FORESTRY COMMISSION
BULLETIN NO. 15

STUDIES OF CERTAIN SCOTTISH MOORLANDS IN RELATION TO TREE GROWTH

LONDON: HIS MAJESTY'S STATIONERY OFFICE
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PREFACE

THIS bulletin is an account of investigations conducted during a number of years by Dr. G. K. Fraser, of the Department of Forestry, Aberdeen University, into the establishment of timber crops on peat soils in Scotland and particularly under west coast conditions as illustrated at Inverliever on Loch Awe. The question is one of great importance in connection with the extension of the woodland area of Scotland because a large proportion of the land which can be made available for the purpose is more or less peaty.

There are numerous examples in Great Britain of timber growing to maturity on peat and also of complete failure to establish plantations. Peaty soils are in fact extremely variable from the point of view of timber production and a major problem in selecting and planting land is to recognise by means of the existing vegetation and the " lie of the land " which types may be successfully afforested.

Without attempting to summarise Dr. Fraser's work, attention may justly be drawn to two points which emerge partly from his research and partly from other investigations carried out in recent years : first, there is the lack of success in planting trees on that class of peat which is characterised by deer grass and heather (the *Scirpus* high moor type) and second, the value of basic slag combined with methods of turf-planting, in helping trees to start growth under unfavourable conditions. Sir John Stirling-Maxwell, late Chairman of the Commission, has made use of basic slag on a large scale and with striking results on his estate at Corrour in Inverness-shire and the Commission's Research Branch has followed up this work with a number of detailed experiments on various types of bad peat.

The growth of trees on peat is also dealt with in Bulletin No. 13 (" Studies on Tree Roots ") by Dr. E. V. Laing, Department of Forestry, Aberdeen University. The preparation of Bulletins Nos. 13 and 15 and much of the actual research have been supervised by Professor A. W. Borthwick to whom the Commissioners desire to express their thanks.

R. L. ROBINSON
Chairman

FORESTRY COMMISSION,
25 Savile Row,
London, W.1.

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INTRODUCTION

SINCE the commencement of State afforestation on a large scale in this country every effort has been made to bring into cultivation under trees as much as possible of those areas which are unsuitable for the production of any other crop. A large area of land which might be made available for forestry is at present covered by a greater or less depth of peat or wet undecomposed plant remains— raw humus—which can only support vegetation of a moorland character. In certain well-known cases private initiative and enterprise have shown that by the adoption of appropriate methods of amelioration much may be accomplished in the planting of otherwise intractable peat areas.

It has been observed that on patches or islands of mineral soil within such areas, certain species of conifers thrive quite well if adapted to the climatic conditions, elevation and exposure. It may therefore be presumed that the direct cause of poor tree growth is due to the peat or raw humus. Much of this ground is so sodden with water for the greater part of the year that it may show little or no immediate response to drainage and tree growth upon it is liable to be so irregular and uncertain that the establishment of uniformly close forest over extensive areas by the usual silvicultural methods is ruled out. A careful study of such peat areas which had been planted by the ordinary methods provided a valuable clue as to the lines along which further profitable investigation might proceed. It was observed that variation in the rate of tree growth followed in a striking manner variations in the living surface vegetation and the character of the peat. It thus became apparent that a closer study of the peat itself and of its living surface vegetation might reveal some fundamental information regarding the cause of those differences and obviously such information would be a valuable guide to future practice in the afforestation of peat areas. As a result of the investigations which were undertaken it is shown that it is now possible definitely to identify different kinds and qualities of peat, and, further, that it is possible to classify and grade peat soils according to their potential silvicultural values.

The investigations recorded in this bulletin are intended to assist the forester in recognising the different kinds of peat in the field and to assess their probable value for afforestation and at the same time to make clear the causes which have led to the unsatisfactory soil conditions in those peat areas which have, in the past, been regarded as unplantable. One object of these investigations has therefore been to obtain information likely to be useful in indicating how the less tractable peat areas may be rendered fit for afforestation.

As peat is the main subject under consideration it is essential that we should, at the outset, obtain a clear understanding as to how the term is used in this bulletin. It must be borne in mind that peat is here discussed only from the point of view of its characteristics as a soil. In distinction from ordinary soils of mineral origin peat soils are organic in origin and character, that is to say, they result from the accumulation of plant remains. Insufficient drainage or the nature of the vegetation itself, in regions of high rainfall, gives rise to water-logging of the soil, air is excluded, and, as a result, the normal decomposition of plant remains is hindered. A further characteristic of peat soils, namely, a high water-content at or near the surface, is emphasised in this bulletin in contrast to the usual idea that a soil can be considered as a peat soil only when organic matter has accumulated to a certain depth. If, therefore, the permanent water-level of a soil is so high that the roots of plants cannot penetrate to the mineral substratum, then such a soil is here regarded as a peat soil, however thin the surface organic layer may be. The term moorland has also a varied meaning, but is here limited to such areas as bear a peat flora, that is, vegetation characteristic of peat soil.

These definitions are justified from the ecological point of view by the fact that the same vegetation may be found on deep peat as on shallow peat, and it is also justified from the silvicultural point of view by the similarity of the results which follow from the direct planting of both, provided the soil structure has not been altered by cultural operations.

GENERAL SURVEY OF THE ORIGIN AND DEVELOPMENT OF PEAT

Peat soil, like mineral soil, is subject to considerable variation in fertility according to its origin and composition. Earlier investigations into the characteristics of peat were carried out chiefly by Continental workers, and, therefore, the descriptive nomenclature or technical terms adopted in this country consist principally of the English equivalent of the terms used by German writers. This being so it may be helpful if the development of those forms of peat to which the terms have been applied is first considered in order that the meaning of those and other terms, where used, may be more clearly understood.

The main types of moorland upon which peat is developed have been called lowland moor and highland or alpine moor (*see* Raman, 1928, Appendix V). These terms refer to the elevation above sea-level at which the types are usually found. They are apt to cause confusion and are based upon too narrow a view as to the distribution of the types. The writer therefore proposes to substitute for them the terms *basin moor* and *climatic moor*, since they originate, the one locally in basins and depressions in which drainage water collects, the other regionally under the influence of climatic factors, chiefly high rainfall.

Basin moor, of which the English Fens afford the best example, begins to form chiefly in regions of low elevation, at the free water surface of shallow lakes or in basin-like depressions where water collects through faulty drainage and where the movement of the water is hindered to such a degree that floating plants, together with marsh plants, may become established over a considerable extent of its surface. Under such conditions—still, shallow water—the growth is more rapid at, or near, the margin of the water surface. Plant remains begin to form and continue to accumulate on the bed of the lake, in time the marginal rim is raised to the level of the water surface, the floating plants disappear, but the marsh plants continue to raise the emerged margin of the lake until the surface of the bog or moor assumes a saucer shaped contour ; at this stage it is called *low moor*. The process of peat formation continues gradually inwards toward the centre of the bog. As time goes on, and while the central portion of the bog remains wet, the surrounding peripheral portion becomes drier. Meanwhile plant growth continues to encroach upon the wetter central area, and this tends to level out the whole moorland, which is then called *transition* or *flat moor*. Plant growth continues in the wetter central portion towards which the drainage water in the subsoil tends to flow, and the bog assumes a domed outline, like an inverted saucer. This form is called *high moor*. All those stages succeed each other in the sequence indicated, given conditions suitable to the formation of basin moor and a sufficiently long period of time. The different stages leading to the formation of high moor are accompanied by changes in the vegetation and in the character of the resulting peat ; for example, as the surface level of the peat rises above that of the water it becomes less rich in mineral content, and as regards chemical reaction high moor is acid, transition moor is less acid or is intermediate in reaction, while low moor is typically basic.

It should be carefully noted that the terms *low moor* and *high moor* refer to the outline or surface contour of the developing peat masses, and have no significance so far as height above sea-level is concerned.

In the usually accepted nomenclature the term low moor is confined to such conditions as permit the formation of basic peat only, *e.g.*, warm regions of low rainfall. In Scotland low moor of this kind, *i.e.*, basic low moor peat is not found. This basis of separation of low moor from other forms is held by the writer to be illogical, since the name low moor refers to the form of the moor and the saucer-shaped form of moor develops in acid as well as basic water. For this reason all moors having this form are here included as low moors, and all peats which have been deposited below the surface of free water are here termed low moor peats. Low moor peats are therefore separated into basic peats, *e.g.*, the English fens, and acid peats, *e.g.*, the Scottish and majority of the northern and western English basin peats.

Climatic moor develops upon the soil surface in areas of high rainfall, much in the same way as high moor develops on transition moor. Where the soil surface has become stabilised, that is, where it is not subject to shifting or erosion, and especially where, for any reason, such as exposure, grazing, etc., tree growth is prevented, the soil becomes covered with a blanket of impervious humus, for example, heather-humus. This layer of humus tends in wet weather to retain water upon the surface, and in those regions of high rainfall, peat-forming plants (*e.g.*, sphagnum moss) obtain a footing and in turn intensify the wetness of the surface. Finally, owing to the water-holding power of the moor-forming plants combined with the high rainfall, aeration of the surface humus is prevented and the plant remains accumulate to form peat. Just as from a water surface, moorland may develop, passing from low moor to high moor, through transition moor, so also upon the mineral surface there is a transition from strongly mineralised organic soil to poorly mineralised soil or true peat. The central portions of such peat areas tend ultimately to become more elevated than the margin. Thus in speaking of the origin and development of climatic moor the term high moor may be used to indicate its final stage in peat formation. The following points may be helpful in emphasising the difference between basin moor and climatic moor. Basin moor develops through bad drainage, climatic moor develops through high rainfall. Basin moor is confined to depressions or basins, climatic moor may develop more rapidly on badly-drained areas, but it also tends to follow the movement of seepage water, and may thus spread, especially in a downward direction, over the whole region in which the rainfall is sufficient to permit of its growth.

Alpine moor is a term also adopted from Continental writers, but before we proceed further its significance must be more fully considered. The fact of outstanding importance in relation to this type—alpine type—of peat development, is that it is not primarily dependent upon topography but upon climate. This term is derived from the geographical position in which it is found on the Continent, but as it is primarily dependent upon rainfall the term alpine moor is apt to be misleading when applied in Britain. In Europe there are few regions outside of the higher mountain ranges where the rainfall is so high and uniformly distributed throughout the year, as on the west and north coasts of the British Isles. In these regions the principal stable soil type is moorland in character, and it bears a vegetation in which alpine moor plants predominate. These, in turn, have given rise to an impervious waterlogged layer of raw humus of variable depth. Hence, although this moorland region includes our greater mountain masses it is by no means confined to them, but may also be found at low elevations in Britain. It is therefore proposed to use the more correct and comprehensive term *climatic moor* instead of alpine moor.

In the study of soil types the combined effect of rainfall and evaporation is found to give a more satisfactory index of the kind of soil which may be developed in any region, than rainfall alone. A simple yet fairly satisfactory method of expressing the combined action of rainfall and rate of evaporation has been formulated by Meyer (*Chemie der Erde*, 1926, pp. 207-347). It is called the N/S ratio. Here the N stands for the amount of rainfall in millimetres, and the S is a measure of the rate of evaporation. It has been found that the fundamental soil forming processes over wide areas depend to a marked degree upon this ratio, although temperature and wind velocity, with their seasonal variations, are also very important. Map III shows the N/S ratio distribution for Great Britain. For the purpose of this bulletin it was compiled from data of the Royal Meteorological Office, extending over the 35 year period from 1881-1916. There is a fairly close parallelism between those regions for which the N/S ratio is over 1,000, and those areas where climatic moorland constitutes the main stable soil type. Where peat occurs outside of this region its origin is definitely topographical, that is, it has been developed as the result of bad drainage (basin peat).

This fact is of considerable importance in the afforestation of different peat areas. In the case of basin peat deposits which are due to insufficient outflow for ground water, the primary cause of the peat formation may be removed by effective drainage. The further formation of peat being thus checked by the removal of excess water, aeration, and consequently decomposition, sets in, and the area becomes available for tree growth. This process may be seen in a number of localities in eastern Scotland where the cutting of peat banks has drained, though unintentionally, the adjacent peat, with the result that in the vicinity of these cuttings natural development of Scots pine has taken place.

On the other hand, in the western area of high rainfall, where the cause of peat formation is principally climatic it is not to be expected that even intensive drainage would be sufficient, in itself, to check or reverse the process of moorland development. Where moorland of climatic origin has reached a stable (climax) stage, then artificial drainage only reduces the intensity of the effect of rain, and some other means must be adopted to check the natural tendency to moorland development under these conditions. This statement is based on the writer's observations in the field and is confirmed by a special experiment which was started six years ago on a deep peat area in the west of Scotland, where a block of peat was surrounded by a ditch extending to 10 feet in depth. No alteration was observable in the vegetation of the area thus isolated, nor have the prospects for its afforestation improved.

The climatic factors which promote the development of this type of moorland are a high rainfall evenly distributed throughout the year, a low summer temperature and consequent high relative-humidity of the atmosphere. The region in which these conditions prevail extends from the north and west across central Scotland, to the higher ground in the east, and southwards over the border hills into England, where it stretches over the elevated portions of the Pennines and also extends into the Lake district, the greater part of Wales and parts of Devon and Cornwall.

The vegetation of climatic moorland may vary from district to district according to local conditions. In Scotland three principal vegetational variations have been observed, but it is possible that some of these may represent transition stages towards the main type.

The writer's studies have not been, as yet, continued over a sufficiently long period to settle this question definitely. The proposed names and the descriptions of these types are as follows :—

(A) Scirpus Moor. The ultimate (climax) stage of moorland vegetation in the west and north-west of Scotland is dominated by *Scirpus caespitosus*, the deer grass, along with *Calluna vulgaris*, the ling, as co-dominant, but the latter is short and open with a general appearance of want of vigour. Other well-known species which are constantly found are : *Narthecium ossifragum*, the bog asphodel, *Erica tetralix*, the cross-leaved heath, *Potentilla tormentilla*, the tormentil, *Empetrum nigrum*, the black crowberry or crakeberry. Mosses are represented by the short, red and brown sphagnums, the common heath and moorland hypnums, *Rhacomitrum lanuginosum* and others, while species of the lichen genus *Cladonia* are always present. Other species are found locally due to special conditions or to the fact that the stage of stable moorland development has not yet been reached.

(B) Calluna Moor. This type of moorland vegetation occurs towards the north-east of Scotland where the rainfall is generally lower and less evenly distributed throughout the year, and where the relative humidity is also lower and the number of days of bright sunshine is greater. Here the dominant plant is *Calluna vulgaris*, the ling, which under the above conditions forms a fairly close cover. Along with it *Eriophorum vaginatum*, the tufted cotton-grass, occurs as the chief subsidiary species. It may be interesting to note that should the ling be burned off, the cotton-grass may become dominant for a considerable period. Some of the more familiar species which occur in this type of moorland vegetation are *Vaccinium myrtillus*, the blaeberry, *Erica cinerea*, the fine-leaved heath, *Erica tetralix*, *Empetrum nigrum*, the black crowberry and a few grasses. The most abundant mosses are those of the hypnum group ; sphagnum is less abundant, but more vigorous than it is in scirpus moor, and occurs in the form of large evenly distributed mounds of species of the acutifolium group ; lichen species of the genus *Cladonia* are again conspicuous. It is possible that, on its western limit and also at its higher elevations, this type of moorland may develop into scirpus moor. It is apparently quite stable in its eastern distribution.

(C) Molinia Moor. The southern Scottish moorlands are mainly dominated by *Molinia caerulea*, the purple moor-grass. This type of moorland extends into England on the one hand and into central Scotland on the other. The dominant species, molinia, at its maximum development, practically obliterates with its large contiguous tussocks, all other plants. The subsidiary species are mainly the ericaceous plants already noted in the two former types (A) and (B). The following points are, however, worthy of note :—*Eriophorum vaginatum* and *Erica tetralix* become abundant on areas of low surface drainage ; *Eriophorum polystachion* and some sedges increase where free water tends to collect ; other special local conditions may favour the growth of various grasses and rushes. Apart from these exceptions the stable vegetation consists of nearly pure molinia. This type of moorland although well marked and apparently very stable, may be only a stage in the development from mineral soil to scirpus moor. Scirpus moor develops in the same region (the Borders), but at higher elevations where the rainfall is heavier and temperature lower. Molinia moor may be taken to be a stable type, where the summer temperature is more effective in drying the soil and thus allowing an upward movement of water containing mineral matter from the underlying mineral soil.

General Classification of the Principal Regional Peat Types

1. Basin Moor :

Status :—Local or topographical, due to bad surface drainage.

Development :—Free water in basins—low moor—flat (transition) moor—high moor.

Examples :—

A. The English Fens—basic peat in low moor stage. (Low rainfall, high temperature, water basic).

B. The Scottish "moss"—acid peat in low moor stage. (Higher rainfall, lower temperature, water acid).

2. Climatic Moor (including alpine moor) :

Status :—Regional, due to high rainfall, low temperature in summer.

Development :—From other soil or vegetation rapidly to high moor.

Examples :—

A. Scirpus moor—north-western type. (Evenly distributed rainfall, low summer temperature).

B. Calluna moor (or *Calluna-Eriophorum*). North central Scottish type. (Somewhat drier summer, higher evaporation).

C. Molinia moor—southerly type. (Warmer and drier summer, higher evaporation).

The moorland types which are specially dealt with are those of section 2 A, and those of 1 B which lie within the region of 2 A. Examples of these occur at Inverliever within the forest area.

THE PHYSIOGRAPHICAL FEATURES OF THE WESTERN SCOTTISH MOORLAND REGION

The forest of Inverliever presents many natural features which are generally typical of the western Scottish moorland region. It was therefore selected as a suitable area for detailed study in this investigation. This area occupies a position between Loch Awe and the western ridge of the Loch Awe—Loch Avic and Glendomhain watersheds. The area is in the form of an elongated strip extending 9 miles up Loch Awe from Ford at the south-western end and varies in width from about 1 to 1½ miles.

Climate

There are no special features which would justify a distinction being made between the climate of Inverliever and that of the west of Scotland as a whole. Climatic data are given in Appendix I.

The rainfall for the Inverliever area varies from 74 inches at Ford to 88 inches at Cruachan ; the latter figure may be nearer the mean rainfall for the area as a whole than the former. During the period of high rainfall from October to January the precipitation per month varies from 7 to 12 inches, while during the low period from March to July it varies from 4 to 5 inches. The transitional months at the beginning and end of these periods, *i.e.*, February, August and September, have a rainfall of about 6 inches per month. During the drier months rain falls on two-thirds of the total number of days, and on four-fifths of the days during the wetter months, so that the difference is largely due to intensity rather than to duration of rainfall. Periods of 10 days without rain are infrequent. Snow is of little account as the small amount which falls is usually melted within a few hours. Data regarding relative humidity are not available, but field observations show that the soil very seldom becomes dry. After an exceptional 20 days of continuous bright weather with no observed rain, in the warmest season of the year, the soil was still thoroughly wet, and within the moorland area the only drying observed affected merely the outer few millimetres of exposed sphagnum mounds. Evaporation may therefore be considered to have very little effect in removing moisture from the soil under such conditions. Days of bright sunshine are comparatively few, they average about 9 days per month in winter and 11 days in summer.

