatic conditions according to their nature. This fact cannot be too strongly emphasized.

Between the thinner and looser humus layers, as for example in the dense spruce and fir stands of the Schwarzwald, or in the forests in middle Sweden on the one hand and those equally or less acid, yet with thicker raw humus layers of the north, on the other there is a difference with respect to its reaction on the soil. The podsolization process in the latter is manifestly stronger. According to Tamm (1920) the thickness of the leached layer has a definite relation to that of the humus layer. The humus-forming plant materials of the middle European and central Sweden coniferous forests are as abundant in the north, if not more so. The humus layer in both cases is approximately equally acid, with an equal percentage by weight of buffer substances. The aforesaid difference in the influences upon the soil must therefore be sought in the further fate of the acid buffer substances. Under a favorable climate these materials can more easily be oxidized to carbonic acid and water while under the influence of a cooler climate a larger part goes into solution. The acid humus materials are also oxidizable. It is known that they are able to consume more or less completely the oxygen as in stagnant water. (Hesselman, 1910). Lundegardh (1921) and Romell (1922) have observed a lively carbonic acid formation in beech raw humus, and according to unpublished investigations they lately found in the raw humus of pine forests of the Vaccinium-type a very lively carbonic acid production. With higher temperature there was found an increase of carbonic acid production and a smaller amount of the soluble acid humus materials formed in the soil.

It is self-evident also that leaching plays a definite role. The greater the precipitation which percolates through the soil toward the ground water regions the greater is the leaching. It is here that the humidity of the climate is important. An examination of the factors which are generally used to explain the humidity of the climate shows, however, that in our country there are no large areas with a strongly marked humid climate. (Hesselman, 1924). Therefore the temperature must have a direct influence upon podsolization. Because of the relatively low summer temperature in the coniferous forests in the northern part of Sweden, only a small part of the acid buffer substances are oxidized, and therefore a greater quantity of them are left to work on the soil than in warmer countries with the same humidity. In view of all this the temperature plays a direct part in the podsolization of the soils of Sweden (Hesselman, 1924).

The acid reaction and the large content of acid buffer substances in the acid humus layer of the coniferous forests are, according to the view here expressed, a natural result of the detritus materials. The acid quality of the humus layer is not produced by an abnormal process. Whether the humus layer becomes thin, light and more like "mull," or thick and matted, helping or impeding the reproduction or the subsequent growth of the forest, depends upon the speed of decomposition of the detritus material. The podsolization process of the humus layer depends upon the water content mass which percolates through it and sinks into the soil, and the speed with which the acid buffer substances are oxidized into carbonic acid and water. The greater the mass of water which passes through the humus layer the greater the podsolization. The oxidization of the acid materials, on the other hand, hinders podsolization. Yet probably not all acid reactions in the soil are of a similar character. A detritus material that is less acid in nature can produce a raw humus. We shall discuss this question further in the following section.

2. THE INFLUENCE OF THE COMPOSITION OF THE STAND UPON THE HUMUS LAYER.

From the above it is to be expected that changing the composition of the stand produced a change in the humus layer. My investigations have indeed shown that this is the case to a high degree in the northern coniferous forests containing an admixture of birch, aspen, willow or other hardwoods. The acidity as well as the content of acid and alkaline buffer substances in the more or less raw-humus-like humus layers is strongly influenced.

Also in the more light "mull"-like humus forms one sees the influences of the detritus material. Nemec and Kvapil (1925) have indicated in a recently published work the relationship between the physical characterists of the forest soil and the acidity; that when its air capacity increases, the pH increases, that is, the soil becomes less acid. As to how this relationship is to be explained these authors say nothing; they apparently seek to ascribe it to the fact that through diminished access of air more acids result in the decomposition of the organic debris. However, there are other causes to be taken into consideration. A greater air capacity is created by a more pronounced mixture of the humus material with the earth whereby wholly mechanically the content of acid substances is decreased. Also it may be that the soils rich in lime, therefore those which are in themselves less acid, become loosest, that is, become greatest in air capacity. No matter what the cause of this relationship may be it is interesting to know that in soils of equal capacity for air, that is between 20 and 25%, the soil under spruce has a pH of 4.8 - 5.2, similar soils beneath pine approximately 5.0, under beech approximately 5.8, under ash about 6.0, and under oak about 5.0. The reaction numbers of the soil under the respective litters are in their relation to one another approximately the same order as the reaction numbers of the detritus materials. The conifers have the most acid soil, the oak, whose debris is more acid than that of the beech and ash, also has a stronger acid soil than these hardwoods.

As is known, a slightly acid detritus material can also form an acid humus layer. The beech raw humus can serve as an example of this. Romell (1922) has investigated the aeration of a beech raw humus layer 2 cm. thick in Hallandsas and found it very good. From this it can be concluded that such a raw humus layer can eventually result exclusively from slow decomposition. The slower the decomposition, the greater the leaching, and the more completely the hydrogen ions can replace the metallic ions in the humus horizon. The alkaline buffer substances become smaller, the acid buffers increase. The samples of beech raw humus from Barenthoren which I investigated were rich in acid buffer substances but poor in alkaline buffers. In order to form an acid humus layer in this way from detritus material slightly acid and proportionately rich in alkaline substances, it is necessary that there should be a strong leaching or slow decomposition or both.

It is however not improbable that impeded aeration can influence the acidity and the content of acid substances. Through impeded aeration acids or other acid materials can result which are different from those produced in the normal decomposition of acid detritus. When the soil is rich in buffer substances such an acid production need not necessarily have as a consequence an abnormal or unusual acid reaction. However, the anions produced can be essentially different from those which are produced in a normal decomposition.

In the thickly-matted needle mass which one sees covering the soil in dense, cultivated forests of spruce, there are formed acids or other materials with an acid reaction. This is the result of an air deficiency which is not characteristic of normal spruce-needle decomposition.

An example of such acid formation is to be had in the abnormally thick raw humus layer in Suodasholmen in Hornavan (see p. 495). The acid reaction is 3.5 or 3.6 and therefore not abnormal, while the content of acid buffer substances is very high. In the titration curves the HCl line lies to the left of the KCl line; therefore in the humus layer free hydrogen-ions are added to those of the HCl.

In order to gain true insight into the nature of the various raw humus forms and their influences upon the stand, soil, and reproduction, it seems to me that it is necessary to draw a sharp line between the various forms of the acid humus layer. A humus layer whose acidity is the result of the character of the detritus material can certainly have entirely different characteristics from one whose acid substances result from incomplete or strongly retarded decomposition. The natural Scandinavian coniferous forests found upon soils without lime have for the most part a humus layer of the first type; on the other hand the acid humus layers of many planted forests can be of the latter type. The differences between these various kinds of humus layers may prove of very great importance for the clearer understanding of the entire humus problem in the forests. A complete explanation of these questions however demands a more fundamental and thorough knowledge of the nature of humus than is at present available. But only through careful studies in the field and through a comparison of the influence of the detritus and the humus layer in various stands can any definite result be achieved. An especially interesting piece of work and well worth while would also be to get a clearer idea of the nature of the strongly acid "mull" forms. They may often be differentiated by strong nitrification (see for example, Weis). It would also be of great interest to know the dependence of the entire process of "Mull" formation upon the detritus material. Because these researches were principally concerned with the coniferous forests of northern types, I have regarded this question rather as a subsidiary one. The "mull" forming detritus of the better hardwoods can be truly acid, (for example, oak leaves) but they are nevertheless rich in alkaline buffer substances. In addition it would also be worth while to know in what way the changes brought about by worms (coprification, Koprofikation) influence the buffer substances of the detritus materials. The "mull" is, as has already been shown, generally poor in buffer substances.

3. THE SILVICULTURAL IMPORTANCE OF THE FOREST TYPES

In the above account the quality of the soil vegetation was given in great detail in order to describe the forests investigated and to differentiate between the various types. In doing this I have followed the old tradition of Swedish forest biological investigation, traces of which are to be found as early as 1880 in Ortenblad's studies, and which were enlarged and developed by Lundstrom, Sernander, Hogbom, Alb. Nilsson and others, and were from the very beginning a guiding viewpoint for the work of the Forest Research Institute. In the year 1909 Cajander published his well-known work on Forest Types, which he recommends as norms for forest site quality. He was of the opinion that taking forest types as a common foundation for the site quality of all tree species, natural standards for site quality would be established, and a comparison of yield for different species on various soils would thereby become easier. Without a doubt this was a fine goal to aim at, Cajander's proposal, however, could not for many reasons be adopted by the Research Institute or by the rest of the Swedish foresters. As finely separated as were the forest types in Cajander's first work there was found in one and the same forest type in a limited forest region (for example the state forest Evois) a strong variation in respect to the growths of the stands, and the various types overlapped each other considerably as regards these variations. The same conclusion also followed in the taxation of the forests of Varmland in 1914, when separate forest types were differentiated and at the same time a site quality was established according to the height growth of the trees. In principle this was the same as the conclusion laid down by Cajander in his first work; large variations in the case of the growth in one and the same type, yet differences in the case of the average increment. Therefore site qualities established on forest types must give uncertain results because of changes in a certain forest or a certain smaller region. There may indeed be expected in the same district an overwhelming of plus or minus variations in a given type. If we know the average possible yield of the forest types common to a certain region we can naturally, therefore, with such a site method, give the average value for the region, though for the single stands on the other hand less certain conclusions are obtained than when using the site determined by the height-growth of the trees. If a site quality founded upon Cajander's principles is to have any practical significance, the regions must necessarily be small. Take, for instance, such common types as Cajander's Myrtillus or Oxalis-Myrtillus type, to which belong the predominating number of Sweden's spruce forests. These types vary extensively in such a country as Sweden, where the climate varies with the height above sea level, the latitude, and the distance from sea and lakes. Average values for the yield capacity of these types good for the whole country can therefore have only a general statistical value.

It also seems to me that in Finland, where under Cajander's energetic lead the forest types have been adopted as norms for site quality, that the intricacies which such a method entails do not disappear. As indicated by the investigations of Ilvessalo (1922) even in the way in which the Finnish foresters limit their types, the variation in yield is large, and the types merge into each other without sharp boundaries. Cajander (1923 p. 8) must himself admit that naming the forest types after the vegetation can be deceptive, since in forests of the Myrtillus type the ground cover may deviate strongly from that of the Myrtillus type; or for example in the Oxalis-Myrtillus type, the plant characteristic of such a type, Oxalis acetosella may be lacking. When, besides, it is recommended (see Cajander & Ilvessalo 1921, page 70) that the site quality named after the vegetation be determined according to the growth of the trees and the opinion is even expressed that the taxation points of view will in future be the deciding factor in type-classification, based upon the vegetation, such a view leads to what for clear scientific thinking can only be a vicious circle. If there is a poor correlation between the increment of stands and the soil vegetation the procedure is unnecessary; if such a correlation does not exist, then the procedure is worthless. In view of our present knowledge there appears to be but one right method, which is to distinguish the site classes by figures corresponding to a certain productivity, and to separate the site classes in practice with reference to the increment of the trees, and with such guiding features as the vegetation can supply. To my mind the designation of site according to ground vegetation gives a false idea that there is a more intimate relationship between living ground cover and tree growth, than is at present accepted by forestry biological research to the development of which this idea is dangerous. Another reason why Cajander's use of forest type as site quality types is unsatisfactory is this, that the sites or the forest types, as the case may be, appear to be independent of tree species. This brings in the question of the influence of the stand on the ground cover. Cajander, as is known, advanced the theory that this influence is very small or of only secondary importance. When the forest type is determined on ground cover alone, there is the possibility that on such a basis one will start arguing in a circle. The differences which arise with respect to the vegetation in stands with various tree species should not be attributed to the influence of the trees but are to be explained on the basis of various forest types. In order to settle the question it is necessary to examine the ground cover in stands of various tree species but on soils as much alike as possible with respect to exposure, geological qualities, water supply, et cetera. Although our three northern species of pine, spruce and birch, have, at any rate in northern Sweden, no striking influence upon the ground cover which has so few species, Ilvessalo's(1922) investigations at least show that the spruce keeps out other species through its dense shading. With regard to the valuable hardwoods, oak, beech, linden, and elm, the situation is somewhat different. Even if the idea be abandoned, as it must be, that certain plants are always associated with certain species of trees, the results are confusing. Linkola (1924) who has studied the forest types in Switzerland and would apply Cajander's ideas to them has, as far as I can see, shown nothing else but that the influence of the stands on the ground cover manifests itself differently on different soils, which is in itself nothing astonishing. The studies of Rubner in the virgin forest of Bialowics are a strong argument in favor of the fact that the stand has such influences the ground cover (Rubner, 1925 p. 293) and the Finnish forester Widar Brenner (1922) who is both a botanist and a soilinvestigator has shown in the case of Finish forests the influence of the kind of trees on the ground vegetation. But even if the ground cover is not influenced by the different kinds of trees, yet the productivity of the soil may be affected by the species. This, which the followers of the Finnish school also admit, is corroborated by the interesting studies of Yrjö Ilvessalo, (1923) a pupil of Cajander, on the correlation between the increment of a stand and the character of the soil. In this work he says (pp. 3-4) that the more luxuriant the growth of the stand the more favorable is its influence on the soil, since it obtains mineral-bearing spring water from the deeper levels. It thus builds up a ground litter by the destruction of which the nitrogen-assimilating organisms raise the nitrogen content of the soil. This is a clear assertion of the relation between stand and soil peculiarities which entirely agrees with my own view. Since the roots of the different kinds of trees penetrate the soil to various depths and their detritus has different characteristics, their influence upon the soil must also be varied. The soil cannot therefore be considered as a factor independent of the tree species for the purpose of classifying the site quality of forest types, with the exception of the regions where no change in tree species has taken place, and where the development has not been hindered by a decreased decomposition of the humus layer. But in Sweden there are few such territories. Cutting and forest burning have had great influence in the distribution of tree species, while under entirely natural conditions the decomposition of the humus layer may cease.