The mean temperature range of the region is low. At Ford the maximum summer temperature is just over 67° F. and occurs during the month of July. The mean minimum temperature is 30°-31° F. and occurs at the beginning of the year. Like the mean annual, the mean daily variation in temperature is also low. The mean variation between day and night in winter is only 10° F. and in summer 20° F. Those mean figures have been worked out for the sake of the general idea they convey regarding the temperature of the district, but the writer does not consider that those mean figures have the same silvicultural importance as the maxima and minima during the growing season.

At Inverliever, where the humidity of the atmosphere is high and the soil moisture-content considerable, frost does not occur more frequently over the peat-covered ground, than over the mineral soil. This is another point of considerable importance in the difference between climatic peat and topographical or basin peat. The general incidence of frost above the latter is well-known and is due to the cooling effect of the rapid evaporation of water from the peat surface, when the dry air from above the adjacent mineral soil passes over the peat. For one year daily records were kept of the minimum temperatures within the peat itself at a depth of 1 inch. The result is shown in Fig. 1 as mean monthly readings and is compared with records taken at the same

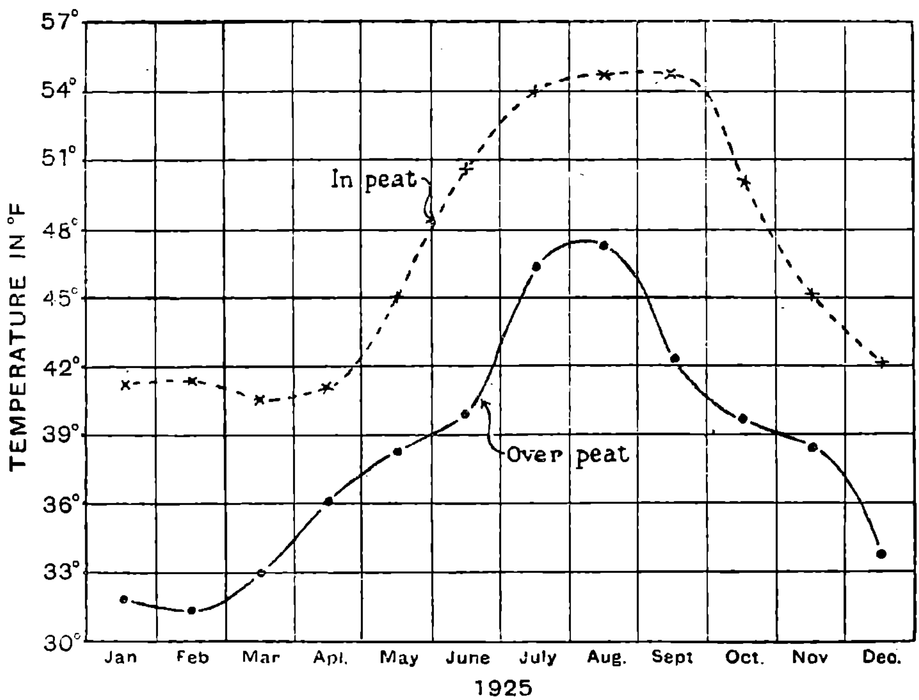

FIG. 1.—Graph of mean monthly temperatures recorded by minimum thermometers at 1 inch below surface and at 3 feet above peat

place at 3 feet above the peat. Variations in the temperature of the peat are much less than in the atmosphere, not only from day to day but throughout the year, and from observations extending over several years it was found that, in deeper peat, the temperature, at a depth of 1 foot, remains stationary, at about 44°-44.5° F. throughout the year.

Silviculturally the temperature at the surface of the peat is of more consequence than that within the peat itself since on many peat soils the roots of young trees creep along the surface of the peat and scarcely penetrate it at all. The temperature readings taken at the Ford and Cruachan stations show that frost may occur in nearly every week of the year, and that it does occur frequently during the growing season with the exception of about seven weeks in July and August. During the months of April and May, which have a mean maximum day temperature of 50°-60° F. and a frost frequency of 4 to 12 nights per month, there is obvious danger to tree growth.

As may be expected, during bright sunshine very marked differences occur between the temperature of the air, the sphagnum moss cover, and the peat itself. In the sphagnum a temperature of 72° F. has been recorded when the air temperature 1 foot above the moss was 48° F., and that below the moss, at the surface of the peat itself, 39° F. Young trees under such conditions are subjected to very marked changes in temperature within a few hours. Should any night, during which ground temperature reaches freezing point, be followed by bright sunshine next morning, the quick change in temperature is apt to intensify the effect of the frost.

To summarise the above, Inverliever is situated within that area of high rainfall which is characteristic of cool temperate, western maritime, mountainous regions. The outstanding features of such an area are :—high annual rainfall fairly evenly distributed throughout the year, a consequent low number of hours of total bright sunshine, and a correspondingly low range of daily and annual mean variations in temperature. Night frosts are frequent in the early growing season. The temperature of the peat rapidly reaches a constant figure at a short distance below the surface, but at the surface the difference between day and night temperature is intensified by the heat absorbing capacity of the ground vegetation, during morning sunshine.

Topography and Exposure

The forest of Inverliever lies about 10 miles inland from the west coast but is to some extent cut off from the influence of the sea by intervening hilly ground. The forest area as we have seen, is in the form of an elongated strip which occupies the western slopes above Loch Awe. Both the loch and the forest run in a north-east to south-west direction. The elevation of the ground rises from both ends, south-west and north-east, towards the centre of the area where it culminates in Dun Corrach, a side ridge above Kilmaha, which cuts across the general direction of the main ridge and valley ; with this modification the general contour consists of a series of slopes and precipitous steps alternating with flats and valleys which run in a direction parallel to the loch (*see* Map I). From the south-west towards Dun Corrach, the ascent from the loch is fairly abrupt, being 600 feet in half a mile ; at Dun Corrach it becomes almost precipitous, reaching 850 feet in a quarter of a mile, beyond Dun Corrach the character of the slope is similar to that on the south-west of the area, until Cruachan is reached, from there to the north-east end the rise towards the north consists of a series of gentle slopes which terminate in low ridges, with wide intervening flats, reaching a height of not more than 200-300 feet, at half a mile from the loch. To the south-west of Cruachan, the presence of morainic slopes and mounds, causes some irregularity in the topography. Behind the summit of Dun Corrach, topography is also irregular, but in this case the irregularity has been caused by glacial action and water erosion.

As the general run of the ridges and valleys is parallel to the loch and the dip of the rock strata is north-west, the ultimate outlet for the drainage water from these low gradient valleys is provided by deeply eroded ravines which strike across from the high ground to the loch.

Owing to the lie of the loch and the surrounding terrain, no barrier is presented to the passage of persistent and frequently strong south-west wind and with the exception of the north-east slopes of Dun Corrach, which affords a partial break, and the lower slopes near Cruachan, the area may be said to be strongly exposed. For about half the year the wind sweeps through the valley in a south-westerly direction ; during the spring months north and north-westerly air movements from the Ben Cruachan massif at the north-east end of the loch must tend to intensify the effect of late frosts.

Geology of Inverliever and its Mineral Soils

Two geological formations occur at Inverliever (*see* Geological Map). Of these, the series of rocks known as the Loch Awe epidiorite sill, occupies the greater part of the area. The other formation, the Loch Awe metamorphic grits, is of much smaller extent. The epidiorite series varies from definitely igneous massive rocks, such as andesite and epidiorite to strongly metamorphosed schistose rocks such as chlorite schist and even calcareous lenticular slates. The rocks, on the whole, are fine grained and are basic in character ; weathering takes place slowly and results in the production of a somewhat heavy soil. The grit series contains also, in small amounts, strata of slate and limestone ; these, however, are confined to the loch shores and to the steep wooded declivities near Kilmaha and therefore do not occur under conditions which permit of the development of peat. In the north-eastern section, from Cruachan and Barmaddy to the boundary of the forest, the grits or quartzite, which often contain a slight admixture of chlorite, are of a greyish or greenish colour and generally coarse in texture. As they are usually overlain by glacial material, they do not contribute markedly to the character of the soil. The more level ground to the north-east, which corresponds roughly with the distribution of the grit, is covered by a stiff till of mixed origin, which is of a greyish-green or blue colour, and which on exposure weathers normally to a yellow or dark red-brown soil. The glacial drift which covers the rest of this section of the area is coarser in character having been washed free of its finer material. The moraines around Cruachan are also composed of somewhat coarse material. The drift on the lower slopes has been altered by the addition of finer material washed down from the higher levels, and fairly heavy clays occur frequently on the lower wooded slopes. Sand and gravels, although present at the south-west end of the loch, do not occur upon the area itself.

A detailed mechanical analysis of the mineral soil was not considered necessary, as it would have served no useful purpose in this inquiry. Suffice it to say that the compact till of the Cruachan-Dalavich area has, on weathering, a similar mechanical composition to the subsoil of the lower epidiorite ground, and that the moraines of Cruachan resemble the drift slopes of the higher ground. Locally, where the grit reaches the surface, the soil is quite coarse. Owing to the irregularity in depth of the generally shallow soil a good deal of variation in its mechanical composition is found throughout the area.

According to structure the mineral soils fall into four types :—(1) creep soil, (2) glei soil, (3) podsol soil, and (4) glei-podsol.

(*See* RAMANN (Trans. Whittles), *Evolution and Classification of Soils*, Cambridge, 1928).

1. **Creep Soil.**—In this type the surface humus or humose soil layer changes gradually to slightly leached yellow or brown mineral soil, which in turn gradually alters to the brown drift below. This type of soil is found on the lower ground where woodlands exist ; it is also found on most areas where grass-land or grassy heath occurs and even on the higher ground with calluna heath vegetation. The main characteristic feature of this type of soil is that there is no appearance, below the surface humus, of strong leaching or washing out of the brown or yellow-coloured iron oxides. This soil is the result of the downward or Creep movement of the surface, which takes place, on steep slopes, under the action of rain. That calluna heath may be found on this type of soil has been mentioned, but in these cases such occupation has been so recent that signs of strong leaching are not yet apparent.

2. **Glei Soil.**—In places where water passes slowly through or over the soil, as on seepage slopes near streams and ditches, or in marshy areas, the soils show the glei structure. The soil, while still typically glei in structure, may present a modified appearance according to its depth and rate of water-flow. For example, where the mineral soil is deeper and the surface movement of the water more rapid, the humus becomes well mixed with the mineral soil. Below the dark humus-coloured surface, due to the admixture of humus with the mineral soil, there occurs a greenish or bluish-grey coloured layer, which, lower down becomes streaked or splashed with a red mottling. On the other hand, where the mineral soil is shallower and the surface movement of the water less rapid *i.e.*, where the water is more stagnant, the surface humus is not so rapidly decomposed and it therefore does not become mixed with the mineral soil. Nevertheless, the exclusion of air owing to the wetter condition of the surface humus, brings about those same changes in the iron compounds which give origin to the decoloration typical of glei, and below this greenish or bluish-grey layer iron accumulates and forms a bright brown more or less pan-like incrustation, instead of the layer with red mottling as found in the deeper soils. It will be seen that, in both those cases, although the top and bottom layers of each differ, the zone of decoloration typical of glei occurs.

Soils in which insufficiency of air produces decoloration (reduction) of iron compounds, followed by their accumulation as concretions (*e.g.*, as pans or as nodules), are termed glei soils ; the glei structure is seen in marshes.

3. **Podsol Soil.**—True podsol soils are confined to morainic knolls and some slopes where the drift is of coarse structure. The dark coloured humus layer is well marked off from the ash grey mineral soil. Below the ash-grey layer occurs a thin but distinctly marked dark brown zone of iron deposition, mostly in the form of a pan, which in turn overlies the reddish-brown weathered drift. The surface organic layer may vary with depth, from heath raw-humus, in the shallower deposits, to peat, in the deeper deposits.

Podsol means ash grey soil. The name arises from the fact that in typical podsol the mineral soil below the surface humus has an ash grey colour. This is the colour of the soil which remains after the yellow or reddish iron compounds have been washed out by the action of rain. The iron compounds along with humus are deposited in the lower soil strata either diffusely or at a certain depth, when the structure known as " pan " or " moorpan " is found.

4. **Glei-Podsol.**—On many parts of the Inverliever area the surface humus is peat and the zone of mineral soil immediately below this is ash grey in colour

and according to our definition this appearance would indicate podsol. But when the ash-grey soil is examined in the laboratory it is found that it still contains iron compounds. The colour is therefore not due entirely to leaching or the removal of the iron compounds, as would be the case in true podsol formation, but the ash-grey colour results from a combined action of leaching and a decoloration of the iron compounds. Consequently we have here a soil type which may best be described as a glei-podsol. In the field it is often difficult to distinguish between glei-podsol and true podsol by appearance, yet we have in these two types a fundamental difference in structure. In most cases the glei-podsol structure is revealed by the presence of a greenish-tinge in the ash grey layer. Also the position in which this type of soil is found may help to give a clue to its structure. Glei-podsol is found below the greater area of the more shallow peat in places where the topography is fairly regular or on slopes which are not very steep.

As regards the silvicultural possibilities of these different soil types it is found that the establishment of woodlands upon the unstable creep soils presents no special difficulties, and where they occur on the lower slopes at Inverliever, conifers have grown quite satisfactorily. The chief difficulty with plants on such soils, at the higher elevations of Dun Corrach, is the strong winds to which they are exposed when they reach a few feet in height. In those places where calluna has taken possession of creep soils, planting becomes more difficult on account of the tendency to waterlogging, caused by the high rainfall which maintains the heath raw-humus in an almost constantly sodden and impervious condition.

On the podsols of the morainic knolls and coarser soils, the chief difficulties lie in the soil itself, one being its poverty in mineral food-material owing to the action of leaching, and the other its high water-content. In the case of glei-podsols these difficulties are accentuated, especially the waterlogging of the soil. Upon glei soils of the deeper type with well decomposed humus, moisture-loving conifers grow rapidly, especially after drainage ; but on podsolic glei soils of the shallower type, where the humus is not well decomposed and where iron accumulation takes place near the surface, drainage is slow in taking effect, owing to the impervious character of the iron oxide deposits and the absence of decomposition in the surface humus. The result is that the growth of conifers on such soil is apt to be slow and very irregular.

THE VEGETATION OF THE WESTERN SCOTTISH MOORLAND REGION

In preface to the descriptions of the vegetational and soil variations, of the west of Scotland moorland region, which now follow, the writer wishes to point out that the subject is treated from the attitude of the silviculturalist. By the ecologist, minor variations in vegetation are apt to be considered of somewhat less importance than a comprehensive view of the vegetation as a whole, since these minor variations are incidental to the general vegetational type. Silviculturally (and edaphically) this is not so, since the development of minor changes in the vegetation may accompany changes in the soil condition of considerable importance, and are thus of great value in guiding the forester in his selection of the right species to plant and of any special methods of preparation and planting which may be advisable. Minor variations from a main vegetational type may be of great silvicultural importance when, as frequently happens, they cover large areas.

As stated in the preceding chapter, Inverliever was regarded as being generally typical of the western moorland, and the detailed investigations concerning vegetation which are described below were carried out there. As in most parts of this country, the vegetation at Inverliever is only semi-natural, since over most of the area interference by man has been sufficient to modify the vegetation either directly or indirectly. These artificial disturbances have taken several forms. In earlier times they resulted from the practice of iron smelting and agriculture (*see* RITCHIE'S *Animal Life in Scotland.*) In more recent times grazing and sport have had their influence. Altogether these disturbances have consisted in the felling of timber, without replanting or natural regeneration, and in the regular grazing and burning of the surface herbage, and this has led to permanent vegetational changes. These practices have been general throughout the west of Scotland, with the result that the present vegetation represents the natural vegetation as modified by man.

Non-Moorland Types of Vegetation

I.—WOODLAND TYPES

Upon the creep soils of the more sheltered sites such as near Loch Awe, and for some distance upwards on the rockier slopes, outcrops and in stream ravines, a well-marked zone of broadleaved woodland occurs. Although coppiced in earlier days, these woodlands have been neglected within recent times. Locally, as at New York, Inverliever Island and around Ford, those old coppice woodlands have been replaced by conifers in pure and mixed plantations. The less altered natural woodland is mainly oakwood, with a marginal screen of elm along the shore of the loch ; alder groups occur locally, especially on the badly drained spots.

Two forms of this woodland may be distinguished :—

I.—1. On the epidiorites, and calcareous rocks near Kilmaha, the natural oak woodland contains a considerable proportion of ash and elm. The under-canopy is very irregularly developed and consists of small trees like hazel, rowan, willows and bird cherry. Here and there, chiefly where the canopy is broken by ground irregularities, a dense undergrowth is formed of wild roses, bramble, blackthorn and other woody shrubs.

The ground flora is very varied, some of the species are generally associated with damp, rich soils in Scotland, *e.g.*, *Circaea alpina*, *Sanicula europaea*, *Asperula odorata* and *Fragaria vesca*. Other and usually more abundant species which occur here are common to damp broadleaved woodlands, *e.g.*, *Ranunculus ficaria*, *Arenaria trinervia* and *Ajuga reptans*. In deeply shaded rocky places, where higher plants are scanty, mosses and liverworts occur in considerable variety.

I.—2. On till and on the grits to the north-east, the oak becomes poorer in quality and in part is replaced by birch. The under-canopy plants become less abundant and of what remains hazel and rowan are the chief species. Thickets of bramble and other woody shrubs are rarely found. In the more open spaces bracken may become abundant. The ground flora is mainly composed of grasses, *e.g.*, *Aira flexuosa*, *Agrostis* spp., *Holcus* spp., *Festuca ovina*. Where the canopy is dense and also where outcrops occur, a few of the common woodland mosses appear, *e.g.*, *Hypnum schreberi*, *Hylocomium splendens*, *Brachythecium purum*, *Plagiothecium undulatum*, *Dicranum scoparium*, *Polytrichum* spp. and *Mnium hornum*.

Within the Forestry Commission's area at Inverliever these woodlands have recently been replaced to a great extent by coniferous plantations.

II.—Grassland Types

At Inverliever a series of grassland or grassy heath types now exist on areas which to a large extent were formerly under oakwood. The true grassland (without raw humus) is apparently always a development from the better (I. 1) type of oak woodland or alternatively it has, in past times, been subjected to intensive cultural operations, like ploughing and liming. Local variations in the character of the vegetation of these grasslands are of frequent occurrence.

II.—1. On the more basic rocks, when tree canopy is removed the thicket or undergrowth plants usually become dominant if left undisturbed, but when grazed, grasses such as *Agrostis* spp., *Aira flexuosa*, *Anthoxanthum odoratum* and *Molinia* take possession of the less humose, better drained places, while on the wetter and more humose sites the following plants appear :—*Juncus articulatus* along with grasses like *Molinia*, *Agrostis alba* and *Holcus lanatus* ; bracken which would be naturally abundant, is artificially reduced by cutting over. The subsidiary plants are represented by *Senecio jacobaea*, *Primula vulgaris*, *Ajuga reptans*, *Digitalis purpurea* and *Hypericum* spp. among many others.