The stand and its care have a manifold effect upon the soil through the character of the detritus by influencing the soil's evaporation, temperature, and fauna. Stand and soil are in a definite relation to one another. According to geological quality, availability of water, climate, etc., the influence of the stand can change, making itself felt sometimes stronger and sometimes weaker. For a rational forest management it is therefore very important to clarify this relationship.

Cajander's exposition of forest types, which has been highly regarded in foreign silvicultural literature, has however won no adherents where there is a question of using the forest types as site quality standards. Rübner (1925), who has made an interesting study of this question cannot accept Cajander's theories for Germany, mainly because in that country a change has taken place in the various tree species on the same soil. He shows that, so far as he is concerned, they are misleading for all forests whose soil has formerly grown hardwoods. Cajander(1923 p. 7) certainly speaks of modifications of forest type as the result of the influence of certain tree species, for example the spruce. But since these modifications may take hundreds of years one has not very much use for site qualities based upon forest types, apart from the difficulty and uncertainty of reconstructing an unmodified forest type in practice. Here the objective standpoint should prevail at the cost of the subjective. Similar points of view are held by Leinigen (1922), Hartmann (1923), Krauss (1924). Wiedemann (1924) declares himself in favor of Cajander's forest types, but his investigations concerning the transformations in the humus layer, which agree entirely with my own, point to a change in the stand quality due to the result of various tree species. Here in Sweden Tamm and Petrini (1922) are opposed to site classification by forest types alone, and behind them stand practically without exception all the Swedish foresters. In Denmark Bornebusch (1925, p. 207) has been interested in Cajander's studies. He does not however agree with Cajander's site classification methods, but he adds to the ground types certain quality types determined by the influence of the tree species and the care of the stand upon the humus layer. This corresponds closely with the standpoint which I had already discussed in 1914 and which I also advocated in my lectures on soil science in the Forestry Academy. The difficulty lies not only in referring the various forest types to predetermined "ground cover types" but also in estimating the influence of the stand which is more or less long-lived, on the possible yield of the soil.

The study of forest types at the Forestry Research Institute of Sweden has from the beginning had in view a different goal from the establishment of various site quality classes. The forest types are to serve for the classification of our stands, which vary in regard to their composition, into types biologically of the same value, which, as a result of their various geographical locations (height above sea level, latitude, etc.), the varied conditions of their humus layers and the history of their various developments, show a varying productivity but which nevertheless on the whole react to forestry measures somewhat similarly. From the Swedish point of view, one might better call the forest types a treatment type instead of quality types. In so far as Cajander's theories emphasize that certain forest types demand in general the same kind of treatment, the Finnish standpoint is in agreement with the Swedish. At the Forest Research Institute in Sweden in the classification of forest types the vegetation is the first thing to observe, and the growth of the trees should not determine the type. In a forest of the Myrtillus type the Myrtillus and other conspicuously characteristic plants must be present, and a forest of the Oxalis-Myrtillus type must include Oxalis acetosella and other plants determining the type. The forest types, as we distinguish them, correspond to the "associations" of plant geographers, and naturally there is nothing to prevent some other association-definition being used than those determined by certain plant geographers. At the Research Institute the study of forest types is conducted principally with a view to causal relations, and its aim is to investigate the factors which influence the growth of the stand and the influence of forestry measures on these factors. It will be unconditionally admitted that as a result of these investigations we can explain only certain of the factors. Even if we only learn to control certain factors, much will have been gained.

The new and different form which Liebig's old Law of the Minimum has gradually assumed provides a good working principle. According to this law the various factors work together in such a way that the growth factors in the dynamic system can have a reciprocal effect, as Romell (1924, 1926) among others has shown. Even if the minimum factor cannot be influenced when certain growth factors are controlled, the growth of plants can be influenced in that the limiting factor will be the better utilized the more favorable are the remaining factors. From this standpoint an attempt will be made to analyze the possibilities of influencing the yield of a site by forest management.