II.—2. Like woodland, grassland also changes on passing from epidiorite to the less massive rocks and to till. Although the chief species of grasses are the same as in II. 1, the relative abundance of the individual species alters ; *Aira flexuosa* becomes very abundant, species like *Festuca ovina* and *Anthoxanthum odoratum* abundant, and the softer grasses like *Agrostis* and *Holcus lanatus* less frequent. Ericaceous plants (*Calluna* and *Vaccinium myrtillus*) and their associates (*Potentilla tormentilla*, *Galium saxatile*, *Teucrium scorodonia* and *Solidago virgaurea*) become frequent in tufts and patches. *Calluna* becomes locally dominant especially where the grassland adjoins moorland. Mosses become abundant principally in association with the ericaceous plants ; the principal species are *Hylocomium splendens*, *Hypnum schreberi*, *Brachythecium purum*, *Hylocomium* spp. and *Dicranum scoparium*.

This type of heath-grassland and its variations occur not only on the low ground but also at higher elevations especially on the unstable soils, for example near the summit of Dun Corrach. On ground of this kind planting has met with a fair degree of success where other locality factors are favourable.

III.—Heath Types

On heath calluna is dominant (it is also dominant in some places as a transitional phase between two vegetational types.) There are two heath types corresponding to two kinds of soil. The distinction between them is more fundamental than that upon which the two divisions made in woodland and in grassland is based.

III.—1. Reference has already been made to the occurrence of calluna on creep soil at higher elevations and on steep slopes. The heath raw-humus overlies scarcely altered soil or rock debris, without visible evidence of iron leaching. For this reason it is considered that this type of calluna heath has only in comparatively recent times replaced grassland. The calluna is of short, vigorous, compact growth. The subsidiary plants, which occur on this type of heath, though fairly frequent are of such habit of growth that they do not interrupt the continuity of the calluna cover. These are *Potentilla tormentilla, Galium saxatile, Aira flexuosa, Luzula campestris* and *Carex binervis*. The mosses present are : *Hypnum schreberi, Hypnum cupressiforme, Hylocomium splendens, Brachythecium purum* and *Dicranum scoparium*. A typical feature is the absence of sphagnum.

III.—2. Moraine Heath.—Calluna heath also occurs on morainic slopes and knolls on podsol soils. Here the calluna is as a rule less dense, of less even height and less vigorous than on the previous type. Subsidiary species are more frequent and the mosses are more abundant and readily visible among the other vegetation. The commoner subsidiary plants are *Erica tetralix, Juncus squarrosus, Carex binervis, Scirpus caespitosus, Empetrum nigrum, Potentilla tormentilla* and *Galium saxatile*. The more common mosses are the same as those of the slope heath with the addition of *Rhacomitrium lanuginosum* and sphagnum, the latter consisting of short forms of the acutifolium group.

The mineral soil below is definitely podsolic and the humus layer on the surface varies from heath raw-humus to peat, peat being the more usual form at Inverliever.

IV.—Subsidiary Vegetational Types

Flushes.—In addition to the main vegetational types described, other local but important types are found. These are mainly associated with ground water movement, such as occurs along the banks of streams, on natural drainage slopes and similar places. A few of the more notable examples of flush vegetation are here given to illustrate the differences in these subsidiary types.

The term " flush " is used to indicate that the soil upon which flush vegetation grows, is irrigated by free-moving water, which passes over or through it from springs or other local sources of water.

IV.—1. Non-humose Flush.—Flush areas, which occur along the margins of shallow streams and on less stable soil where organic matter has not accumulated, may not show a marked difference from the surrounding vegetation ; on the other hand they are often occupied by quite distinctive vegetation. For example, in woodland, such trees as hazel and bird cherry which belong to the under canopy may become more abundant without altering the general character of the wood. In grassland flushes, especially on those grasslands with underlying basic rocks, *Juncus articulatus. Myrica gale, Molinia caerulea* and other marsh plants become abundant among the usual grassland plants. On the grits and boulder till, *Aira caespitosa* is specially liable to become dominant and may oust the other plants. Scrubby *Salix cinerea* and *S. aurita* may frequently appear under both conditions of the grassland substratum.

IV.—2. Fresh Humose Flush.—Humose flushes are more common than the non-humose flushes. Where the flush water is fresh and well aerated, plant remains decompose into mould and humus accumulates. This type of flush may therefore be referred to as fresh-flush. In woodlands dense groups of alder may often occur on such flushes to the exclusion of the ground vegetation, but otherwise under opener canopy, *Iris pseudacorus, Juncus articulatus, Phragmites communis* and wet meadow grasses occur along with other marsh plants. When the trees are removed, these plants form a dense growth along with many shade and half-shade marsh plants. While *Juncus* flush is of general occurrence over the area, iris flush is confined to the lower ground and mainly to the basic rocks. The soils of these flushes may vary from humose mud or clay to organic soils with little inorganic matter present. So far as these have been examined no real pan has been found, and the mineral soil is glei.

IV.—3. Humose Iron Flush.—When flush water contains quantities of iron the type of vegetation is altered.

(*a*) On the heavier and deeper soils of the more massive epidiorites, the most abundant plant is *Juncus articulatus* (including subspecies *Juncus lamprocarpus*). *Myrica gale* may frequently occur in abundance, though this is not always the case. The wet moorland grasses are also present. Molinia is often abundant, and sedges are generally frequent. A notable feature of all kinds of iron flush is the presence in quantity of *Euphrasia* spp. (*Euphrasia scotica** seems to be confined to moorland and other soils where iron occurs in abundance). Among the plants which are grown upon this kind of iron flush, many occur which are of almost casual distribution. The moss flora, while varied, is mainly made up of *Hypnum schreberi*, *Hypnum cuspidatum* and *Brachythecium purum*, but other marsh and moorland species occur, such as *Rhacomitrium lanuginosum* (diffuse form), *Aulacomnium palustre* and *Funaria hygrometrica*. Sphagnum is mainly transitional, though various species occur here and there, usually of the acutifolium group.

The soil is a humose glei and, when shallow, shows iron incrustations near the surface. In contrast to the next type of iron flush to be described, the humus of the surface here is not completely cemented with iron oxide, it is of a dense black colour, which indicates better condition of aeration than the following type.

(*b*) Where iron flush occurs on the more stable soils of heath and grassland, the flush vegetation is of a different type. The moss cover is much more prominent, sphagnum is more frequent and the higher plants grow in open formation on the mossy surface. Moorland plants predominate and grasses are less abundant. *Molinia caerulea*, *Narthecium ossifragum*, *Aira flexuosa*, the cotton grasses, *Juncus squarrosus*, *Erica tetralix*, and sedges occur in an open matrix of *Juncus articulatus* which is of characteristically short growth. *Myrica gale* may or may not be abundant. The complete list of plants in any one example may run into a high number.

The soil is covered by very tough raw-humus, encrusted with iron-oxide precipitation, which forms a pan-like deposit at the surface or a real iron-pan at a depth of a few inches.

These non-moorland types of vegetation cover less than half the area at Inverliever. They are principally confined to the area below the road (shown on Map 1). The area above the road is mainly moorland.

Moorland Types of Vegetation

V.—Transitional Types

Since man began to upset the balance of the natural vegetation, there can be no doubt that the area covered by moorland has been extending. Development to the climax moorland vegetation, however, has not yet had time to take place over the whole area. In the opinion of the writer a very great

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* *Euphrasia scotica*, see F. Townsend, *Jour. of Bot.*, 41, 1903, p. 57

proportion of the moorland vegetation of the west of Scotland is as yet in a transitional stage. The transitional types are generally found upon shallow peat overlying the glei-podsol mineral soil type. In the following description the vegetation is linked up with that of the non-moorland types, from which the writer's field studies have led him to conclude they have been derived.

V.—1. Transitional Grass to Moor. Scirpus-Molinia.—Upon the heavier and richer soils the progress from grassland to moorland is slow and is not marked by any rapid change in flora. The grassland plants are gradually displaced by moorland plants. *Molinia* becomes more abundant, pads of *Sphagnum* appear amongst the grasses. The normal grassland plants are replaced by *Scirpus, Narthecium ossifragum* and *Eriophorum polystachion. Erica tetralix* is confined to the wetter hollows at first, but later it becomes more general. *Calluna* is, to begin with, comparatively infrequent. Plants like *Molinia, Juncus articulatus* and *Myrica gale* become locally abundant.

In time *Scirpus* becomes dominant, and along with it, the chief subsidiary plants are : *Molinia* of a short stunted growth, *Narthecium ossifragum, Potentilla tormentilla, Erica tetralix* and *Eriophorum polystachion.* The moss flora consists of frequent small pads of species of *Sphagnum* of the *Acutifolia* group, *Sphagnum compactum* and other short compact forms, along with smaller quantities of *Hypnum schreberi, Brachythecium purum* and others. A large number of relict plants or survivors from the earlier vegetation are also found.

The extinction of these relicts and the increase of calluna of short growth which ultimately occurs, is the next stage in the development towards the climax vegetation.

V.—2. Transitional Heath to Moor. Scirpus-Calluna-Molinia.—As calluna and other ericaceous plants become more abundant upon the heath-grassland a layer of impervious humus begins to accumulate upon the soil surface so that it becomes distinctly wetter. Upon this wet surface and in the shelter afforded by the calluna tufts, sphagnum becomes more abundant. It appears in the form of pads or mounds and is of rapid growth, especially when the calluna is high and vigorous and where the ground is sheltered, as on steep slopes or near plantations. These mounds of sphagnum suppress the original heath plants such as the grasses (*e.g., Aira flexuosa*), while around the mounds moorland plants begin to appear. In general, scirpus is the most notable of these (locally *Eriophorum vaginatum* is most abundant). After this modification of the vegetation has been produced by the rapid growth of sphagnum in the shelter of calluna, a more stable condition is reached. Calluna and subsequently sphagnum decrease in vigour of growth ; the sphagnum mounds become flattened down and, on the level sphagnum bed thus formed, scirpus, calluna and molinia become co-dominant with *Narthecium, Erica tetralix* abundant, though not so noticeable as calluna and molinia. Scirpus occurs, throughout the moss matrix principally in the form of tufts, though also in diffuse distribution. Calluna, on the other hand, occurs diffusely scattered, and it is of short, slow growth with only occasional tufts here and there ; molinia is diffuse and of short growth. These plants are in general sufficiently open to show the moss ground-cover below. The mosses are chiefly sphagnums (short red brown and yellow members of the acutifolia and compact cymbifolia forms) along with diffuse *Rhacomitrium lanuginosum, Hypnum schreberi, Hylocomium splendens, Brachythecium purum* and others.

Further change toward climax vegetation consists chiefly in the reduction in quantity of molinia, the disappearance of subsidiary relict species and the levelling off of the calluna tufts to evenly short growth.

V.—(2) (a) At higher elevations and especially on sheltered steep slopes (for example, on north to north-west aspects) grass-heath and calluna-heath change in a similar way to begin with. But at these higher elevations the growth of the sphagnum mounds is not rapidly suppressed and they therefore tend to envelop other plants. To the eye the vegetation presents the general appearance of mounds of sphagnum which give a dreary reddish-yellow colour to the ground, amongst which calluna forms long tufts and brooms. The species of sphagnum are somewhat varied but consist chiefly of the more robust members of the Acutifolia group; for example, *S. acutifolium*, *S. rubellum*, *S. warnstorfii*. Subsidiary higher plants, though not always conspicuous, may be present in considerable variety; such are *Potentilla tormentilla*, *Scirpus caespitosus*, *Eriophorum vaginatum*, *Erica tetralix*, *Vaccinium myrtillus*, *Aira flexuosa* and *Luzula campestris*.

This subtype, although only a stage in the development towards the climax vegetation, is at least fairly permanent. It owes its stability to those site conditions where the sphagnum mounds find shelter from direct sunlight. Without shade, growth of sphagnum in mounds falls off when height carries them above the protective shelter of the ground vegetation. Under partial shelter this mound-growth continues. This is an important point in relation to the growth of trees in sphagnum, when it is borne in mind that a checked tree crop may afford sphagnum the amount of shelter necessary for its rapid growth.

V.—3. Transition on Morainic Heath. Calluna-Scirpus.—The details of the changes in vegetation which take place upon morainic knolls vary considerably from site to site. On those sites where the sphagnum finds shelter the changes which take place are not essentially different from those of heath-grassland. As a rule, however, the short and open condition of the calluna and the exposed position of such knolls retard the development of sphagnum which under these conditions is able to form only small pads in the more open places amongst the heather. These conditions, however, allow scirpus and other moorland plants to become more abundant. To distinguish this from the more usual type of *Scirpus-Calluna* vegetation, it is called *Calluna-Scirpus* type. Here calluna is more abundant than scirpus and this gives the area a much darker appearance than that presented by the *Scirpus-Calluna* type. At the same time scirpus is on the whole of fairly robust growth forming fairly strong tufts. Molinia, where it occurs, is short in growth and rarely tufted. Apart from *Potentilla tormentilla*, which is very general, other species are not worth special note. Sphagnum (acutifolia) is the principal moss along with which occurs such heath-moorland species as *Hypnum schreberi*, *Brachythecium purum* and *Hylocomium splendens*.

Vegetation of this type lends itself readily to burning, with the result that, at Inverliever and elsewhere, the actual dominant plant may be *Scirpus*, as this species is not affected by the burning to the same extent as *Calluna*. However, if the area is left unburnt over some years, calluna again re-asserts its dominance.

The silvicultural treatment of these transitional types is extremely troublesome. On grass moor, in its earlier stages of transition, tree growth is satisfactory though irregular. In the later stages of transformation, when sphagnum and scirpus have become abundant, the young trees do not readily recover from the initial planting check, and where *Erica tetralix* is present the check is severe. In the case of heath moor, when the transition is entering the sphagnum mound-forming stage, a gradually increasing check period is noticeable in recently planted trees, and this becomes progressively more severe as the sphagnum mounds increase. In this case density of planting is important, since by close planting the earlier formation of canopy is secured and the shade thus produced stops further development of the injurious sphagnum. On the other hand wide planting only affords side shelter, which accelerates the growth of sphagnum mounds.

In the case of the subtype, mentioned above, where mound formation of sphagnum is a permanent feature, no examples of successful planting have been observed, all that can be said is that trees may remain alive for a long time. On *Calluna-Scirpus* morainic mounds, the difficulties associated with calluna heath are accentuated by the formation of peat.

VI.—The Flush Types

Although flush areas owe their origin to a factor which is not dependent upon the properties of the soil itself, still on different sites and in different soils the reaction, as may be anticipated, will vary, and this is what gives rise to the different types of flush areas.

As might be expected flush vegetation is more stable than the surrounding vegetation, until the latter has reached its climax stage, the underlying reason being that the soil of the flush area has an extra water supply which is not dependent upon the nature of the soil covering, or the character of the soil itself, and as long as this flush water passes through the soil, the flush vegetation will persist.

In dealing with the non-moorland vegetation a number of flush types were described. As these types are more or less stable in character it follows that when grassland or heath have given place to moorland, the same type of flush vegetation may be common to both the moorland and non-moorland vegetation. There are, however, one or two flush types which are associated only with mineral soils. For example, iris flush is essentially a marsh type, having a humose soil with a large admixture of mineral matter, and again *Aira caespitosa* flush does not occur on peat. Upon peat soils many varieties of flush are to be found, but apart from the following well-marked examples they are of little importance or may be grouped with the types now described.

VI.—1. Rush Flush.—This type, found on humose mineral soil, persists in moorland so long as water rich in mineral material passes through the surface of the ground. On peat, the details of the vegetation may vary from rush flush on mineral soil areas, but the general appearance is the same. The dominant plant is *Juncus articulatus*, and although it is of close growth, it is accompanied by some grasses. Other subsidiary plants occur and these may become abundant locally. On moorland the chief grass is *Molinia caerulea* but *Agrostis* spp. and *Holcus lanatus* are also usually present in quantity. Grasses are usually dominant in the marginal zone, although in the heath types calluna may replace these. Of the other plants *Myrica gale* often becomes abundant especially in the opener rush canopy, but no other species of the many which occur requires special mention.

VI.—2. Molinia Flush.—This occurs where the accumulation of water is more marked and where its mineral quality is lower. In its most luxuriant development, in the form of well developed clumps or tufts, molinia excludes all other plants, but pure molinia is not of frequent occurrence. *Eriophorum vaginatum* is a common associate of the molinia, and it may become abundant around the margin of a flush bordering on scirpus moorland. Where the drainage is slower and the water inclines to lodge, the higher plants begin to open out and in the intervening spaces sphagnum of the Cymbifolia group assume possession along with *Eriophorum polystachion* and *Erica tetralix*. In certain localities molinia flush merges into the iron flush type, previously described. In these cases the transitional stage consists of short non-tufted molinia mixed with *Eriophorum polystachion*. In all of these types *Myrica gale* may be found in occasional or abundant partnership.

Flushes in which the water is more stagnant and less rich in mineral content may be grouped under two headings.

VI.—3. Eriophorum vaginatum Flush.—This indicates slow percolation of poorly mineralised water, down slopes. The subtypes grouped under this head may show considerable variation in appearance, but silviculturally they form a definite group. We have seen that in molinia flush where the effect of flush water becomes less marked—that is towards the margin—*Eriophorum vaginatum* becomes abundant. The conditions which occur locally in this marginal phase are similar to those on sloping ground where surface water movement is slow. On sites of this kind *Eriophorum vaginatum* develops whatever may have been the earlier vegetation. In wet grassland the abundance of *Eriophorum* may be a short transitional phase to scirpus moor.

Eriophorum quickly forms peat because of its tufted mode of growth and the resistance of its remains to decay. Various sphagnums tend to develop in the shelter formed by its tussocks and the vegetational type developed remains quite stable until the growth of peat on the surface alters the contour sufficiently to prevent flush action. The subsidiary plants vary from one place to another. Variation in degree of shading both by *Eriophorum* and by the chief subsidiary plants alters the degree of development of sphagnum. In some cases, therefore, for example on wet grassland, sphagnum is not abundant and is not generally visible ; in others, for example, in the earlier stages of development from grassy-heath, sphagnum is abundant, and very vigorous. Subsequently at Inverliever these variations become similar since sub-shrubs like *Calluna*, *Vaccinium myrtillus*, *V. vitis-idaea*, *Myrica gale* and *Erica tetralix* find suitable conditions for growth on the *Eriophorum* tufts and may to a considerable degree mask the abundance of *Eriophorum*. Variation in this type is therefore mainly due on the one hand, to the persistence of relict plants of the grass and heath types on which *Eriophorum* has developed and, on the other hand, to the degree of success with which those secondary species mentioned have developed upon the *Eriophorum*. The extreme example of calluna completely dominating *Eriophorum* occurs on northern and eastern moors, so that although fundamentally *Eriophorum* moors, these are usually called calluna moors.

When the *Eriophorum vaginatum* type rises above the influence of flush water it slowly passes into scirpus moor. Scirpus and its associates occupy in the first place the wetter hollows surrounding the *Eriophorum* tufts, and subsequently spread over the whole area.

VI.—4. Iron Flush of the Moorland Zone.—Iron flushes are usually distinctly local. Their vegetation is largely determined by the type within which they occur. They are distinguished from the surrounding vegetation by slight changes in the relative abundance and vigour of their plants. Plants which are not frequent in general may become frequent or abundant, for example, the sedges, *Carex panicea*, *C. echinata* and *C. pulicaris*. *Myrica gale* is frequently abundant, and the small variety of euphrasia, *E. scotica*, is almost constantly found. Unusual species and forms of sphagnum and other mosses indicate iron flush.

Silviculturally, the flush types include those areas of moorland vegetation in which plantations have been more successful. Tree growth is very satisfactory in rush flush and in tufted molinia, but is only moderately satisfactory in less robust molinia, where *Erica tetralix* and *Eriophorum vaginatum* are the chief subsidiary plants. In *Eriophorum vaginatum* flush growth is very slow to begin with but successful growth may occur later. Iron flush is not of great extent but occurs frequently, causing patches and strips of very poor appearance in plantations since tree growth is almost always poorer on iron flush than on the adjacent ground.

VII.—Basin Types

(Acid Low Moor to High Moor)

In addition to flushes which result from percolating water, the accumulation of water in basins results as we have seen in the formation of peat, of the low moor/high moor types, each with its corresponding vegetational changes. These areas in the earlier stages of peat formation are not of much direct importance in forestry, as they are then still submerged under water. The stages leading up to transition moor are summarised merely to afford a complete view of the processes involved in the formation of basin peat, and although such peat does not cover any large area, this history of its development is a useful guide to the conditions which occur on other sites where similar types of vegetation may cover considerable areas.

(In order to avoid unnecessary detail and at the same time to present a general view of the vegetational changes to be described below, Field Sketches I, II and III are given for reference on pages 100 and 101.)

VII.—1. Low Moor Vegetational Type.—The moderately shallow marginal water of lochs is invaded by long and rigid plants like *Equisetum limosum* and *Carex ampullacea*, which stand up against wind, and provide a sheltered water-surface for the subsequent growth of plants with floating leaves, such as water-lilies and floating pondweed. The floor of the loch becomes silted up with the remains of these and with other debris carried down by streams. This silting up process advances slowly into the deeper water. The silting up produces better conditions for the original shelter plants which grow more densely and the movement of water amongst them is reduced to a still greater degree. This favours the growth of *Sphagnum cuspidatum* in submerged and partially submerged forms and these in turn displace the earlier floating-leaved plants.

(These phases are shown in Sketch I, to the right of the "deeper open water." In Sketch II the process has gone so far that floating leaved plants now cover the central area of free water and are entirely surrounded by the sheltering "carex submerged sphagnum" phase in the form of a narrow belt, and in Sketch III the original free water surface is represented by a small pool ("open water") almost covered by sedge and submerged sphagnum. Floating-leaved plants are represented by a few scattered specimens of *Nuphar pumila*.) These phases constitute the low moor vegetation.

VII.—2. The Sphagnum "Flat" Transition Moor Type.—As the bottom of the loch becomes silted up to the level of the surface, the submerged *Sphagnum cuspidatum* is replaced by more rigid and compactly growing forms of the *Sphagnum cymbifolium* group, such as *S. medium*, *S. centrale* and *S. papillosum*. These in time form a continuous and dense cover, sometimes over a considerable area. *Carex ampullacea* becomes stunted and as time goes on may disappear. To the eye this type presents a flat or gently undulating surface of pale yellow to brownish red sphagnum upon which are scattered only a few plants. In addition to sedges which persist locally, *Erica tetralix*, *Vaccinium oxycoccus* and *Narthecium ossifragum* are the most frequent. As a transition to the next stage the following plants invade the sphagnum usually in the order in which they are given :—Stunted *Molinia*, *Eriophorum polystachion*, *E. vaginatum* (local), *Calluna*, *Scirpus*. This type of vegetation constitutes the earlier stage of flat-moor development.

(In Sketch I, this stage is seen in the half-moon shaped delta to the right of the free-water surface. In Sketch II it is well developed, around the loch, but in part altered by abnormal flooding which has swept away the sphagnum from the areas marked " peat mud " and " peat debris." In Sketch III it is shown only in the small area marked " sp. medium," since a secondary drainage channel has caused reversion in the surrounding zone marked " sphagnum submerged forms.")

VII.—3. Scirpus-Calluna Transition Moor Type.—Reference has already been made to the invasion of sphagnum flat moor by several higher plants. As these become more abundant, the character of the sphagnum gradually alters. The larger leaved sphagnums are more and more replaced by the small leaved forms of the Acutifolium group. These scarcely form mounds, but rather raised patches, sometimes of considerable diameter. By the time that calluna has become abundant on the ground, the Cymbifolium group has almost wholly disappeared. Upon the more compact surface offered by the short dense sphagnum, scirpus becomes abundant and a fairly permanent *Scirpus-Calluna* type of vegetation replaces the earlier sphagnum " flat " type. Calluna is abundant and forms moderately large tufts ; scirpus forms somewhat small tufts but is of long growth ; along with these occur the usual subsidiary plants *Narthecium*, *Molinia*, *Eriophorum polystachion*, and a few relict plants from the low-moor phase, of a more special character, *e.g.*, *Carex pulicaris*, *C. echinata*.

When the surface of the peat rises above the level of the plane of the flat moor this type gives place to the high moor type, to be described later.

Within these types several variations occur frequently. The more important of these are due to the presence of adjacent flush water percolating into the basin. For example, mineralised flush may encourage an open or dense growth of *Juncus articulatus* in the sphagnum flat type, accompanied by a change in the species of sphagnum itself, as well as in the subsidiary higher plants (*see* Sketch II). Diffuse flush conditions may likewise occasionally have a modifying effect producing an *Eriophorum vaginatum* type.

These basin types which originate through the accumulation of water in badly drained hollows or depressions, present a special but easily solved silvicultural problem. The treatment consists in the prevention, where possible, of the inflow of water and in any case the basin itself must be deeply and completely drained. Surface drainage is useless, since even where the top layer is naturally suitable for the growth of young trees, the underlying wet peat offers such a poor and unstable anchorage for root hold, that after a few years the trees would be thrown by the wind. Examples of this are not uncommon.

The chief importance of the study of basin peat rests in the light which the history of its development casts upon the unfavourable conditions for tree growth which develop very frequently upon all flatter areas of peat, and in depressions in uneven ground, namely, conditions where a modified sphagnum flat vegetation develops. As an indication of such conditions the presence of considerable quantities of *Sphagnum medium*, *S. centrale*, *Eriophorum polystachion* and *Erica tetralix* are evidence that water is collecting in pools even although not visible above the moss, and that deep drainage is necessary.

VIII.—Climax Vegetation

(The Scirpus High Moor Type)

The permanent type of vegetation which ultimately succeeds those hitherto described, is termed the scirpus type. It is to be found, therefore, under widely varying conditions of altitude and topography. It may thus be expected to show slight variation in vegetational detail but does not alter in its general character. It is characterised by dominant *Scirpus caespitosus* which forms an open, even or diffuse-tufted green cover over the ground in the growing season. Amongst this, calluna is present in abundance as scattered open patches of low growth with short flowering shoots. In winter the dark stems of calluna are more prominent amongst the flattened brown straw of the scirpus. *Narthecium ossifragum* is always abundant but is of small size. *Potentilla tormentilla*, *Erica tetralix*, *Eriophorum polystachion*, are constantly found along with a few other less noticeable plants. A considerable number of other plants may also be present in places but the writer considers these to be relict plants from previous vegetation, for example, *Eriophorum vaginatum*, *Molinia caerulea*, *Juncus squarrosus*, *Carex panicea*, *Polygala vulgaris*, *Myrica gale* and others are local in their occurrence.

The normal moss flora consists of a fairly equal superficial distribution of smaller sphagnums on the one hand and on the other of the common moorland and heath mosses, *Hypnum schreberi*, *Hypnum cupressiforme*, *Brachythecium purum*, *Hylocomium splendens*, *Rhacomitrium lanuginosum*. Here and there the last named moss forms hoary pads on heather tufts. The liverwort *Pleurosia purpurea* is found in compact masses in slight depressions. When the dome-shaped contour of high moor has developed, the whole surface may become very monotonous and unvarying in character. Uneven contours either within or around the area of the high-moor can cause minor variations in the vegetation. These variations may be readily associated with their causes if compared with the transitional topographical types already described. For example, the presence of *Euphrasia scotica*, *Myrica gale* or *Carex panicea* in quantity indicates iron seepage ; on flat stretches local subsidence of the surface produces the sphagnum " flat " type. On slopes a " ridge-and-furrow " effect is often produced along the contour lines. This condition results from the growth of small mounds of sphagnum on the sheltered side of calluna tufts. These mounds lengthen out and become joined together in the direction of the prevailing wind, producing a ridged surface not unlike the " sheep runs " which are familiar everywhere on steep grassy slopes.

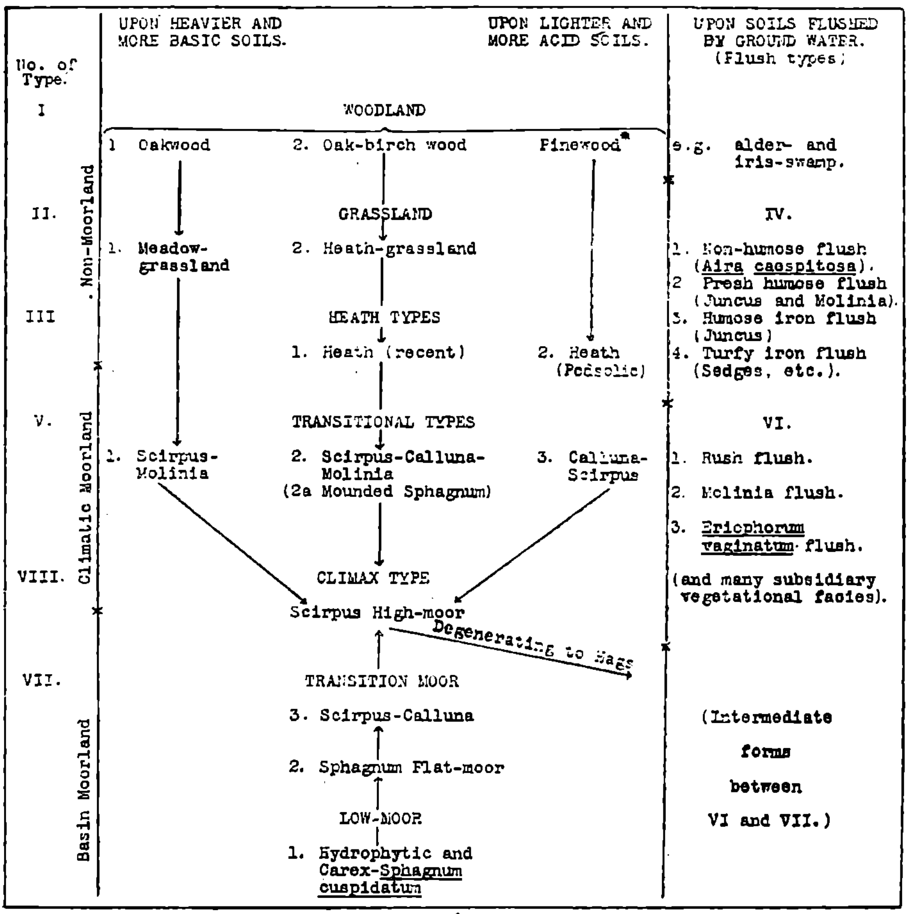
IX.—The Degeneration of Peat

(Peat Hags)

In most larger masses of peat, cracks, or channels develop naturally in certain places ; these are called hags. They may be quite small, a few feet long and about a foot or so in depth and width ; usually however they are much more extensive. In depth they may reach well over 6 feet, cutting through the peat to the mineral soil ; and they may form an irregular network covering a wide area. Sometimes little or nothing of the original peat mass is left except a few islands or ridges in a loch of peat mud.

The writer considers that at Inverliever and in the west of Scotland in general, the formation of peat hags is not due to the action of wind which is considered to be the chief cause in peats of drier regions. The orientation of all western hags is found to coincide with natural drainage channels, *i.e.*, ditches and streams, and my conclusion is that these hags are formed by the ordinary action of streams in cutting backward into the higher ground. Here the higher ground is represented by deep peat, and since it is much softer than mineral soil the process of erosion is more rapid. Further, the peat on the exposed sides of these channels crumbles off under the action of weather and frost, falls to the bottom of the channel and is rapidly washed away; under the action of this undercutting the banks of the hag are rapidly widened. Wind seems to play only a secondary part in this process.

This "hagging" of the peat has little effect upon the vegetation of the high moor in which it occurs. The most noticeable changes are confined to the immediate neighbourhood of the hag. Here calluna becomes more robust and mosses of the hypnum group become more abundant; the moss *Rhacomitrium lanuginosum* occurs as a border at the edge of the hag and forms greyish white mounds among the calluna. Depressions appear in the surface of the peat at some little distance from the hag. They are most likely due to the subsidence of the underlying peat, toward the hag. On these are formed a variety of the sphagnum "flat" type with *Sphagnum centrale* as the most abundant sphagnum.



* Natural pinewood does not occur at Inverliever

Diagram showing the types of vegetation at Inverliever and their relationships

As the hag system becomes more extensive a variety of local types of vegetation appear, which are similar to one or other of the local types already described, such as flush slopes with molinia, or pools with *Sphagnum subsecundum*. Usually these are of limited extent.

On scirpus high moor successful tree growth has not yet been observed. The growth of the young trees is completely checked and they usually die in a few years. Near hags, where drainage might be expected to improve conditions there is little sign of improvement, judging by the growth of trees. But where the surface is denuded of vegetation in the process of hag-formation, and the peat broken up by frost, and secondary vegetation such as molinia comes in, then the growth of trees is much better.

The types of vegetation at Inverliever which have been described, and which are summarised in the following diagram, are considered to be representative of or comparable with those of the west of Scotland as a whole. Types which may be found in other districts can readily be associated with those which have been given here. For example, in somewhat drier districts, as at Achnashellach, Scots pine forest occurs on podsolic soils similar to the morainic soils of Inverliever. This forest, however, is changing into moorland in a manner similar to the change of calluna heath to moorland, since natural regeneration of the Scots pine does not occur on the margin where forest meets moorland. Under lower rainfall, moorland development is slower than at Inverliever, calluna is more abundant and more vigorous in the scirpus types. On slopes with shallow mineral soil the mat grass (*Nardus stricta*) *Molinia caerulea* and *Juncus squarrosus* may cover wide areas. Nardus is almost absent from Inverliever, but the transition to moorland is fundamentally the same as that occurring on other grassy-heath types. Often the chief point of difference lies in the subsidiary plants, *e.g.*, *Drosera rotundifolia* alone occurs in many of the moorland types at Inverliever ; at Fort Augustus both *Drosera rotundifolia* and *D. longifolia* are found ; in the Borgie area in the north-west, *Drosera rotundifolia* is unusual while *D. longifolia* is generally abundant.

NOTE ON THE EFFECT OF LONG-CONTINUED HEATHER-BURNING AND GRAZING UPON THE MOORLAND VEGETATION OF THE WEST OF SCOTLAND

It is necessary to point out that the burning of herbage referred to in this note means the regular periodic burning carried out as a cultural operation over a considerable number of years in connection with grazing or game preservation with a view to the production of a crop of fresh shoots, which may provide more palatable food for stock and game. It does not refer to the silvicultural operation of heather-burning which takes place only once or at long intervals, and is followed by the planting of trees.

The growth form of a plant is of primary importance in relation to the effect produced on it by burning. For example, annual plants may escape the direct effects of burning altogether since, when burning is carried out in early spring as is usual, their seeds are embedded in the wet surface of the ground or in the wet turf and are thus protected from fire. On the other hand perennial plants of low stature which have no power of reproducing their new shoots from underground organs, for example, young conifers, may be completely wiped out by ground fire.

Between these two extreme examples there are many gradations, but in this respect the important moorland plants fall into two well-marked groups :—

(1) Caespitose or tufted plants in which the winter buds and food stores are protected by a dead matting of leaf sheaths and of last year's leaves (for example, *Eriophorum vaginatum*, *Scirpus*, or *Molinia*), and plants whose winter buds and reserve food stores lie below the surface of the ground, for example, grasses like *Holcus mollis*, sedges and *Eriophorum polystachion*. Plants of this group are scarcely affected by fire at all. Even when burnt over in the early growing season they are only defoliated and soon recover.

(2) Sub-shrubs and other plants with winter buds at or near the surface of the ground and with their food reserves stored in the stem, and which do not regenerate readily from roots. Such plants may be completely destroyed by fire, for example, calluna and the heaths.

Certain plants are intermediate between those two groups, for example, *Vaccinium myrtillus* on which winter buds occur not only on the stem above ground but also on underground stems or rhizomes. Such plants, although their aerial parts may be destroyed by fire, quickly repair the damage by new growth from their underground stems.

Mosses may also be divided into two groups :—

(1) The sphagnum group, with its adaptation for water-storage, is non-inflammable under ordinary weather conditions, while in most forms the habit of growth in compact even societies affords mutual protection against fire.

(2) The second group is exemplified by the Hypnaceae in which no provision exists for water-storage and in which the loosely-felted growth-form offers no protection against fire.

Again intermediate forms occur such as the caespitose mosses like *Leucobryum glaucum* or *Dicranum scoparium* in which the fairly compact habit of growth affords mutual protection.

When, therefore, burning of herbage is periodically carried out in the spring, higher plants and mosses of the first groups are greatly favoured at the expense of those of the second groups which become almost eliminated by systematic burning. Even when the stems of plants like heather are not wholly destroyed, the loss of the food stored in the sub-aerial parts makes recovery very slow, so that for some time the more resistant plants have greater scope for extending their growth.

Grazing is similar in its effects as far as higher plants are concerned. The grass-like plants become more abundant by increased scope for " tillering " or the development of new shoots, owing to the reduction of shade which follows the grazing of the vegetation in general, so that an increase in the total area of ground covered by such plants follows, even though they do suffer a partial loss of leaves. When sub-shrubs like calluna are grazed, a similar but not so complete loss of buds, leaves, and shoots, occurs as when they are burnt over, and since the competitive power of such plants depends chiefly upon their height growth, and ability to over-shade other plants, they are therefore placed at a great disadvantage as compared with the caespitose and grass-like plants.

The effect of grazing and of heather-burning, especially when combined, is to favour the caespitose plants at the expense of sub-shrubs. In terms of the nomenclature applied to vegetation, grazing and burning favour the development of grassland at the expense of heathland in the eastern half of Scotland where these types are in competition ; but in the west, where heath is in competition with moorland, the most characteristic species of which are caespitose plants like *Eriophorum vaginatum* and scirpus, the burning and grazing of surface herbage favours the development of moorland vegetation. When it is remembered that moorland mosses like sphagnum are also favoured by burning, it is obvious that this operation in conjunction with grazing by sheep has played a very direct part in extending the area covered by moorland vegetation.