4. THE POSSIBILITY OF INCREASING THE YIELD CAPACITY OF A SOIL BY RATIONAL CARE OF THE STAND.

The factors or, more correctly, the groups of factors which control or determine the productivity of a forest soil are the climate, the quantity of water in the soil, the quality of the humus layer and the mineral earth. Through rational forest management it is possible in the first place to influence the condition of the humus; this nevertheless is under the influence of other factors; the climate, the access of water and the chemical conditions of the mineral earth. Insofar as artificial fertilizing is not adopted, and this for most cases cannot for economic reasons, be considered in forestry the growth factors which are contained in the mineral earth can be altered only indirectly. With the expenditure of comparatively little money superfluous water can be drained from the soil; less often is it feasible to irrigate where the water is insufficient. However, these measures for the care of the soil are quite outside the scope of these studies. By thinnings the temperature in the upper soil layers is influenced; the temperature can be raised and the transformations in the upper humus layer accelerated. The characteristics of this humus layer are however most influenced by the composition of the stand. By the admixture of broadleaf trees the pH of the humus layer in coniferous forests can be changed in an alkaline direction by which conditions more favorable for the transformation of nitrogen can be created. Also the growth conditions are improved for the fungi which form the mycorrhiza, so important for the absorption of nutrient materials of the coniferous trees. According to Melin's (1925) investigations the pH which is most favorable for the mycorrhizal fungi lies between 4 and 5, and the absolute optimum lies a little below 5. The most lively ammonia formation without accompanying stronger nitrification takes place between 4.4 and 4.9 (see figures 39-41). The admixture of birch or poplar in the Northern coniferous forests easily brings about a change of pH in the humus layer toward this value, while the humus layer of the pure coniferous forest under conditions otherwise the same has a lower pH value, that is, a more acid humus. A very important part of the most beautiful and productive of Sweden's coniferous forest was developed from stands with a birch admixture and this has undoubtedly played an important part. Nordfors (1923) has shown the biological importance of the birch for the development of spruce in the forests high up in the mountains. Especially beautiful examples of this I myself have seen in the mountain regions of Jamtland (Dunnervattnet) and Lappland (Stensele). With the increasing age of the stand the birch disappears more and more; first of all goes the Betula pubescens, which in the North does not become very old. A weaker admixture of this kind of birch as it occurs in older spruce forests seems to be without significance as regards the yield of the soil. (Cf. Fig. 74). Even when the birch influences only the coniferous stand in its early stages of development, its importance must not be underestimated. Whether the favorable influence of birch upon the humus layer ceases with its disappearance from the stand -- by axe or by age -- is still an open question. I incline to the opinion that this is not the case. The amounts of alkaline buffer substances introduced into the soil by the fallen birch leaves may be able favorabl to influence the decomposition for a long time. Since it is practicall always found that a humus layer exceptionally rich in alkaline buffer substances produces a course of decomposition more favorable to the sta than a humus poor in such substances, one is tempted to ascribe great importance for sound humus development to the admixture of birch, aspen, and other trees which form a characteristic feature in the northern coniferous forests. Most of the Swedish writers on forestry, such as Holmgren (1914), Wahlgren (1917, 1922), Wallmo and Ortenblad, are also in favor of a birch admixture in the coniferous forest. The birch however plays a different role under different external conditions. In regions rich in lime, as in eastern Jamtland, where the humus of the pure coniferous forest is rich in alkaline material, the birch may play a less important role in the coniferous forest. But where the moraine consists almost entirely of granites and gneisses, the result is quite different. But even in such regions the significance of the birch apparently varies; the leaves rot the best where the soil is somewhat damp. Here the birch is probably of the greatest importance, as e.g. in such forest types as the spruce forests of *Dryopteris* and *Geranium silvaticum* types. But in the spruce forests of the *Vaccinium* type also the birch clearly exercises a favorable influence on the humus layer. This is shown by my investigations, among others, on the nitrogen transformations in various raw humus layers (see p. 354). On pine heaths with a mixture of birch one often gets a strong impression that here the birch is of real significance. This is probably the case, although in my investigations the humus layers of the pine woods with the birch mixture have not shown a very lively nitrogen transformation.

A question which has been discussed very heatedly, at least by our practical foresters, is that of the influence of dimension selection in the development of raw humus in old coniferous forests. It seems to be the common opinion that by such cutting the stand is opened to light unwisely and that as a result the bilberry increases and the raw humus formation is accelerated. How thick such a raw humus can become will be seen from Figure 66. The forests pictured in Figures 74 and 75 have a raw humus layer still thicker. Is the formation of such a raw humus to be ascribed to the bilberry or does the latter only indicate the quality of the raw humus layer? I have previously expressed myself in favor of the first view (Hesselman, 1917, pp. 946-948) but now I am not so sure. Judging from the condition of the detritus one has no reason to regard the bilberry as a dangerous builder of raw humus. The leaf of the bilberry is rich in alkaline buffer substances and from this point of view more favorable than the needles of the pine and spruce. It is possible, as I have previously suggested, that the bilberry by its dense root system and its large leaf surface dries out the humus layer in such a way that rotting ceases. I believe however that the explanation is to be sought elsewhere. In the old raw humus layers there are present either no alkaline buffer substances at all or only small amounts, while in younger stands the humus layer is rich in such substances, especially in the duff horizon. In the humus layer these substances are consumed or leached out and so new alkaline substances have to be brought in continually. For these the addition of detritus is the most important source. Indications would show that the fall of the needles from the old, weak, poorly-growing spruce trees is unimportant, among other reasons, because of the thinness (low density) of the stand. The detritus of the ground-cover cannot replace the decreased supply from the trees. The humus layer therefore becomes poor in alkaline buffers, and since the stand is too dense for the sun adequately to warm up the soil, decomposition ceases. At the same time, as my investigations show (Sect. XIII, part 6), the nitrogen is closely bound, and rendered unavailable to the organisms, a phenomenon, however, which requires a special explanation. In the raw humus layer there is collected again and again a nutrition capital that brings in no interest.