Burning and grazing also work indirectly in many ways to produce the same result. Burning liberates in a soluble form the mineral nutrients contained in the plants and plant litter which is burnt, and when rain follows burning these are washed off the area and so lost to the soil. The more frequent the burning the more impoverished does the soil become. Similarly, when sheep are removed from an area large amounts of mineral nutrients (especially calcium phosphate in the bones) gathered from the vegetation are lost altogether. The plants least affected by soil poverty are moorland plants, *e.g.*, scirpus and sphagnum ; that is to say moorland vegetation is favoured at the expense of heath or grassland.

When the burning is sufficiently intense to expose the surface of the soil, the humus on it forms a pan-like crust with the ashes of the burnt plants. This hard crust is unfavourable to the germination of seedlings of higher plants. The caespitose plants may resist burning even of this intensity and their chance of ultimately gaining possession of the bare ground is much increased. Grasses like *Aira flexuosa* often spring up abundantly on heaths of the east, but in the west scirpus is much more frequent. For example, on a severely burnt area of *Scirpus-Calluna* on morainic ground, the exposed peat was examined two years after burning had taken place. On an average two seedlings of scirpus were found on each square of three inches picked at random, while only one ericaceous seedling was found on thirty such squares. Scirpus, calluna and *Erica tetralix* were abundant nearby but only scirpus had survived burning on the area. This hardened surface also collects water in wet periods when it becomes colonised by gelatinous algal scum (*e.g.*, " witches' butter ") and caespitose mosses ; when dry, crustaceous lichens may cover it. These pioneer plants prevent the growth of non-moorland plants and favour the growth of moorland plants like scirpus.

Finally, both grazing and burning tend to plane down the height of the vegetation to a few inches above the level of the soil surface. This intensifies the effects of exposure and favours mosses such as the short, compact light-demanding sphagnums ; the puddling action of hoofs of sheep like the crusting action of fire helps to accumulate water upon the soil-surface, so that intensely grazed heath adjoining moorland is usually colonised by the short, compact sphagnums (*e.g.*, *S. compactum*) *Leucobryum glaucum* and *Campylopus* spp. and as these become more abundant, moorland plants replace the heath plants, so that in time heath gives way to moorland.

The practice of grazing and the burning of heather which usually accompanies it must, therefore, have contributed considerably to the extension of moorland in the west of Scotland. No reference has been made to the effect of the intentional or incidental destruction of self-sown trees by grazing and burning, since the effect of shade in reversing the development of moorland is referred to in detail later (pages 60-61). It is thus apparent that the methods of land exploitation in most general use in the past have extended the area of moorland and in this way have decreased the value of the soil not only for agriculture but also for afforestation.

From these observations it may be readily understood that the types of vegetation, described in the earlier section of this paper, show modifications varying with the treatment to which they have been subjected during recent years. The types as described there, represent the stable condition reached by the vegetation a few years after intense grazing and heather-burning have ceased. The chief feature in which the grazed vegetation differs from the ungrazed is the relatively small growth of calluna and other subsidiary ericaceous plants. On recently-burned ground these plants may be almost entirely absent ; for example, many of the morainic knolls would bear a calluna vegetation with scirpus as the chief subsidiary plant under more natural conditions, but when burnt they bear scirpus with little else for some time ; only after a few years does calluna again become the dominant species. In the west of Scotland a general feature of the enclosure of ground for afforestation is the change from the smooth green rounded surface formed by grasses and scirpus to the irregular outline and dull colour of heather. Where heather has not been previously destroyed by burning, this change in appearance is chiefly due to the relatively more robust growth of calluna. For example, a quadrat was fixed upon newly enclosed scirpus highmoor and was remapped after an ioterval of five years. The frequencies of the plants occurring in it has scarcely changed. Measurements of the species which occurred on the plot showed that a general increase in vigour had taken place ; scirpus was about one-third longer, calluna had more than doubled its height and all the plants measured showed increased growth. Owing to its relatively more vigorous growth calluna seemed to be more abundant than it previously was.

This relatively greater abundance and more vigorous growth of calluna especially, is the most noteworthy feature of the exclusion of sheep from moorland. When calluna becomes sufficiently large, as occurs only on transitional types and on sheltered morainic knolls, sphagnum mounds may be formed in its shelter and the sub-type V. 2 (*a*) results as a special consequence of enclosure against grazing animals. Apart from these results no special features have been observed to result from enclosure.

The foregoing observations upon burning may be applied to the practice of burning ground vegetation which is carried out as a common preparatory practice in planting operations. Where heather is a constituent of grassy vegetation or where grasses (*e.g.*, molinia) form the chief subsidiary species in heather, burning is of advantage especially when spruces are to be planted. So with *Eriophorum vaginatum* and heather. On the other hand, where scirpus is abundant or dominant no advantage is obtained from heather-burning, since the scirpus and sphagnums are favoured and the young trees lose the benefit of the shelter given by the heather.

Intense burning is harmful on any moorland area on the west, as well as on most heather in the east of Scotland, unless followed by cultivation in order to break up the hardened humus crust which forms over the surface of the soil, and so incorporate the turf ashes with the surface soil. Since cultivation is not often practicable, it follows that intense burning of surface vegetation and turf is not recommended on heath and moorland in wetter districts. Intense burning of peat, it may be noted, is not favoured even in agricultural practice on the Continent, although it was formerly a common means of reclamation in eastern Scotland in both agriculture and forestry, and is still occasionally practised in agriculture.

PEAT AND ITS ASSOCIATED TYPES OF VEGETATION

The Classification of Peat Soils

A peat soil, as already stated, is a soil composed of plant remains, the decomposition of which is hindered or prevented chiefly by the exclusion of air, which is a result of its high permanent water level. This high permanent water-level also prevents the roots of plants from penetrating to the underlying mineral soil.

The general classification of peat soils may be arranged upon a climatic basis, in the same way as the classification of moorland. In Scotland three principal climatic peat regions are found, each with its characteristic kind of peat, since both peat and moorland have developed under the influence of the same climatic factors. These peat regions, as might be expected, correspond with the principal moorland regions. They are as follows :—

A. The north-west and west peat region with pseudo-fibrous peat. (Corresponding to the region of scirpus moor.)

B. The north-east and east peat region with fibrous peat. (Corresponding to the region of calluna moor.)

C. The southern peat region with amorphous peat. (Corresponding to the region of molinia moor.)

Special local conditions give rise to special types of peat within any of these regions. For example amorphous peat, which is characteristic of the southern region, may be found in flush conditions in either the western or the eastern regions of the north, just as the molinia type of vegetation of the south is represented in flush areas in the north-east or north-west regions.

In the following descriptions reference is not made to the surface turf, which contains, as well as recently-dead plant remains, the stems and roots of living plants, but to the peat proper which is to be found below the turf or which is no longer occupied by living stems or roots. All turf is more or less fibrous.

The two principal kinds of peat are termed respectively *structural* peat and *amorphous* peat. In structural peat the plant remains are so slightly decomposed as to be readily recognizable, especially in those plants and parts of plants in which the structure is more resistant to decay. In amorphous peat the plant remains are so completely altered through decomposition that no skeleton structures can be recognized. Since the fibrous tissues of plants are more resistant to decay structural peats are usually described as being fibrous. Nevertheless all structural peats are not fibrous, since the fibres which they contain are no longer tough and flexible as they were in the original plant. The distinction is of considerable importance, and may be illustrated by comparing an ordinary fibrous peat with peat from scirpus high-moor. When a really fibrous peat, in the fresh condition, is squeezed in the hand, water runs from it as from a sponge, and its fibrous structure is not materially altered by the compression. If, on the other hand, fresh peat from scirpus high-moor is squeezed, the whole mass squelches through the fingers without losing any of its water and its fibrous appearance is destroyed. This kind of peat cannot be properly called fibrous although it *looks* fibrous. The writer proposes therefore to call this soft, plastic, fibrous-looking peat pseudo-fibrous in contradistinction to really fibrous (ortho-fibrous) peat.

(A) Pseudo-Fibrous Peat—Characteristic of Scirpus Moor

Pseudo-fibrous scirpus peat is a structural peat, being composed of recognizable remains of scirpus, sphagnum and other plants. Of these remains the stems and roots are easily visible, so that the peat has a fibrous appearance. It is, however, quite plastic since the apparently fibrous structures have undergone fundamental changes so that their strength and tenacity are completely lost. The organic matter as a whole has so altered that the peat acts in the same way as gelatine, *i.e.*, it is capable of absorbing a large quantity of water and swelling considerably, and on the other hand, shrinking to a remarkable degree when slowly dried. This change in the plant remains takes place only in the complete absence of air, and it is important to note that if pseudo-fibrous peat is exposed to the air, *i.e.*, if conditions for aeration are established, changes take place, by which the fibres regain their strength, and the peat becomes fibrous, while the gelatinous matrix shrinks into black grains or brown encrustations upon the fibres.

Pseudo-fibrous peat has been observed as a surface peat, only in the west Scottish high rainfall area, and elsewhere where scirpus vegetation has been found. Where the surface of the ground occasionally becomes sufficiently dry to permit of partial aeration, the fibrous structures either do not soften, as in true fibrous peat, or the softening may be only partial as in intermediate forms. Pseudo-fibrous peat is typically yellow in colour. Darker shades such as light brown to dark brown are found on exposed sites or under such other conditions as may permit of intermittent aeration, and as conditions of aeration improve the colour becomes black.

Since air is completely excluded from the lower layers of deeper peat masses, pseudo-fibrous peat is not infrequent in such positions. In these deeper layers complete exclusion of air may not have taken place till sometime after they had been deposited, and therefore the darker colours are more prevalent than the lighter.

(B) Fibrous Peat—Characteristic of Calluna Moor

The nature of fibrous peat has already been indicated in the above section. Fibrous peat includes those structural peats in which the strength and tenacity of the original plant tissues are retained, and for this reason fibrous peat shrinks to a much less extent than pseudo-fibrous peat. It is not markedly different in appearance from the turf below which it occurs.

Fibrous peat varies much in character and in outward appearance according to the conditions under which it was deposited. The fibrous peat of calluna moor is usually dark brown to black in colour as a result of partial aeration ; it is composed of the remains of ericaceous plants, *Eriophorum vaginatum* and small-leaved sphagnums.

In the western area, fibrous peat varies in colour from the yellow or light brown masses of scarcely altered sphagnum on the one hand, to the light-brown or dark-brown shades of the remains, in consolidated masses, of tough plants like the cotton-grasses and sedges on the other.

(C) Amorphous Peat—Characteristic of Molinia Moor

By amorphous peat is meant that in which the processes of decay have gone so far that a form of true humus or mould has been produced from the peat-forming plant remains. In this kind of peat the remnants of plant structures are not any more visible than in the organic matter of an ordinary soil. Amorphous peat is dark-brown or black in colour and is composed of small particles or units invisible to the naked eye. In appearance it may be indistinguishable from very humose clay soil, but of course it contains little or no mineral particles. The amorphous peat of molinia moor varies from a black mud-like peat mass, which on drying becomes granular in appearance, to a brown-coloured peat of spongy texture which in its dry or wet condition is similar in appearance to well rotted farmyard manure.

In the western area amorphous peat varies considerably in appearance, depending upon the conditions under which it was formed.

Apart from the foregoing broad regional and structural basis, peat cannot be classified except upon the basis of the vegetation from which it is derived. The various kinds of peat which have been found in the west of Scotland are classified and referred to their associated types of vegetation below.

The Peats of the Western Scottish Moorland Region

SCHEMATIC CLASSIFICATION

Structural peats—mainly composed of recognisable plant tissues :—

A. *Pseudo-fibrous peat* : Soft and plastic, rigidity and tenacity lost, fibrous in appearance only. (Typical of west of Scotland.)

(*a*) *var. Cheesy peat* : Rigidity partly maintained under intermittent aeration. (Transitional.)

B. *Fibrous peat* : Tough and flexible, composed of scarcely altered remains of plants. (Typical of east of Scotland.)

C. *Amorphous peat* : Showing no recognisable plant tissues. (Typical of south of Scotland.)

In the west of Scotland these peats are associated with the following types of vegetation (the numbers* refer to the vegetational type numbers of the previous section ; see pages 16-28) :—

A. *Pseudo-fibrous peat* :—

V. —Transitional types—1, 2 and 3 (where peat is deeper).

VII. —Basin type—3 *Scirpus-Calluna*, transition moor peat.

VIII. —High moor type—*Scirpus* high moor peat.

(*a*) *Cheesy peat* :—

V. —Transitional types :—1, 2 and 3 (where peat is shallower) and in many transitional vegetational zones.

B. *Fibrous peat* (local) :—

V. —Transitional types—2A (2 and 3 occasionally) sphagnum peat.

VI.—Flush types—3 *Eriophorum vaginatum* peat.

Subsidiary local types (of VII, 1 and 2) where water accumulates above the peat surface. } *Eriophorum polystachion*, *Carex* spp., *Sphagnum* } peats.

VII. —Basin types—

1. Sedge (*Carex ampullacea*) and *Sphagnum* peat.
2. *Sphagnum* flat moor peat.

C. *Amorphous peat* (Local) :—

VI. —Flush types—

1. Rush peat (grading to humose soil).
2. Molinia peat (grading to humose soil).

VII. —Basin type—1. Lake mud peat.

VIII. —Hag mud—Fragmental high moor peat.

(A) Pseudo-Fibrous Peat and its Varieties

Pseudo-fibrous peat is the climax peat of the western Scottish region. It is found in its typical form in scirpus high moor and also in association with transitional vegetational types which are in process of change into scirpus high moor. On scirpus high moor (VIII) the covering turf is thin, and consists of scarcely altered plant remains through which roots of living plants may pass. As a rule, the peat is of the pseudo-fibrous type at about 4 inches from the surface of the moss covering. When the surface turf has been broken through, a blunt pole can be pushed readily into the peat below, which is soft and offers but slight resistance. At the same time this peat is sufficiently firm to permit of samples being extracted by means of a cylindrical soil auger, or cut from it in slabs with a blunt spade. These samples retain their shape when not handled but may be easily pulped and moulded by the fingers. The typical colour when freshly cut, is yellow-brown, but this changes to dark brown or almost black when exposed to air. Apart from the tubular fibres of scirpus roots and the remains of sphagnum, little structure is visible. In the fresh condition this peat has the physical properties of a somewhat stiff jelly or plaster, and when slowly dried contracts to hard brown lumps. When exposed to the weather and thus aerated, and partially dried, a black amorphous crust is formed on the exposed surface in which the hardened fibres are embedded, while in the interior the hardened fibres form an open spongy mass, in which little shrinkage takes place.

Pseudo-fibrous peat is also found under those vegetational types which contain a high proportion of scirpus and the shorter, small-leaved sphagnums, provided the peat is more than about 1 foot in depth (*e.g.*, types V and VII, 3).

On the moderately shallow peats under transitional types of vegetation (V) a variant of this kind of peat is frequently to be found. This variant corresponds in character to the crust which has been described as occurring upon dried pseudo-fibrous peat. In it the fibres are tough and resistant to fracture ; the finer material has shrunk into a dense, dark brown, curdy or spongy mass so that the peat is no longer plastic, but can be broken into pieces, even when wet. For want of a better term this variety is termed " cheesy " because, in texture and mode of breaking or crushing when in the fresh condition, it calls to mind somewhat stiff cheese. As compared with pseudo-fibrous peat, it has a much lower water-retaining power. Cheesy peat is transitional between the better aerated kinds of peat or raw-humus, and true pseudo-fibrous peat. It is rarely as much as a foot in depth. When dried it cracks into blackish cindery-like fragments. This variety is very general in the west of Scotland, just as are transitional vegetational types.

The peat of transitional types of morainic heath moor (V, 3) is very similar to this when wet. The main difference being that the fibres are mostly rootlets of calluna and the matrix on drying becomes more powdery. In the north, for example, at Borgie, this form, although of the same general appearance, is somewhat flexible when wet, and when dry becomes bright brown in colour, sponge-like and friable ; it is composed almost entirely of calluna rootlets with little gelatinous amorphous matter.

On grass moor (V, 1) the transitional peat, when very shallow, is largely amorphous, with only a small amount of fibrous material, but at a depth of a few inches or at least when scirpus becomes frequent in the vegetation it becomes dark pseudo-fibrous or cheesy peat.

In heath moor (V, 2), the underlying heath raw humus gradually changes to cheesy peat.

In the variety of heath moor with mounded sphagnum (V, 2a), when recently formed, the surface peat is largely unaltered sphagnum remains, lying upon heath raw-humus. As accumulation continues these sphagnum remains become consolidated, and when a certain depth is reached pseudo-fibrous peat is formed.

(B) Fibrous Peat

Fibrous peat is considered to be a transitory or temporary form in the west of Scotland. Given sufficient time, it alters to the soft plastic condition of pseudo-fibrous peat, whatever its original character may have been. Thus in any deep deposit of *Eriophorum vaginatum* peat, although the upper two to three feet may be tough and fibrous, below that depth it becomes progressively less tough and more plastic, even although the entire deposit consists of the remains of *Eriophorum.*

Fibrous or slightly altered structural peat is found, in western Scotland, on all sites upon which rapid growth of sphagnum is taking place. Such sites are : where shelter permits of the formation of sphagnum mounds (V,2 and V, 2a), also in places where shallow water collects on the surface, *e.g.*, in the sphagnum flat type (VII, 2), and where similar local types of vegetation collect on moorland and transitional moorland. These fibrous types consist of sphagnum remains sometimes mixed with other fibrous plants such as sedges and cotton grasses, especially *Eriophorum polystachion.* When dried they become light in colour and open in texture, and show comparatively little sign of decomposition. When the softer species of sphagnum, for example, *S. cuspidatum,* are present in quantity, the resulting peat may be less tough and rigid.

The most important fibrous peat is produced by *Eriophorum vaginatum.* It is very tough and a blunt implement can scarcely be driven through it. At a foot or two below the surface it may easily be sliced with a spade, but even then it cannot be broken up and moulded in the hand, or squeezed through the fingers. When compressed, water exudes, but it returns to its original size when released from compression. When dried it becomes quite open and porous and does not show any marked evidence of shrinkage.

In colour *Eriophorum vaginatum* peat varies from light brown to dark brown. When exposed it alters in colour only slightly, becoming darker or, where sphagnum is contained in abundance, marbled dark and greyish yellow.

Where mixed with molinia, *Eriophorum vaginatum* peat is darker brown when wet, and when dry is mottled with black amorphous material—a mixed fibrous-amorphous peat.

(C) Amorphous Peat

Amorphous peats are in the west of Scotland confined to fresh-flush conditions and to basins in the low moor stage, and in addition, the presence of black amorphous material in peat is an index of transition from or to fresh flush conditions.

The amorphous peat of low moor (VII, 1) has not been examined widely since it has not been found under conditions where tree-growth is possible. It is, however, best described as organic mud with a rather soapy feel, in which fragments of less altered material are abundant. The amorphous peat of shallower rush flushes on mineral soil and transitional moorland is mixed with varying amounts of mineral matter ; the organic matter is well decomposed into fine-grained clay-like mould having when wet the character of humose clay, although distinctly soapy to the touch ; when dry it becomes friable on the surface, but hardens into cindery-looking lumps.

Where inorganic matter forms a very small percentage of its composition, and where flush water passes mainly below the surface it becomes less soapy and even minutely spongy when wet and dries to a friable granular powder. This form is typical of the deeper amorphous deposits in transition and high moor.

Molinia-flush peat varies similarly. In deep peat, where surface flushing occurs, the amorphous matter is somewhat different from what has already been described. In the wet condition it forms dense black granular masses, permeated by the living and dead roots of molinia the whole being quite spongy. When dry the amorphous matter dries into hard black grains with a coal or even pitch-like lustre.

Transitional forms intermediate between amorphous (flush) peat and pseudo-fibrous and cheesy peat, are often nodular in appearance. Nodules of less decomposed peat are sometimes surrounded by veins of amorphous granules or they may be simply streaked with veins of black colour. The latter kind of nodular peat is found below the surface, in deep peat, where flush conditions have developed upon fibrous or pseudo-fibrous peat.

The peat of iron flushes in moorland is similar in character to the peat within which the flush develops. It may, however, be slightly blacker in colour, often with a bluish tint. This black colour is retained when dry except where iron is present in very large amounts, when iron oxide may be deposited as a rusty red incrustation.

SOIL-FORMING (EDAPHIC) PROPERTIES OF PEAT

It is now necessary to consider in detail the soil-forming properties of the various kinds of peat, especially in so far as trees are concerned.

The major properties of soil in relation to plant growth are (1) water-supply, (2) aeration, (3) reaction and (4) nutrient value or plant-food content.

(1) Water Content of Peat Soils.—In the case of western Scottish peats under a rainfall varying from 50 to over 100 inches, and evenly distributed over the year, the question of insufficiency of water does not arise. On the contrary, it will be obvious from the definition of peat which has been given, that one of the chief characters which separate peat from other soils is the presence of excess water at the surface or at a relatively short distance below the surface. This water is not in itself harmful but it acts injuriously by excluding air from the soil and consequently from the roots of trees ; it also prevents the chemical processes necessary for the production of food material from the organic matter. The amount of air absorbed by water depends upon the amount of surface exposed by the water. Freely-running water, therefore, with its ever-changing surface, is always better supplied with air than stagnant water, more especially if stagnant water is cut off from the atmosphere by a dense cover of living and dead vegetable matter. In soils which are loaded with stagnant water, soil aeration can only take place effectively at such times as the level of the water is reduced by evaporation.

Peat soils can be separated into three classes, according to the nature of their water content.

(i) In the first class the zone of stagnant water is overlain by soil (peat) through which flush-water is in moderately rapid movement and which is therefore to some degree aerated at the surface (by flush-water). In this case the organisms which decompose plant remains are active, and tree roots are able to function. The soil-condition and tree-growth are thus approximately similar to those found in water-flushed mineral soil. This class comprises the amorphous peat soils of flush conditions.

(ii) In the second class the level of stagnant water is lowered, in times of drought, to such a depth that aeration of the surface layers may take place. Where aeration and other conditions are adequate, amorphous peat is formed, for example, in the southern peat region. Where aeration and other conditions are inadequate, fibrous peat is formed, for example, in the eastern peat region, where summer heat is insufficient not only to compensate for rainfall, but also to allow decomposition of moorland plant remains.

(iii) In the third class the level of the stagnant water remains high throughout the year ; air is thus excluded and decomposition in the ordinary sense cannot take place, consequently the dead vegetable matter remains more or less unaltered in the stagnant water. Any change which takes place consists of chemical rearrangements within the organic material in the absence of oxygen and is not in the nature of decomposition in the ordinary sense, which requires oxygen from the air. The peat deposits of low-moor, whether amorphous as a result of temporary decomposition, or structural, belong to this class. The most notable example, however, is pseudo-fibrous peat of the western moorland, where decomposition cannot be said to occur at all, owing to the heavy rainfall on the one hand which keeps the remains of plants on the surface of the soil sodden with water, and on the other hand, to the high humidity of the atmosphere which reduces evaporation to a minimum and thus keeps the ground water level at or near the surface of the peat.

It will therefore be apparent that the relationship between water content and aeration in peat soils is of special importance especially in regions of high rainfall, like the west of Scotland.

(2) The Aeration of Peat Soils.—As an approach to the problem of ascertaining how far aeration occurs in peat soils of the west, the ground water level was determined in all the more important structural peat types at Inverliever. This was done by digging pits after two weeks of rainless weather in July, when it was considered that the surface-water should have drained off. Without exception, the pits became filled with seepage water to the level of the top of the turf or to within two inches of the top of the turf. The water had not appreciably sunk in the pits during the following six days of dry weather. although this was the only period of three weeks without rain which has occurred during the few years which this investigation has covered. Even on apparently dry ground, at a distance of 1 foot from the wall of a hag, the pit which was dug became filled with water to one inch from the surface of the turf.

The conclusion to be drawn from this experiment is that the permanent water level, in all the more "solid" structural peat soils, is at or near the surface.

In the sphagnum "flat" types the sphagnum itself rises and falls with the water surface. For example, in the loch shown in Sketch III, and at the position of the middle of the transect line B C, it was found that when the level of the water in the loch was high after heavy rain the level of the sphagnum had also risen.

It was observed at an early stage in the investigation that scirpus peat, when exposed to air, changes colour from yellow to black. In the laboratory this change was found to be accompanied by the absorption of oxygen from the air. It was therefore considered that the amount of oxygen absorbed by peat would afford a satisfactory indication of the degree to which it is deficient in natural aeration.

The determination of the quantity of oxygen removed from the air by a substance like wet peat is not a very manageable routine laboratory determination. For this reason the cognate process of reducing a ferric iron solution to the ferrous condition (*i.e.*, from a higher state of oxidation to a lower) was adopted. The results obtained are comparable, and are given here as if oxygen had been absorbed by peat. These results are stated as the weight of oxygen absorbed per cent. of air dry peat, and this percentage figure is called the oxygen-requirement of the peat. (*See* Appendix III for analytical methods used.)

It should be noted that the oxygen-requirement of any kind of peat is not a measure of its degree of aeration which would be a measurement of the suitability of the peat for tree growth. It is, however, a measure of the amount of air which must be absorbed by the peat, in order to bring it into a suitable condition for trees as well as for the organisms which cause the peat to decay into humus. The oxygen-requirement depends upon the degree to which the vegetable matter forming the peat has been altered by anaerobic action, that is, biological chemical action taking place in the absence of air. Therefore unaltered vegetable matter, as well as humus formed under good conditions of aeration, has a low oxygen-requirement.

As an example of the value of the method for the purpose of testing the degree to which a peat is deficient in aeration, the following preliminary test is quoted. Fresh scirpus peat, which has a high oxygen-requirement, was subjected to slight, medium and strong aeration by mascerating in air. As a result of this treatment the colour of the peat became progressively darker, and when tested by the ferric solution method it was found that the oxygen-requirement had become progressively reduced. It is therefore concluded that the method gives a quite satisfactory indication of the amount of oxygen or air required by different kinds of peat. It is apparent also that this test may be applied in ascertaining the influence of any drainage operations, which may have been carried out upon peat, in promoting oxidation.

For purposes of comparison some mineral soils were tested, among which were creep soil from oak woodland at Inverliever and podsol soil from a Scots pine wood near Aberdeen. These mineral soils were generally found to have an oxygen-requirement of less than 0.5 per cent.

The oxygen-requirements of some typical peat soils are given in Table I, showing the oxygen absorbed by each at varying depths down to 12 inches. The oxygen-requirement generally becomes greater with increasing depth.

No. 1, the oxygen-requirement (or air-deficiency) of the surface of amorphous flush peat is not much higher than that of mineral soils. At a few inches from the surface it becomes higher. In some cases (not shown in the table) very high oxygen-requirement figures were obtained at greater depths.

No. 2, pseudo-fibrous peat, has a high oxygen-requirement even at the surface.

No. 3, the intermediate cheesy peat, shows a lower oxygen-requirement than pseudo-fibrous peat at the surface, but below the first two inches the oxygen-requirement becomes very high.

No. 4, fibrous *Eriophorum vaginatum* peat, is intermediate between fibrous

TABLE I

Depth of Sample	(1) Amorphous Flush Peat Rush-Molinia	(2) Pseudo-Fibrous Scirpus	(3) Shallow dark (Cheesy) Inter-mediate	(4) Fibrous *Erio-phorum vaginatum*	(5) Fibrous Sphagnum peat	(6) Frag-mental Hag Mud
Inches						
0–1	2.0	17.7	5.3	3.7	0.75	3.6
1–2	2.3	20.5	6.7	8.9	0.93	4.8
2–3	2.7	20.1	13.3	8.0	1.7	4.8
5	4.2	20.0	16.6	10.3	—	†13.3
7	9.0	20.1	16.6	—	1.7	20.0
9	9.1	20.3	—	14.5	1.9	—
12	9.0	20.0	—	14.7	2.5	—

† No. 6 here changes to unaltered scirpus peat

and pseudo-fibrous peat, a fact which is due partly to aeration and partly to the unaltered fibrous material it contains.

No. 5, a fibrous peat composed of unaltered sphagnum deposited in the free water of a basin, shows a low oxygen-requirement throughout ; this is as might be expected, since no anaerobic chemical change has occurred in the sphagnum since its deposition. At greater depths, both cotton-grass and sphagnum peat become altered to the pseudo-fibrous condition when their oxygen-requirements are similar to that of scirpus peat.

No. 6, fragmental peat, is illustrative of the effect of disintegration and temporary aeration on pseudo-fibrous scirpus peat which is undergoing the process of hag-formation. The upper three to four inches show a much reduced oxygen-requirement, not higher than is to be found in the peat of some fresh flush types. The scirpus peat from which it originated and upon which it lies has the typically high air-deficiency.

The term " fragmental " is applied to peat derived from fragments of organic matter which have been broken down by physical agencies such as running water, and subsequently re-deposited. When peat is coarsely weathered by frost and re-deposited it forms fragmental peat. This kind of peat occurs only on a small scale in the climatic peat areas, but may be important in the silt of lakes.

In peat soils, in which iron is accumulating either throughout the general mass, or in layers, the oxygen-requirement figures are abnormally high. This fact offers an explanation for the very unsatisfactory growth of trees in such soils.

Since tree roots cannot grow and function without an adequate supply of oxygen, it becomes apparent from the figures given in Table I that, in most of the peat soils of the west of Scotland, root growth *in* the peat is impossible, as the peat itself will absorb any oxygen which may be available. This is confirmed by the position taken up by the roots of trees planted on such peat.

In the case of pseudo-fibrous peat living tree roots are found only on the surface.

In fibrous peat, although the tree roots may sometimes penetrate into the peat, they are more usually confined to the surface zone of unaltered plant remains and living plants which can scarcely be termed peat.

In amorphous and recently-deposited fragmental peat the surface oxygen-requirement is not sufficiently high to prevent the growth of tree roots. Various observers have noted the tendency of tree roots to concentrate at certain places in the surface mat of vegetation (*e.g.*, in tufts of living or dead sphagnum), but no correlation could be obtained between such concentration and oxygen-requirement, which is usually low (about 1 per cent.) in the surface moss layer.

TABLE II

Vegetational Type and Peat Type	*p*H Values		
	Mean	Minimum	Maximum
Low moor ; amorphous peat	4.5	4.2	4.6 (6.3)
Low moor series ; sphagnum-flat ; fibrous ...	4.0	3.6	4.5
,, ,, transitional Carex ; fibrous ...	4.1	3.3	4.5
,, ,, ,, later ; ,, ...	3.9	3.2	4.2
Variants in Scirpus high moor—			
Scirpus moor general	3.5	2.8	4.0
Scirpus ; pseudo-structural	3.4	2.8	4.0
Calluna ridges ; pseudo-structural ...	3.4	2.8	4.0
Wet depressions—			
Sphagnum medium, etc. ; fibrous	3.5	3.3	3.7
Sphagnum subsecundum ,, ...	3.5	3.3	3.4
E. polystachion in Hag ,, ...	3.5	2.8	3.7
Hag-Molinia ; fragmental	3.6	3.0	3.9
*Eastern Calluna high moor ; fibrous	3.3	3.0	4.2
Heath and grassy Heath ; mull-humus	4.5	3.0	6.0
Scirpus—Calluna—Molinia ; cheesy	3.6	3.0	3.9
Scirpus—Calluna ; cheesy...	3.5	3.0	3.9
Shallower Scirpus slopes (grazed) ; cheesy ...	3.5	3.3	3.9
Flush Types—			
Iris flush—amorphous	5.0	4.0	6.5
Deeper Rush flush—amorphous	4.8	3.5	5.8
Shallower Rush flush with Myrica—amorphous	3.6	3.0	3.9
Molinia flush—amorphous	4.8	3.0	5.5
Eriophorum polystachion—Molinia (old Hag) ...	3.3	2.8	3.9
Iron flushes of lower ground	3.3	2.6	3.9
Iron flushes of higher ground	3.3	2.6	3.6
Eriophorum vaginatum ; fibrous	4.0	3.3	4.8
E. vaginatum and Molinia—fibrous	4.0	3.6	4.8
Morainic knolls (cheesy)	3.6	3.0	4.5
Steep Calluna slopes (Raw humus)	3.6	2.8	4.8†
*Scirpus ; morainic knolls (cheesy)	3.6	3.3	3.8
Deep Sphagnum north exposures, etc. (fibrous)	3.6	3.0	3.9
*Molinia of southern uplands ; amorphous ...	4.3	2.6	5.8
§Creep soils ; Inverliever	6.5	4.0	7.2
Subsoil in shallower peats	—	2.6	6.8

* Not from Inverliever or chiefly from other areas.

† Apparently an exceptional figure, since subsequent sampling did not verify.

§ No great value is placed upon the mean figure since no attempt was made to obtain a sufficient number of samples to cover all the soil varieties which occur.

From the practical aspect it will be apparent from Table I that, even with efficient drains, a longer period must be required for the thorough aeration of pseudo-fibrous peat than for other kinds of peat. In general the absorption of oxygen from the air by peat is a fairly slow process.

(3) **The Reaction of Peat Soils—Peat Acidity.**—The reaction, or degree of acidity of any soil is a matter of considerable importance, since each plant has a limited range of acidity (and/or alkalinity) within which it can grow satisfactorily. This applies not only to higher plants, but also to the lower plants, including bacteria and fungi. These are the active agents in the disintegration of plant remains, and the formation of humus. In their absence peat accumulates.

The direct measurement of acidity is recorded as the "*p*H value." We are not concerned with the exact meaning of this term, for our purpose it is enough to note that the stronger the acidity the lower the "*p*H value" figure. Thus *p*H = 2 to 3 represents the highest limit in the range of soil acidity, *p*H = 3 to 5 means strongly acid, *p*H = 5 to 6.5 means acid, *p*H = 7 is neutral, and where the *p*H value lies above 7 the reaction is alkaline.

The peat soils of the west of Scotland have a high acidity. The range of acidity in the surface layer of peat is from *p*H 2.8 to 6.5 The average acidity for all types at Inverliever is *p*H 4.2.

Table II gives a record of the *p*H values obtained at the surface of the peat associated with the various vegetational types which occur at Inverliever, together with some other soils, which are included for comparison. Table III is a record of a selection of these values arranged with reference to the species of plant occurring at the point at which the sample was taken. (See Appendix III, p. 97-8, for methods used).

TABLE III

Species of Plant	*p*H Values		
	Mean	Minimum	Maximum
Calluna	3.9	2.6	4.8
Molinia in tufts	4.2	2.6	5.8
Molinia short less vigorous plants	3.9	3.3	4.2
Molinia Total	4.0	2.6	5.8
Scirpus	3.8	3.0	4.4
Eriophorum vaginatum	4.0	3.5	4.8
Sphagna acutifolia	3.3	2.9	3.6
Sphagnum—medium and centrale	3.5	3.3	3.7
Sphagnum—subsecunda and cuspidata	3.6	3.3	4.3
Hypnaceous mosses in high moor	3.5	2.8	3.8

From these tables it will be seen that there is considerable variation in the acidity of the peat of the west of Scotland. The acidity of any individual kind of peat also varies. This variation is so irregular that the determination of *p*H value is of no practical significance as a means of separating one type of vegetation or kind of peat from another in assessing its silvicultural quality. At the same time certain tendencies are observable. For example, in basin peat, acidity becomes progressively stronger from the amorphous peat of low moor to peat of the transitional types, and culminates in scirpus peat of the high moor. In general the fresh flush and *Eriophorum vaginatum* flush peat is less acid than other kinds of peat, while iron flush peat is more strongly acid. The range of *p*H value of different types of vegetation or kinds of peat may overlap to such an extent that any attempt to classify types of vegetation and kinds of peat on this basis would obviously be of no practical value. The same remarks apply to the acidities obtained from individual species of plants, the range of one species may overlap the range of others. In the course of my investigations, however, it has been found that the peat below dense tufts of calluna is usually more acid than on other parts of the moorland in which calluna occurs, either pure or in association with other plants. For example :—

Peat from calluna tufts	*p*H	General peat	*p*H
From tufted molinia	4.1	Molinia	4.5
;, short molinia	3.7	Molinia	3.9
,, scirpus high moor	3.0	Scirpus	3.3
,, *Eriophorum vaginatum* ...	3.6	*Eriophorum*	3.9

Scirpus, in association with plants other than calluna, such as molinia and *Eriophorum vaginatum*, also appears to increase acidity.

The acidity of the peat at 8-12 inches below the surface varies almost as much as at the surface. In deep peat, however, the extreme figures obtained at the surface are not repeated at a depth of 12 or more inches down, for example, in scirpus high moor peat the following acidities were found respectively at the surface and at a depth of 12 inches :—

——	Mean	Minimum	Maximum
At the surface	3.5	2.8	4.0
At 12 inches depth	3.4	3.2	3.5

In the shallower peats a zone of very high acidity is frequently found to occur at the junction of mineral soil and peat. For example, *p*H 2.6 has been recorded for this zone. The same figure has also been obtained for fresh flush peat overlying deep pseudo-fibrous peat. In both cases it is most probably due to mineral acids derived from rock decomposition, for example, sulphuric acid, accumulating at the junction of mobile and stagnant water.

Acidity may vary markedly from place to place within a small area. Table IV is introduced here to illustrate this feature.