But even this is not all. From investigations, the results of which I am shortly to publish, it appears that in such a raw humus layer live certain kinds of fungi which are harmful to pine and spruce roots. The development must proceed in an entirely different direction if the soil is to give greater yields. Such a transformation takes place in clear cuttings and has taken place to a large extent on burned areas. The humus layer in dense stands on old burnt areas is rich in alkaline buffers, especially where birch, aspen and other such broadleaf trees are included. The nitrogen transformation is lively (Sect. XIII, paft 6) and in the humus layer, as are shown by the investigations just cited, there live kinds of fungi favorable to pine and spruce. The strong contrast, therefore, between the old, poorly-growing spruce woods covered with lichens (see Fig. 64, 68, 71, 74, 75) and the fine well-growing or easily reproduced stands which have arisen on burned-over soil is easily explainable if the peculiarities of the humus conditions are considered. The fact that fire has on the whole had a favorable influence on the reproduction and growth of the forest naturally does not exclude the possibility that it has also had, in many cases, an unfavorable influence especially on dry soil. It is quite apparent that clear cutting, which in Norrland often results in an active decomposition and an increase of alkaline buffers will prove to be a surer and in many cases a better method than burning the soil (see Fig. 72). But since burning under certain conditions seems to be necessary, an investigation is now in progress at the Research Institute in order to determine the influence of burning on the old raw humus layer. The results of this investigation should soon be published.

As for the mossy spruce forests or the coniferous mixed forests of Norrland, my studies substantiate the view that through the introduction of birch into the young stand; through better stand-closure and shorter rotations there can be maintained a better decomposition and a more lively nitrogen-transformation than is the case in the old selected natural forest. The average yield is increased and the difficulties with which we have to contend in securing reproduction are essentially decreased. The method spoken of above must influence the humus layer favorably; the content of alkaline buffer substances in time becomes very large in the fertilizing layer of the stand. The degeneration which results from decreasing the percentage of these buffer substances, is counteracted by avoiding unnecessary clearing and by shortening the period of rotation. However, all spruce forest types do not form sterile raw humus layers with the same ease. Where herbs, in addition to dwarf plants, cover the soil, forests degenerate less easily than where moss and shrubs grow exclusively, and soil fertility is least likely to decrease in those forests where the lime content of the soil is favorable for mull formation. If the requirements of the soil are taken into consideration, the rotation depends upon the forest type. The superiority of the stand with herbs over those rich in shrubs is to be found, among other things, in the peculiarities of the soil vegetation. The detritus of the herbs is less acid and richer in alkaline buffer substances than the detritus of the shrubs, characteristics which must contribute to the formation of a good humus layer. Recently Bornebusch (1925, p. 248-249), in discussing the significance of herbs in beech forests has pointed out that they influence the humus layer in a very advantageous manner.

In the preceding I have discussed principally the usual conditions in Norrland, where the greater part of this investigation was conducted. Equally important may be the role of the birch and similar hardwoods in the developmental history of the coniferous forests in central and southern Sweden. Perhaps it may be that the role of the birch is even greater, since it appears that the birch produces an herb and grass vegetation which is of beneficial influence on the soil and humus formations. The good growth of spruce in the old birch pasture forests is well known. With regard to this point I have not yet started an investigation of my own, but the Research Institute will soon take up this question.

Another question which, at least for the present, concerns rather sourthern and central Sweden and the southern part of Norrland as far as Medalpad, is that of the soil condition in the well-closed coniferous forests where the soil cover is exclusively or for the greater part of Hylocomia. Our foresters are commonly of the opinion that these stands conform to good silviculture with respect to high yield and good soil condition. My studies are in agreement with the views of practical foresters as far as soil condition is concerned; the acidity is often, though not always, somewhat less than in the stands rich in shrubs; the content of alkaline buffer substances is often considerable; the nitrogen transformation is often lively, and the nitrogen after inoculation is easily nitrified. The common idea that the appearance of whortleberries and bilberries indicates the deterioration of the soil is corroborated by certain observations in the research forest of Siljansfors, while on the other hand observations from Jonaker and the forests of Alkvettern point in another direction. Because of this fact I will leave this question open for the present.

As regards the southernmost parts of Sweden, we have to consider not only the birch, aspen, etc., as soil-improvers, but here also the beech plays a part. In connection with this region the well-known and beautiful studies of Wibeck (1909) should be recalled, which show how gradually in the southern part of Smaland the beech has had to give way to the spruce. For many of these soils the succession of spruce is certainly followed by deterioration. As Lundblad has just shown the succession of spruce in this region may change the soil; the "Mull" is changed into a more or less pronounced raw humus layer and the brown earth profile which is bound up with the "Mull" form is changed into a distinctly podsol profile. Such a development in this region must signify a degeneration of the soil. The path of the change is nevertheless easily explained with reference to the various characteristics of the spruce needles and the hardwood leaves. It is still an open question whether this process can be reversed to mull earth with a brown soil profile and how this can be done.

The influence of silviculture upon the soil only affects the top layers; the humus layer and those parts worked by worms and insects. The principal part of the soil concerned is that in which the nitrogen is transformed and where an assimilation of the free nitrogen of the air takes place. To influence these processes in a direction favorable for the stand is a problem which would highly repay the attention of foresters.

My investigations show that the nitrogen transformation or the abundance of available nitrogen is one of the factors which most strongly influence the growth of stands. In an investigation into the relationship between the characteristics of the soil and the growth of trees, Ilvessalo (1923) came to the same conclusions. A statistical treatment of the studies of Valmari (1921) shows that there is a very good correlation between the growth, the lime and nitrogen content of the soils in the pine stands investigated. However, the factors lime and nitrogen in combination signify a good nitrogen transformation.

But measures which are to be taken to give these factors a chance to better the conditions must be chosen according to the environment circumstances in each case. The importance of the various hardwoods as soil-improvers varies with the climate. The birch which plays such an important part in the coniferous forests of Sweden is, according to German foresters, of less importance in middle Europe. While in Sweden it is often the function of the birch to improve the composition of the detritus, the German foresters on the other hand desire a more abundant leaf-fall than that of the birch in order to further "Mull" formation. In a warmer climate, where the decomposition proceeds very rapidly, an abundant amount of leaf fall is necessary. It appears to me also that those hardwoods which naturally belong to the plant community or forest type are the best soil-improvers. To produce the result artificially by the introduction of elements foreign to the whole development is less valuable. The beech, which in certain forest types is of outstanding importance as a soil improver, is of little value in others. For every soil-improving silvicultural measure the biologically determined forest type is important. What is good for one forest type is not good for another. Also it should not be forgotten that there are factors in the primary geological peculiarities of the soil which limit the importance of our silvicultural measures. Recently this has been brought out most distinctly by Albert in Eberswalde (1925); he has shown important differences in the mechanical composition of the fine sands of Eberswalde. The content of fine material determines its water-retaining capacity, and this again affects its forest qualities. The planting of beech in pine forests in order to improve the soils is successful on certain soils, and contrzrily is not so on others. Many a keen German forester has been betrayed into exaggerating the importance of certain forestry measures because he did not pay sufficient attention to the primary characteristics of the soil. Among these, judging by later experiments, is to be counted Wiebecks, a prominent forester keen on soil-treatment on silvicultural practice. In recent years Barenthoren in Anhalt has become well known for the silvicultural soil-treatment of its owner Dr. von Kalitsch who has done splendid work in order to improve the soil. This silviculture has been designated by Moller (1920) as the well known "perpetual forest" (Dauerwald) system. Wiedemann (1925) of Tharandt has lately made a contrasting critical study of the forests of Barenthoren. He came to the conclusion that the original condition of the forest had been undervalued and thus the influence of the treatment of the stand upon its present condition had been exaggerated. He ascribes the good reproduction to the original characteristics of the soil, as, for example, its ability to retain suitable quantities of water. From similar investigations into the height growth and reproduction in neighboring regions of similar geological character it is shown that the treatment characteristic of the "Dauerwald" system had not improved the soil. It must be confessed that through Wiedemann's investigations the high hopes which had been placed on the results of a careful soil-treatment in silviculture have been in no small degree frustrated. The first communications concerning the noteworthy results of the "Dauerwald" system were of a sort which appeared to the critical reader to be improbable. Since I myself had the opportunity of seeing Barenthoren and of investigating a number of the characteristic humus samples found there, and also since I wrote a short chapter in Wiedemann's book, I venture to make a few remarks on the subject.

From my investigations it is evident, I think, that the soil-improving measures employed by von Kalitsch, the faggot-thinnings and planting of hardwoods have had different effects on different parts of the forest, and the best results in the characteristics of the humus layer are to be found in those places which are most favorable from a geological viewpoint. To this belong for example Sections 1, 4, 42, 43. Within these regions the faggot-thinning and the planting of oak have had a favorable influence. In other sections, for example 10 and 16, the results are poorer; here, however, the fundamental conditions are from a geological viewpoint not so good. Such results can to my mind be regarded as neither unexpected nor discouraging. It is only natural that in forest areas mismanaged by the removal of the litter or in other ways, that the soil improving-treatment will produce good results first of all where the best fundamental conditions are to be found for the formation of a good humus layer. I was particularly struck by the fact that in the areas of Sections 1 and 4, which before von Kalitsch's time were well-known for the rich abundance of heath herbs and where because of this the beehives of the apiarists were brought in the spring, there now grow "Mull" plants, for example, Fragaria vesca, Viola riviniana, Dactylis glomerata, hexapetala, Galium rotundifolium. Here it appears v. Kalitsch has strong evidence in proof of his assertion of a change in the flora through manuring with brushwood. The influence of the oak appears to me to be very striking, although limited locally as the good mull is found under the crowns of the oak but not outside of them. As I hope to revisit Barenthoren again shortly, I will content myself for the present with emphasizing that, according to my own impression, the method of v. Kalitsch manuring with brushwood and planting of hardwoods in certain parts of Barenthoren have shown tangible and good results, whereas in other places they have not. For an objecti judgment it is necessary to compare geologically similar regions, for which purpose the investigation must extend to areas more favored biologically. Only upon such a detailed investigation can the value of v. Kalitsch's methods be objectively judged.

The beech is highly prized by the foresters of Middle Europe as a soil-improver and has even been given the name "the mother of the forest." Undoubtedly under certain climatic conditions it has great ability to create a good soil condition. This is especially well shown in my opinion, in the Bohmerwald, not only in the managed forest, but also in the virgin forest at Kubani, where in a region without beech the humus layer has a marked raw humus nature but is otherwise "Mull"-like. In the cultivated spruce forests at Eleonorenhain the humus layer was like raw humus but in the larch forest was distinctly "Mull"-like (Table 42:5). The larch needles are, it is true, acid and rich in acid buffers (Sect. 9:2) but they are richer in basic buffers than the spruce and pine needles. Their titration curve reminds one of that of the oak leaves. In Sweden also larch needles have a better effect on the humus layer than pine and spruce needles. I have seen examples of this as far noth as Lappland, for example at Husbondliden in the parish of Lycksele in rather young planted stands of Siberian larch. In their studies in the Schwarzland, Ramn (1911) and Harsch (1912) have arrived at the conclusion that the soil has become poorer since they started to grow pure coniferous stands, and that previously, when the stands were mixed with beech, reproduction was easier. In this connection it is also of interest to note that those parts of the forest in the district of Langenbrand in which Dr. Eberhard did not have to employ soil measures in order to bring about reproduction the stands were mixed with beech. With a moderate amount of thinning out for the purpose of lighting, lively change took place in the humus layer. Scattered nitrophilous plants appeared and on the ground fine plants of silver spruce were abundant.

But not only are climatic and geological factors determinants for the degree of soil improvements which the broad-leaf trees can produce. Purely biological conditions play a large part. The quick decomposition of the beech leaves on the ground in the virgin forest Kubani in a rather cold and raw climate emphasizes the great importance of the organisms in the soil -- fungi, bacteria, worms, and insects -- for the favorable decomposition of the detritus. The balance existing in this virgin forest between the production and destruction of detritus is probably best explained by the conception of a rich fauna and flora of detritus-destroying organisms suited to the forest type. When manifold life has been disturbed by thoughtless measures on the part of man it is some time before the soil-improving kinds of trees which one introduces begin to show their favorable influence. This must be taken in conjunction with the fact that the very kinds of broad-leaf trees which belong to the normal development of a forest type seem to have the greatest importance from a soil biological point of view.