The data recorded were obtained on a planted area along a line one chain in length. Samples were taken at from about 3 to 4 yards apart, with the exception of No. 6 which was only 2 yards distant from No. 5. At these six points, the type of vegetation, the character of the surface organic matter, and the relative rate of growth of the crop, were noted. Further, field tests were made of the acidity in the organic surface and sub-surface soil, and also of the mineral soil below, with a view to finding out whether any connection could be shown to exist between acidity, vegetation and tree growth. It is apparent that great variation in *p*H value occurs horizontally from place to place as well

TABLE IV

Vegetational Type	Surface Organic Matter	Growth of Spruce	Peat		Soil below peat
			Surface	Sub-surface	
1. Molinia flush ...	Black, finely granular	Good ...	5.2	3.4	3.2
2. Grassy heath ...	Black - brown raw humus	Slow ; few needles of last year left	4.5	3.3	3.3
3. Higher ridge in scirpus moor with calluna dominant	Dark brown to yellow brown	Bad ; many dead...	4.0	4.5	4.2
4. Rush — molinia flush	Black coarsely granular	Good spruce ...	5.0	4.5 Soil	4.4
5. Heath calluna—vaccinium with *Aira flexuosa*	Black, finely granular, powdery when dry	Slow, but good colour in summer	3.8	5.0	6.2
6. Flush with willow and birch rush flush	Coarse and containing mineral salt	Very good... ...	3.8	4.5	6.2

as vertically below the surface of the soil. *p*H value therefore cannot be used as an index of the rate of growth of trees, nor does it vary regularly from type to type of vegetation. It will be seen from the table that highest and lowest surface figures were obtained in one type, the rush-flush.

No seasonal changes in the surface acidity were observable. In dry weather, drainage-water in natural streams or old ditches may become more acid, but the surface-drainage water of the area, on the whole, remains neutral, that is to say it is purely rain water. This, however, is not so in areas of lower rainfall than Inverliever, for example, at Borgie, during the growing season, the drainage-water usually shows a distinctly or strongly acid reaction. From these facts it may be concluded that water from the peat reaches the natural drainage system only in very small amounts, and that at Inverliever it is so diluted by rain as to have no appreciable effect on the acidity of the drainage water and, conversely, that it is only during drier periods, in areas of lower rainfall that sufficient water passes from the peat to affect the acidity of the general drainage.

(4) **The "Lime-Requirement" of Peat Soils.**—In practice soil-acidity is neutralised by treatment with lime. Hence the determination of the quantity of lime required to neutralise acidity is of more direct practical importance than the determination of acidity itself. The quantity of lime required to counteract the acidity of a soil is called the "lime-requirement" of the soil. This may be determined by several methods which, for various reasons, give somewhat different results. The method selected for this investigation is that known as the calcium acetate method. (*See* Appendix III). The figures obtained represent the amount of lime absorbed per cent. of air dry peat ; these figures when multiplied by 1.75 give approximately the official "lime-requirement" of the soil.

Table V shows the "calcium acetate acidity" of peat obtained from the more important types of vegetation.

TABLE V

Vegetation and Peat Type	Acidity (Calcium Acetate) as C.C. N. acid per 100g. Varying— From	To
Low moor ; sphagnum flat ; fibrous	30	35
Transitional sedge ; fibrous	30	35
Later transitional ; fibrous	30	40
Scirpus high moor—		
Scirpus moor general	32	46
Scirpus pseudo-structural	34	46
Calluna ridges pseudo-structural	39	41
Sphagnum in pools ; fibrous	32	40
E. polystachion in hag ; fibrous	32	38
Fragmental peat of hags	28	30
Scirpus—Calluna—Molinia ; cheesy...	25	50
Scirpus—Calluna ; cheesy	35	50
Shallow scirpus slopes ; cheesy	32	42
Flush Types—		
Iris flush ; amorphous	19	25
Deeper rush flush ; amorphous	20	25
Molinia flush ; amorphous	20	30
Iron flush ; turf	30	40
Eriophorum vaginatum ; fibrous	25	35
E. vaginatum and molinia	25	32
Calluna ; morainic knolls (cheesy)	30	50
Mull calluna slopes	27	37

In the case of lime-requirement as in *p*H value, there is considerable overlapping from type to type. At the same time, however, the lime-requirement is distinctly lower in the fresh flush types and in some of the *Eriophorum vaginatum* types, that is, where trees are growing well or fairly well. Wherever a series of determinations has been made across areas on which tree growth showed considerable variation, the writer has found a much better correlation between tree-growth and lime-requirement than between growth and *p*H value. For example, in comparison with the data in Table IV, the following are the calcium acetate acidities of the transect along which the growth of trees and *p*H values are there recorded.

Number : ...	1.	2.	3.	4.	5.	6.
Acidity (Ca-Ac) ...	22.3	37.6	41.1	18.7	29.3	22.6
Growth	Good	Slow	Bad	Good	Slow	Very Good

There is a much better correlation here between acidity and tree growth than is shown in Table IV. In certain instances, however, the correlation is not so satisfactory. Sometimes, but not always, this lack of correlation could be ascribed to definite causes.

The general conclusion was reached that the lime-requirement method is a distinctly more satisfactory method of comparing the relative quality of adjacent peat types than *p*H value, and that therefore lime-requirement is of more importance in relation to tree growth on peat, than actual acidity.

(5) **The Mineral Content of Peat Soils—Plant Nutrients.**—Although peat itself is an organic substance, it nevertheless contains a certain, but variable, quantity of mineral matter. This mineral matter is represented by the ash

which remains after the organic matter is burned. Peats, however, may also contain mineral matter derived from external sources, such as mineral soil particles washed down from higher levels, or wind-blown in the form of dust. In the west of Scotland, the general wetness of the soil throughout the year makes wind-action a negligible factor, but the prevailing irregularity in surface features combined with the high rainfall, increases the importance of down-wash.

As low moor develops and becomes high moor or rises higher and higher above the mineral soil, its surface is gradually elevated above the source of mineral matter, until the plants growing upon it are dependent upon the remains of their predecessors for mineral food supplies. But all peat soils do not show this gradual diminution of mineral content with increasing depth, for example, some of the flush peats. Table VI illustrates these points.

TABLE VI

VARIATION IN THE ASH CONTENT OF TWO KINDS OF DEEP PEAT WITH VARYING DEPTH

Depth of Sampling	Ash Content Percentage of Dry Weight of Sample	
	I.—Scirpus high moor	II.—Deep rush flush
Feet		
0–½	4.83*	10.15
½–1½	4.51	16.80
1½–2½	4.60	17.33
2½–3½	5.05	11.15
3½–4½	5.58	10.16
5½–6½	6.03	13.16
	Mineral soil begins	
6½–7½	10.68	22.73
At 8 feet	90.30	60.91

*The ash content of the surface sample is higher than that below it, owing to the unavoidable inclusion of living plants in the sample ; the *turf* as a whole is represented in the analyses.

In the typical scirpus high moor peat the ash content (mineral matter) increases slowly but regularly from above downward, until the mineral soil is reached. The flush peat shows no such regular increase in ash content. It has a variable amount of clay and even sand incorporated in it at all depths as a result of down-wash from neighbouring mineral soil.

In the shallower peat soils of the transitional types of vegetation the ash content usually shows some irregularity. With higher ash content the vegetation often shows change toward flush types, for example, molinia or *Juncus articulatus* appear locally or become more luxuriant. Where little or no change appears in the vegetation, it has been usually found that the mineral matter is strongly leached or is very coarse in texture (sand or grit) ; that is to say, it has a low plant-food content.

It will thus be apparent (Table VII) that the quantity of mineral matter alone is only of slight value in determining the quality of peat. The composition of the mineral matter is of more importance.

The principal mineral elements necessary to plant life are lime, potash, phosphorus and magnesium, to which might be added others of lesser importance as regards the present discussion since they are required in smaller quantities, such as iron and manganese.

TABLE VII

ASH CONTENT AND ASH ANALYSIS OF TYPICAL PEATS (EXPRESSED AS PER CENT. OF WEIGHT OF PEAT DRIED AT 98°–100° C.)

Type of Vegetation and of Peat	Ash Content			Analysis of Soluble Ash				
	Total	Insoluble Silicates	Soluble HCl	Sesquioxides Fe_2O_3 & Al_2O_3	Lime CaO	Magnesia MgO	Potash K_2O	Phosphate P_2O_5
Fibrous Peats—								
Sphagnum flat moor ...	2.67	1.92	0.75	0.34	0.13	0.17	0.021	0.073
	2.74	1.91	0.83	0.37	0.14	0.17	0.023	0.073
Transitions toward high moor ...	3.10	2.15	0.85	0.36	0.14	0.15	0.035	0.070
	4.56	3.61	0.95	0.38	0.17	0.15	0.041	0.071
Pseudo-Fibrous—								
Deep Scirpus Maximum ...	7.69	6.51	1.73	1.31	0.23	0.30	0.07	0.09
Deep Scirpus Minimum ...	4.35	3.38	1.16	0.78	0.16	0.06	0.02	0.06
Deep Scirpus Mean ...	5.69	4.20	1.49	1.04	0.17	0.09	0.04	0.06
Fibrous—								
Eriophorum vaginatum Types ...	11.17	5.92	5.15	3.53	1.13	0.21	0.11	0.08
	5.14	2.75	2.38	1.53	0.44	0.30	0.05	0.07
	6.89	4.93	1.96	1.14	0.20	0.31	0.04	0.05
	3.08	1.06	1.92	1.14	0.33	0.29	0.04	0.05
Molinia and E. vaginatum (Fibrous with Amorphous Surface) ...	4.29	2.96	1.33	0.12	0.66	0.32	0.09	0.11
Fragmental—								
Molinia in old hag	6.69	4.52	2.17	1.37	0.31	0.21	0.07	0.05
Amorphous Flush Types—								
Juncus articulatus dominant ... Maximum ...	22.67	18.87	20.23	20.29	2.46	0.43	0.20	0.20
Juncus articulatus dominant ... Minimum ...	9.69	4.35	4.39	2.01	1.12	0.10	0.06	0.07
Juncus articulatus dominant ... Mean ...	13.72	8.15	5.57	2.81	1.46	0.21	0.09	0.15

Molinia with little Juncus (intermediate)	22.54	18.22	4.32	2.80	1.25	0.09	0.08	0.08
Molinia flushes — Maximum ...	30.31	22.42	19.89	24.00	1.03	0.16	0.16	0.11
Molinia flushes — Minimum ...	8.53	5.68	4.32	4.40	0.63	0.09	0.09	0.07
Molinia flushes — Mean ...	21.54	13.27	8.30	10.65	0.75	0.10	0.10	0.09
Shallow cheesy peats—								
Scirpus—Calluna—Molinia ... — Maximum ...	22.00	8.25	15.31	14.01	0.93	0.47	0.09	0.07
Scirpus—Calluna—Molinia ... — Minimum ...	13.11	6.69	4.86	3.33	0.45	0.44	0.07	0.03
Scirpus—Calluna	11.54	7.14	4.40	3.21	0.48	0.43	0.09	0.07
Scirpus	10.03	6.04	3.99	3.53	0.28	0.11	0.06	0.04
Moraine Calluna	6.98	5.63	1.35	0.56	0.46	0.11	0.03	0.05
Heath mull (Type III, 1)	22.58	16.72	5.86	2.85	0.99	1.38	0.08	0.11
"Good" Continental Peat (Ramann)	(N = 3.23. *See* Table IX)				6.0	0.2	0.05	0.25

Table VII shows the quantities and the principal constituents of the mineral matter which has been found to occur in the various kinds of peat in the west of Scotland. The samples analysed were obtained mainly from Inverliever, but samples from other areas show similar results to those from Inverliever. Since the results cannot be compared with analyses of mineral soils, the analysis of a heath humus from Inverliever is included, and that of a good peat in which tree growth is satisfactory is quoted from Ramann (*Bodenkunde*).

The insoluble ash has little direct bearing upon the growth of plants in peat. The soluble constituents only are likely to be available to plants, but it must be recognised that even these are not necessarily in a suitable condition for absorption by plant-roots. Of the soluble ash constituents, iron and aluminium are correlated with the total ash content rather than with the type of peat, and they are of minor importance in relation to the nutritional value of the peat. The influence of other soluble mineral constituents, which comprise those of nutritional importance, can be correlated in a general way with type of vegetation and with the quality of the peat. The influence of lime is most marked in this respect ; the lime content increases, from the poorer types to the better types, quite regularly, with only occasional exceptions, which are easily explained.

The general conclusion may be accepted that where the lime-content falls below 0.2 per cent. the peat is infertile and when it rises above 0.2 per cent. the peat is of at least moderately good quality, with the exception of the shallower cheesy peat which may have a higher lime-content and yet be of low fertility.

Magnesium content varies, on the whole, with lime content. In shallow and flush peat the correlation is not so marked as in deeper peats.

Potash content varies in a general way with the fertility of the peat, but it is noteworthy that in almost all the samples analysed the potash content is higher than in the case of the good peat quoted from Ramann.

The lowest phosphate contents have been found occasionally in *Eriophorum vaginatum* peat and also in shallow peat overlying leached mineral soil. It may be noted that the lime and phosphate contents are always lower than those of Ramann's " good " peat ; the potash content is more frequently higher.

Although the total content of mineral food material in peat is a fairly good index of its silvicultural fertility, it is not the final criterion. Some of the nutrient materials may be in a form which plants cannot readily utilise, in which case they are said to be unavailable to plants in contradistinction to available nutrients which usually occur in a soluble form either in a state of solution or in a state from which they may easily dissolve.

As a test of the concentration of salts in the soil water, use is made of the well-known fact that, when a substance is dissolved in water, the solution has a lower freezing temperature than that of pure water. The extent to which the temperature must be lowered before freezing takes place offers a measure of the quantity of substance in solution. By this method fifty to sixty determinations of the strength of peat soil solution were made and in no case was the temperature at freezing point (0.002°C.) lower than that of pure water. That is to say, the nutrient materials present in peat are not in solution but are held by the peat itself. They may be present in the peat in two forms. On the one hand, the nutrient materials may be chemically united to the peat in such a way that they are liberated and become available for plants only when the peat undergoes decomposition. On the other hand, they may be held by the peat in such a condition that they can be absorbed by plant-roots which come into contact with them. This form of available food-material can be liberated from the peat by displacement with solutions of common salt. The process is called "base exchange" since the base of the salt takes the place of the bases in the peat which then pass into the salt solution. Table VIII shows the quantities of available bases present in average samples of some typical peats. Data from a nursery soil are given for comparison.

TABLE VIII

MATERIALS DISSOLVED BY BASE EXCHANGE FROM TYPICAL PEATS

The figures represent parts per 100 of dry peat.
? = small amount but less than 0.0001 parts per 100.
Results in brackets = totals present in ashes as percentages.

Peat Types	Sesquioxides (Fe_2O_3 and Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Potash (K_2O)
Rush flush ...	0.0065 (3.37)	0.088 (1.53)	0.0003 (0.20)	0.00056 (0.17)
Molinia flush ...	0.0073 (4.68)	0.032 (0.92)	0.0007 (0.13)	0.00046 (0.09)
Eriophorum vaginatum ...	0.00033 (1.14)	0.0091 (0.20)	0.0013 (0.31)	0.00035 (0.04)
Scirpus high moor	0.00032 (1.14)	0.00061 (0.18)	? (0.07)	? (0.02)
Calluna moraine	0.00126 (0.56)	0.0009 (0.46)	0.0008 (0.11)	? (0.03)
Nursery soil—(Seaton) ...	0.0011	0.1055	0.0087	0.0027

The quantities of available basic nutrient materials are lower in those kinds of peat examined than in the nursery soil. Some kinds of peat, however, compare quite favourably with many of the heath and woodland soils of the more acid types. These are especially amorphous peat, and most of the better qualities of *Eriophorum vaginatum* peat. In deeper scirpus peat and in peat of leached moraine, the quantity of available basic food material is distinctly lower than any hitherto recorded for mineral soils in this country.

The inference is that the infertility of these kinds of peat is due not only to bad aeration, but also to lack of available mineral food material.

(6) The Nitrogenous Compounds in Peat.—The nitrogen present in peat occurs mainly in the form of complex organic compounds which are not available to plants, but when the peat undergoes decomposition these complex nitrogen compounds become changed to ammonia and perhaps to nitrate, and in this form the nitrogen is available to plants. The determination of the total nitrogen content of peat is therefore useful chiefly as an indication of the nitrogen reserve locked up in the peat.

Table IX shows a selection of nitrogen determinations which give a general idea of the nitrogen-content and of the forms in which it is found in peat in the west of Scotland. The figures are calculated as percentages of the organic matter present in the peat.

TABLE IX

Peat Types	Organic Matter	Total Nitrogen as N. Percentage of Organic Matter	Ammonia as NH_4	Nitrate formed on storage as NO_3	*p*H
Fibrous flat moor ... ... Sphagnum peat	94.31	2.62	0.061	Nil	4.0
Pseudo-fibrous ...	96.62	2.01	0.021	Nil	3.0
Deep scirpus ...	93.49	2.13	0.023	Nil	3.0
Fibrous	91.35	2.03	0.035	Trace	4.6
Eriophorum vaginatum	92.13	2.47	0.032	Nil	3.3
Amorphous flush types—					
Juncus	90.13	2.53	0.023	Trace	4.2
	84.36	2.87	0.037	0.002	5.0
Molinia	91.67	1.99	0.039	0.001	4.3
	85.65	2.71	0.029	Trace	3.5
Cheesy peats—					
Shallow scirpus	89.97	1.78	0.019	Nil	3.3
Calluna (moraine) ...	93.02	1.05	0.0063	Nil	3.3

As may be seen, the total nitrogen does not show much variation from one kind of peat to another, with the exception of shallow cheesy peat on calluna-moraine. Speaking generally, the peats of flush types show higher ammonia content; that is to say, the better the silvicultural quality of the peat, as shown by tree growth, the higher, on the whole, is the ammonia content. Even in one kind of peat the ammonia content may vary considerably; for example, in fibrous sphagnum peat the ammonia content is not usually so high as the sample of flat moor sphagnum peat given in the table.

Corresponding with the low total nitrogen content of shallower peat on leached soil, there was found a low ammonia content. Ammonia is always present in peat, but the amount present in any kind of peat is found to vary in an irregular way from season to season and from year to year.

With some doubtful exceptions nitrate has not been found in any west Scottish peat. It does not, however, follow from this that nitrate is not produced, since it might be taken up by plants, or washed away by rain or flush water as soon as it is formed. In order to ascertain whether nitrate-formation is likely to take place in different kinds of peat, samples were broken up and allowed to stand for six weeks in loosely-covered beakers. Table IX, column 5, records the result. Only some of the flush peats showed any nitrate-formation, and in these the amount produced during six weeks was very small.

The **p**H values of the samples analysed are given in column 6. It will be seen that there is only a very limited correlation between acidity and ammonia-content or nitrate-formation. The ammonia-content and the quantity of nitrate formed in the laboratory both decrease with increasing acidity.

In review of the whole question of plant nutrients in peat the conclusions reached are as follows :—

Although there is a general tendency for those kinds of peat upon which tree growth is more satisfactory to contain more plant nutrient, yet the nutrient content is lower in some of the better quality peats than in many of those in which trees do not grow well.

Analysis of the peat is not always an index to its quality as soil; for example, in peat which carries a good crop, flush water is usually present, and may contain those nutrients which are most readily available to the crop. Analysis gives no indication of the quantity of nutrient offered to the crop in this way.