The question of the influence of the different kinds of silvicultural systems upon the soil is closely bound up with problems of an economic as well as a biological nature. In order to get clear results investigations must be carried on over a long period of years and under accurately known conditions. For such investigations the research forests belonging to the Research Institute are well adapted. Tonnersjoheden in Halland is an area preeminently suited for the investigations in southern Sweden. The Kulbacksliden -- Svartberget is suited for the study of the important question as to how the soil may best be transformed in the old Norrland forests which have stood too long. Siljansfors affords a good example of how forestry developed in connection with our iron industry has been able to influence the humus layer and life in the soil. If the Institute is granted the proposed larger experimental forest in central and upper Norrland, this area will involve most of the soil problems that are of interest to forestry in Sweden.

The investigations referred to in this work can to a certain extent be regarded as an orientation in the complex of problems which offer themselves for study at the Research Institute.

For forestry production the condition of the humus layer plays an obvious and indisputable role. The more easily the nitrogen transformation is influenced the more favorably does the humus layer react to treatment for the purpose of securing reproduction. As, however, the question of the condition of the humus layer and reproduction is of more limited scope I will treat it by itself in the succeeding publication, Volume 23, entitled: "The Importance of Nitrogen Transformation in the Humus Layer for the Earliest Development of Pine and Spruce Reproduction."

Section XV.

Special Descriptions. (Swedish Text pp. 381-500)

In this section are summarized the geographical, geological, soil and plant data for the localities investigated, and there are also given the results of the laboratory investigations arranged geographically. The material is arranged according to rather large geographical units, (States, and in Sweden according to districts) generally proceeding from south to north.

We need not repeat these special descriptions. A German translation with titles of the tables makes it intelligible for foreign readers who may be interested in some details. For the rest, it may be noted that all of the analysis data relating to the humus layer, which are given in the tables with the special descriptions, may also be found in table 38, Sect. XIII, arranged according to forest types. (Reference figures in the second column of this table indicate the page and number where they are found in the special description). The symbols and ab-

abbreviations in the analysis tables are explained at the beginning of Sec. IV:10. The vegetation descriptions are treated partly according to Raunkiaer (cf. above Sect. IV:1) and partly according to Hult-Sernander. In a single case (Tab. 44) was used the method of Raunkiaer as modified according to Lagerberg applied to 0.5 square meter plots. In the tables "F %" means frequency percentage, and "A %" the percentage of area occupied.

The symbols for the degree of abundance after Hult-Sernander are:

e = solitary
t = sparse
s = frequent
r = abundant
y = covering entirely

Of symbols previously met with in the vegetation analysis:

fl. = spotted
inspr. = sprinkled
h = high
sall. = seldom
rotvalv. = on roots of felled trees

stubb. = on tree stumps

The symbols following the latin name of the plant on p. 387 indicate the strength of the nitrate reaction of the plants (tested with diphenylamin and sulfuric acid) and thus signify:

(Some of the results are referred to by the full
(Phrase on pp. 385, 389 & 406):

s = strong = "stark reaktion"
t = rather strong or significant = "tydlig reaktion"
sv = weak = "svag reaktion"
o = no reaction = "ingen reaktion"

With respect to the plant names used see Nomenklature p. 172.

The numerals at the top in the analysis or vegetation tables indicate the various localities mentioned in the accompanying text. The Latin plant names are printed in italics throughout and so are easily found in the text.

The Swedish terminology for describing the humus layer is fully explained in Sect. 5 above. In order to make the rest of the text somewhat intelligible to foreign readers, the following list may be given.

al (-bestand, -skog), Erle (nbestand - nwald) alder, (alder stand, for forest)

alder, Alter age

aldre, alter(er, e) older, earlier

allman (na), allgemein (e), haufig, general, frequent, common alvsand, Alluvialsand, alluvial sand

antydan till, Andeutung an, indication of

arsskott, Jahr (estrieb), year's growth, shoot, sprout

asp, Espe, aspen

avbrand, abgebrannt, burned down

avdikad, entwassert, drained

avverkning (-syta), Abholzung (-sflache), clearing

avverka, -d, abholzen, abgeholzt, to clear, cleared

back, Bach, brook

barr (-skog, -trad), Nadel (wald, holzer), needle (coniferous)
(forest, tree)

barrbland (bestand, skog), Nadelmischwald, - mixed coniferous forest

barris Vaccinia, (einschliesslich, including, Myrtillus and Oxycoccus)

begynnande, beginnend, - beginning

berg (-grund, -topp), Gestein (sgrund), Berg, (gipfel), - rock stratum
mountain peak

bestand, Bestand - stand

bevuxen, bewachsen, - grown

bjork, Birke, - birch

Blabar (sris), Heidelbeer (kraut), bilberry (plant)

blandad med, mit....gemischt, - mixed with

blekjord, Bleicherde, Bleidherde, Bleisand, - leached earth horizon, white sand

bok (-blad, -lov), Buchen (-blatter, -laub) beech leaves

branna,- brand, brennen, - burn (burned places) burned

brunjord (styp), Braunerde (typus) - brown earth (type)

dald, Talchen, - little valley, dale

dod, tot, - dead

ek, Eiche, - oak

enbuskar, Wacholder, - juniper bushes

faladsmark, alte Weide (Schonen), - old pasture, (Scania, So. We. So. Swed. Prov.)

finkornig, feinkornig, - fine grained

forbrand, verbrannt, - burned up

forharskande, vorherrschend, (pre) - dominant

foryngring (stya), Verjungung (sflache), - reproduction (area)

frodig (t), uppig, - luxuriant

fro (tallar, -trad), Samen (baume) - seed (tree)

fuktig, feucht, - damp

gallring (syta, - sforsok), Durchforstung (sflache, -sversuch), thinning, (area, experiment)

genomarbetad, durchgewahlt., - rooted up, prepared by ploughing

genomsipprande vatten, durchsicherndes Wasser - seeping water

genomvavd, -t, durchwoben, - woven through

graal, - *Alnus incana*

gran (-barr, -skog), Fichte (-nnadeln, -nwald), spruce (needles, forest)

groddplantor, Keimpflanzen, - germinating plants

grynstruktor, Krumelstruktor, - crumb structure

hall, - stones with flat tops

hygge, Kahlschlaglache, - clearcut area

illa behandlad, ubel mitgefahren, - badly treated (managed)

inblandning, Einmischung, - introduction, mixture

ingen, kein, - none

jamforelseyta, Vergleichsflache, - check plot, control area

kal (yta), Kahl (flache), clear-cutting, clear-cut area kalk (-alskande, -berg, -sten,) Kalk (-liebend, -berg, -stein) Lime (-loving, mountain, stone)

kalliknande floden, quellenartige Grundwasserlaufe, spring-like waters

(i) kant (en av), (am) Rand (von),-(on) the edge (of)

klumpstruktur, Krumelstruktur, - crumb structure

krakris, - Empetrum nigrum

krongallring, Hochdurchforstung, - high-cut, German method.

Kvave, Stickstoff, - nitrogen

lav(ar, -behangd, -flack, -rik, -tacke, Flechte (-n, nbehangen, Fleck mit, -n, -reich, -ndecke). Lichen (-covered, spot with -, lichen abundant, -cover).

lag, niedrig, - low

laga, umgefallener Stamm, - felled (trunk)

laggallring, niederdurchforstung, - low-cut, French method

lark, Larche, - larch

lera, Lehm, - loam

lid, sanfter Abhang, - gentle slope

lingon, Preiselbeere, - red whortleberries (Vaccinium vitis idaea)

linnea, - Linnaea borealis

ljung(hed), Heidekraut (Heide), - heath herbs, heath.

ljusgron, hellgrun, - light or bright green

los(t), locker, wenig zusammenhaltend, - loose, lightly held together

lopande arlig tillvaxt, jahrlicher laufender Zuwachs, current annual growth

lov, Laub, - leaf

lucka, Lichtung, Lucke,- clearing, opening (through canopy, glade)

lucker, locker - loose, light

lund, Hain, - grove

maktig(t), machtig, - thick, heavy

mar (-granar, -tallar) unwuchsige kleine (Fichte, Kiefern)
poorly growing (spruce, pines)

massvis, massenhaft, - massed together, in masses

matta, (-or), Matte(n), Teppich (e), - meadow, carpet

markbetackning, Bodendecke, - ground cover (vegetation)

maskar, Wurmer, - worms

mattligt, massig, - moderate

medelalders, mittelaltrig, - middle-aged

metmaskar, Regenwurmer, - earth- or (dew-) worms, (Lumbricus terrestr)

moran, Morane, - moraine

morkgron (a), dunkelgrun, - dark green

moss(-flack, -rik, -tacke), Moos (-flecken, -reich, -decke) - moss

multna, vermodern, - decompose

Myr (en), (das) Moor, (the) Moor

nagot, ein wenig, - a little

nastan, - fast, almost, nearly

norsluttning, Nordabhang, - northern slope

o(ar), Insel (n) - island(s)

oppen, offen,-open

obrand, -t, nicht gebrannt, - unburned

odon, - Vaccinium uliginosum

ormbunkar, Farne, - fern

orord, ungeruhrt, - untouched, unchanged

ort (-er, rik, -vegetation), Kraut (-er, -erreich, -ervegetation)
herb, (herbs, rich in herbs, herbaceous vegetation)

prov(yta), Probe (flache), - test, sample (spot) area

ren(t), - rein, - pure
renlav, Renntierflechte reindeer-moss
rensa, -d, reinigen, gereinigt, - cleanse, purified
riklig (are), reichlich(er), - richly,
ris, Zwergstrauch, auch Reisig, - dwarf bush, also faggots
rorlig(t), beweglich, - mobile, lively
rostjord, Orterde, - (reddish collored-rich layer)
rotter, wurzeln, - roots
sandblandad, mit Sand vermischt, - mixed (blended) with sand
sanka, Vertiefung, - hollow
sidlant (mark) nass(er Boden), low-lying, marshy, (soil, ground)
silvergran, Tanne, - fir
skikt, schicht, - horizon, layer
skog, Wald, - forest
skott, Trieb, - sprout, shoot
Skreva, Kluft, Riss, - cleft, crack, fissure
slottermark, Mahwiese, - hay-field, cropped ground.
sluten, geschlossen, - closed
sluttande, geneiget, - inclined, sloping
sorlandsk, sudschwedisch, - south Swedish
sma, kleine, - small
smarre, kleinere, - smaller
sparsamt, sparlich, - infrequent, sparing
stubbe, -ar, Stummel, - stump, stub
svag (t), schwach, - weak

svart, schwarz, - black

sved, -ja, abgebrannte Flache, abbrennen, - burned area, (fire clearance), burn up

svedning, Abbrennen - clearing by fire

svedjebestand, Bestand auf abgebranntem Boden, - stand on burned ground

tackande, deckend, - covering

tall (hed), Kiefer (nheide), pine (heath)

tat, dicht, - thick, dense

tillvaxt, Zuwachs, - growth

torr (t), trocken, - dry

torvdy, starkt humifer (humifizierte) - Torf, strongly humified peat

torvmark, Torfboden, - peat soil

tunn, -t, dunn, - thin

under, unter, - under

ungplantor, Jungpflazen, - young plants

upptorka (de), vertrocknet, - dried (up)

ur (berg), -skog), Ur (-gestein, -wald), -primitive, virgin (gneiss, primaeval forest)

uthuggen, ausgehauen, - cut out

utmed vagkanter, an Wegrainen entlang, - along the sides of the road

utpraglad, -t, ausgepragt, - markedly

al (sluten), gut (geschlossen), well closed

vanlig, haufig, gewohnlich, - frequently, usual

vaxtlig, gutwachsig, - growing well

vittring (sjord), Verwitterung (sboden), disintegration, weathered soil

yngre, junger (e), - younger