No element of nutrition can be said to be present in the poorer kinds of peat in such small amounts as to limit the growth of trees, with the possible exceptions of phosphate and available nitrogen. Among the more fertile kinds of peat the minimum figure for phosphate (0.07 per cent.) was obtained from molinia flush in which trees were growing quite well. Lower phosphate-contents than this are quite frequent, but are not confined to the most infertile peats. The conclusion is therefore reached that a phosphate-content lower than 0.07 per cent. is likely to interfere with the normal growth of trees on peat. By similar reasoning it is concluded that an ammonia-content of less than 0.02 per cent. is insufficient for tree growth on peat.

Available bases may be present in peat in very small quantities, but only in a few cases is the available base lower than has been found in some mineral soils.

There can be no doubt that, in the west of Scotland, bad aeration is of much more importance in relation to the growth of trees in peat than nutritional infertility, although lack of phosphate and of available nitrogen may be important contributory causes of infertility. When, by improved aeration, decomposition of peat is accelerated, the plant nutrients thus liberated should be sufficient to support the growth of young trees.

THE SILVICULTURAL QUALITY OF PEAT SOILS AS ASSESSED BY THE RATE OF TREE GROWTH

A number of species, chiefly conifers, have been planted on moorland at Inverliever and elsewhere in the west of Scotland. These plantations form a valuable guide to the silvicultural quality of the different kinds of peat and they are also of assistance in estimating the effect upon peat of the silvicultural methods of treatment which were adopted in their formation. The growth of trees on peat was studied chiefly from this point of view, and since, as a rule, only young plantations are to be found, the term "quality of the peat" refers only to the rate of growth of young trees and not to the quality class of the mature crop.

The species available for study at Inverliever are Scots pine, mountain pine, common spruce, Sitka spruce and white spruce. The Scots pine has been planted on those sites which were considered to be drier and more heath-like. Apparently abundance of vigorous calluna was used as an indicator of Scots pine ground. On felled woodland areas there are no recent plantations, but the older woodlands frequently contain, among other species, fairly well grown Scots pine. On the drier grassland wherever the soil surface is not strongly humose, Scots pine grows quite well. On the heath and moorland types where the surface soil consists of waterlogged humus, tree growth is unsatisfactory or extremely poor. On heath, about two years after planting, the rate of growth becomes more and more retarded. This is due to the development of sphagnum mounds, which has been referred to earlier. In fact, on heath-ground, Scots pine seems to hasten the change from heath to moorland, by the partial shelter which it provides for sphagnum. Similar results are frequent where Scots pine is planted upon *Eriophorum vaginatum* flush. On the better flush types like rush and molinia-flush, Scots pine has not been planted. On morainic knolls its growth is very poor and wherever the peat is pseudo-fibrous, or cheesy with yellow or light brown colour, Scots pine seems to have died out.

Where rainfall is lower and summer drought more frequent than at Inverliever, the darker colour of the cheesy kinds of peat is reflected in the better growth of Scots pine.

At Achnashellach a remnant of the ancient Scots pine forest is being invaded by moorland. Here, natural regeneration takes place freely where the soil is less humose, but where even a few inches of sodden humus lies on the surface, only occasional and unhealthy plants are to be found.

It will be seen from these facts that Scots pine is not of much value as a guide to the relative silvicultural value of moorland soils, owing to its uniformly poor growth on moorland and transitional areas.

Mountain pine has been planted on a considerable range of soils, varying from non-humose grassland and grassy heath to the worst forms of scirpus high moor. At Inverliever its habit in almost all cases is that of the bush-like *mughus* form in which rate of growth is so slow that its value as a soil-indicator is much reduced. On the other hand it shows great vitality, since it has persisted on the worst kinds of pseudo-fibrous peat, where spruces have completely died out. It has been used as a nurse and as a check to the ground vegetation, *i.e.*, as a soil improver. At Inverliever, on peat, it has not proved satisfactory for this purpose owing to its slow growth ; it would require many years, at the usual distance of planting, to cover the ground and produce sufficient shade to change the vegetation. In calluna vegetation, mountain pine does not suffer from growth check like the spruces.

As compared with the spruces, mountain pine is not of great value as a soil indicator, except on soils which are heath-like or very poor, where it remains healthy when the spruces are checked or killed out. In some other areas where the upright variety of mountain pine has been planted, it provides better shelter and shade than it does at Inverliever.

After due consideration it was decided to confine attention to the spruces for the purpose of assessing by tree growth the relative fertility of the different kinds of peat. Common spruce is more abundant in the earlier, and Sitka spruce in the more recent plantations.

The Growth of Spruces on Peat

The growth of young trees upon peat in the west of Scotland is, with few exceptions, very slow at first. The exceptions are found on the fresh flush types of vegetation. The irregularity in growth which is frequent in flush types is due to factors like frost, or lodging of rank herbage, and is not inherent in the peat soil. While this abnormally slow rate of growth continues the trees are said to be " in check " or in the checked condition. Trees which are in check may recover after a few years of slow growth, or they may remain in check for a long time and ultimately succumb. The intensity of check also varies. Plants affected may either slowly or rapidly become less healthy in appearance and slower in growth. Measurements of very strongly checked trees are not of much use since growth is so slow. For example, trees planted 15 years ago may not be measurably higher than they were two years after planting.

The less intense forms of growth-check are illustrated in Table X. The data are derived from measurements of groups of five sample trees. (*a*), (*b*) and (*c*) are Sitka spruce ; (*d*) is common spruce. The vegetation of (*a*) is tufted molinia flush ; of (*b*) *Eriophorum vaginatum* with *Molinia* and *Aira flexuosa* ; of (*c*) *Molinia* with *Juncus articulatus, Erica tetralix* and *Sphagnum cymbifolium* ; of (*d*) grassy heath, changing to *Calluna* with *Sphagnum rubellum* and *S. acutifolium.*

TABLE X

EXAMPLES OF CHECK ON PEAT

—	Length of the Year's Shoot in Inches					
	1917	1918	1919	1920	1921	1922
Planted in 1916—						
(*a*) Molinia Flush ...	5	2	2	2	1	1
(*b*) *Eriophorum* ...	4½	2½	3	2½	2½	2½
(*c*) Molinia and Juncus	5	4	4½	3	4½	3
Planted in 1917—						
(*d*) Grassy heath ...	—	2½	2	2½	3	3

—	Length of the Year's Shoot in Inches					
	1923	1924	1925	1926	1927	1928
Planted in 1916—						
(*a*)	4	4½	6½	8	9½	—
(*b*)	¾	¾	½	½	2	—
(*c*)	2	2	2	4½	6½	9
Planted in 1917 (*d*) ...	4½	4½	3	2	1½	½

In (*a*) the period of check was of short duration, and the check, which was not severe, was followed by rapid recovery. In (*b*) check had become progressively stronger during the first 10 years, that is until the ground vegetation had become opener, owing to the shade of the branches of the trees. In (*c*) check was not so intense but it was more prolonged owing to the ability of the sphagnum to grow under moderately strong shade.

In (*d*) is shown the kind of check which is frequent when spruce is planted on ericaceous heath, or on sheltered slopes, where ericaceous plants are abundant. Here, after a fairly good recovery from initial planting check, in the years 1925 and onward, a secondary check has set in from which the crop may not recover. This secondary check is due to the rapid growth of sphagnum mounds near or around the bases of the trees. This is the only cause of general subsequent check in blocks of trees which have recovered from initial check. It is primarily due to the combined partial shelter which the trees themselves and ericaceous sub-shrubs provide for the rapid growth of sphagnum. If the young crop were more closely spaced, canopy would close up more rapidly and the growth of sphagnum would be checked. For example, Sitka spruce, with its more rapid initial growth on heath ground, is not so liable to this kind of check as common spruce.

Individual trees on exposed sites or at the sides of blocks or in small groups may again suffer from growth-check after recovery from primary check, but this is due to their exposed position in which defoliation by wind, loss of leader, or damage by frost are likely to occur; such injury can produce check, but in this case the cause is not due to soil conditions.

The period and intensity of check vary from type to type of moorland. On all types in which *Scirpus caespitosus* is fairly abundant or abundant, with short densely-packed sphagnum, check is intense and permanent. In all types in which calluna is abundant, or becomes so during the initial check period, common spruce either dies or the check becomes unduly prolonged; with Sitka spruce the check is less severe. In vegetation where *Erica tetralix* is abundant, check is more intense than in similar vegetation where it is absent. Where the species of mound-forming sphagnum is the more dense *S. rubellum*, check is more intense than where *S. acutifolium* with its looser habit, forms mounds.

The principal plants of the ground vegetation may be arranged in the following order, according to the intensity of check shown by trees planted on sites where they are present :—

Check very slight : *Juncus articulatus*, softer grasses (*e.g.*, *Holcus* and *Agrostis*) and *Molinia*.

Check strong : Harder grasses (*Aira flexuosa* and *Festuca ovina*) and *Eriophorum vaginatum*.

Check very strong : *Calluna*, Ericaceous plants in general, *Scirpus*.

Mosses growing upon peat may be similarly arranged.

Check slight : Open *Sphagnum*, especially the more robust members of the *Cymbifolium* group.

Check moderate : The more vigorous and open members of the *Acutifolium* group; *e.g.*, *S. acutifolium*, *S. warnstorfii*.

Check fairly strong : The compact forms, *S. rubellum*, *S. medium*, *S. centrale*.

Check very strong : Densely compact short forms of the *Acutifolium* group, and *S. compactum*, the heath mosses usually associated with *Calluna*, *Rhacomitrium lanuginosum*. When *Rhacomitrium* is present in the form of grey tufts and where *Pleurosia purpurea* is abundant the spruces usually die in a very short time.

From the foregoing it will be seen that in the main climatic types of vegetation the spruces suffer severe check and recovery does not take place. In the transitional types check intensity can be correlated with the amount of calluna, scirpus, or both in the vegetation. Check is complete in the strongly ferruginous and poorly aerated flushes in moorland, especially where scirpus and *Erica tetralix* are abundant. In *Eriophorum vaginatum* flushes, check is more intense where scirpus is, or where *Empetrum nigrum*, *Erica tetralix*, calluna and other ericaceous plants are abundant. It is less intense where

Eriophorum is luxuriant and other ground vegetation (*e.g.*, ericaceous plants and scirpus) is not abundant. It is least marked when *Eriophorum* is accompanied by molinia and other grasses. That is to say, young trees on *Eriophorum vaginatum* ground show a better appearance and have more chance of success than on climax moorland, but growth is slower and more irregular than on the fresh-flush types of vegetation.

In the fresh-flush types the relative rate of recovery of trees from check is as follows :—Where *Juncus articulatus* is abundant check scarcely occurs and growth is very good. Next follows molinia in well-formed tussocks or mixed with the softer grasses, then molinia with the harder grasses and with *Eriophorum vaginatum*, in which a definite period of check occurs. In molinia of the diffuse type with *Eriophorum vaginatum* and *Erica tetralix*, and with *Eriophorum polystachion*, the check period is prolonged and recovery is not certain. In the less tussocky molinia types, where recovery from check is slow, the growth of calluna before recovery has taken place may produce permanent check.

Although the degree to which the young trees in the crop become checked varies with the vegetation and can be correlated with the actual species among which young trees are planted, *e.g.*, *Calluna*, *Sphagnum rubellum*, it does not necessarily follow that the ground vegetation is in itself the direct cause of the check. It is known that certain plants have a harmful influence upon the growth of others ; for example, grass under fruit trees ; the checking of spruce planted in calluna is also at least in part due to the injurious action of the calluna upon the roots of the spruce (E. V. Laing, Forestry Commission Bulletin No. 13, "*Studies on Tree Roots*").

Quite apart from this "toxic" effect, the vegetation may interfere with the rate of growth of trees in a simple mechanical way, as has been already pointed out in the case of vigorously-growing sphagnum mounds, which in time exclude air from the roots. It is considered that the chief cause of check on peat is want of proper aeration. In the sphagnum flat, and in similar conditions where stagnant water lies at or near the surface of the sphagnum, tree roots have only stagnant water at their disposal, and therefore the trees die off quickly. In peat of climax moorland and in similar peats of transitional moorland in which aeration is poor even at the surface, whether the moss covering be thin or compact, tree roots have only a water-logged surface in which they may grow, and here, again, except in places where local tufts of herbage provide a better aerated turf, check is intense.

In those transitional types in which partly-aerated dark cheesy peat occurs, conditions are not much better, since aeration is only intermittent at best. The greater variety of subsidiary plants like *Eriophorum vaginatum*, molinia and sphagnum provides a certain depth of partly-aerated turf in which tree roots may live. Although check is usually intense and prolonged, the number of plants which die in the first few years is much reduced as compared with areas on which scirpus and calluna and short, compact sphagnums predominate.

In *Eriophorum vaginatum* flush, in the absence of ericaceous plants, check is not very intense. Young trees are usually of good colour, although growth is slow. The tufts of cotton-grass afford a considerable depth of aerated fibre in which roots may grow ; and if the tufts remain free of calluna, recovery from check is likely. Where *Erica tetralix* is abundant in flush, water is usually accumulating, and is the cause of check.

Where molinia forms tufts and where the peat is amorphous, even although the roots are confined to the surface, they can ramify in the well-aerated tufts and below the loose litter which the molinia produces so that checking of growth scarcely occurs.

In rush-flush and in wet meadow peat in which rushes, molinia and other grasses are abundant, aeration of the surface layer is sufficient to produce conditions for tree growth similar to those of flush mineral soil, and therefore growth is not checked.

In discussing the causes of check of trees growing upon peat reference must be made to the temperature data given above (pp. 11-13) in so far as these relate to the surface turf. It was pointed out that unusually high and rapid changes in temperature result from the insolation of certain plants such as *Sphagnum* and *Rhacomitrium*. There is a distinct correlation between the degree of temperature change and the intensity of check shown by individual trees growing in tufts of surface vegetation such as *Calluna*, *Rhacomitrium*, *Sphagnum* and *Eriophorum vaginatum*.

The writer concludes, therefore, that the principal cause of growth check in Norway and Sitka spruces when planted in peat is traceable to want of aeration in the soil which prevents the roots of these trees from entering it, to obtain the food materials necessary for growth. The roots are confined to the surface turf, in which available food material is lacking, with the result that the plants suffer from starvation. In addition, owing to their position on the surface of the ground, the roots themselves are subject to fluctuations in weather conditions, such as rainfall resulting in temporary waterlogging, frost, insolation and the like. The influence of these factors is modified by the surface herbage which, in addition, may of itself injure tree roots, by overlying and suffocating them, as for example sphagnum, or in a more direct manner by toxic action.

Table XI is added to give a general idea of the relative rate of growth of Sitka spruce and common spruce on different types of vegetation where no special method of treatment, beyond ordinary drainage, has been applied.

The figures have been calculated from measurements made in plots of from 50 to 100 plants. The plots were selected as being representative of the growth of the tree on each particular type. The relative shoot-growth figures represent the mean annual growth in length of the leading shoot over the period of 6 to 10 years after planting. Plants which had obviously suffered from any special injury (*e.g.*, frosted leader, damage by deer) were rejected. No account was taken of numbers of dead plants. In the first column the mean length of all shoots is shown, in the second column the mean length of those shoots longer than the mean are recorded as the mean maximum, and in the third column the mean length of those shorter than the mean are recorded as the mean minimum. The mean height was calculated only from measurements of trees which showed an annual shoot length approximately equal to the mean annual shoot.

The data show that spruce grows satisfactorily only on some of the flush types, and in the earlier transitional types from grassy-heath or grass-meadow to moorland. In *Eriophorum vaginatum* flush, growth is very irregular but the mean height at 10 years is not unsatisfactory. On morainic knolls with peat, at 10 years Sitka spruce shows up much better than common spruce but neither is satisfactory. On all the types with scirpus, growth of the crop as a whole is scarcely measurable. The growth data relative to fragmental peat (molinia and *E. polystachion* type), shown in the table, are compiled from comparatively few measurements, but are considered of some value in showing the growth which does occur in recent hags where bad peat has become broken down and aerated by exposure to the weather.

TABLE XI

Type of Vegetation	Sitka Spruce at 10 years				Common Spruce at 10 years			
	Relative Shoot Growth			Mean Height	Relative Shoot Growth			Mean Height
	Mean	Max.	Min.		Mean	Max.	Min.	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Juncus dominant...	12	22	4	80	9	18	3	68
Molinia in tussocks	6½	12	2½	48	5	10	2½	37½
Molinia with *Eriophorum vaginatum*	4½	9	2½	35	4	7½	3	32
Iron flush type on lower ground ...	4	6	2	32	3	6	2	26
Eriophorum vaginatum	4	9	1½	33	3	6½	1	29
Morainic knolls (Calluna) ...	1½	3	½	27	1	3	½	21
Grassy moor ...	3	7	½	39	2	4½	½	32
Grass-heath ...	3	6½	½	39	2¼	4½	½	27
Scirpus Calluna Molinia	1	2¼	¼	16	½	2	—¼	13
Scirpus (shallower peat)	¾	2¼	¼	14—0	½	1	—¼	10—0
Scirpus (deep peat)	¾	1½	¼	14—0	½	1	—¼	10—0
Molinia fragmental peat)	6¼	8½	1½	38	3	4½	1¼	28

Although white spruce, ***Picea alba*** has not been frequently planted in the west of Scotland, it is held in high estimation in the Belgian peat region where it grows better than the other spruces. The figures given in Table XII show that as yet it has not proved to be as good at Inverliever as Sitka spruce, although its height growth is not much different from that of common spruce.

The data were obtained from one area with very variable vegetation where white spruce and Sitka spruce were growing side by side, so that they are quite comparable. Since, however, the ages of the trees may not be the same the means of the last five years' shoot growth were also recorded and a note was made of the general appearance of the trees. The measurements refer to five adjacent pairs of Sitka and white spruces in each of the following vegetational facies or types.

The measurements confirm the opinion based upon general observation on the area, that Sitka spruce is superior to white spruce. In white spruce the colour is sometimes better than that of Sitka spruce and in a number of individual plants the rate of increase of growth in later years is markedly better than that of Sitka spruce. The conclusion is, however, reached that, although the white spruce grows better than Sitka spruce upon peat on the Continent, it does not compare favourably with Sitka spruce upon peat in the west of Scotland.

Reference may be made to other two species, namely, Lodgpole pine, *Pinus*

TABLE XII

Site	Sitka Spruce			White Spruce		
	Total Height	Shoot Mean Length	Appearance	Total Height	Shoot Mean Length	Appearance
	Ins.	Ins.		Ins.	Ins.	
Deep *Eriophorum*	78	12.26	Good	61	8.33	Good.
Grass heath	80	12.45	Normal ...	50	7.00	Normal.
Calluna heath	43	3.82	Stem bent, Needles short	28	2.50	Yellow, but good general appearance.
Shallow flush, Poor molinia	39	3.50	Good (Previously frosted)	34	3.33	Side buds regularly frosted.
Scirpus-Calluna	29	3.33	Pale ; last year's shoot green	32	3.25	Poor general appearance ; colour good.

contorta, and Japanese larch, *Larix leptolepis*, which have been planted in the west in smaller amounts. Although planted on too limited a scale to be used as soil indicators, they, at least, compare favourably with the spruces on some of those types in which calluna is abundant. Lodgepole pine grows more rapidly than spruce upon the shallower transitional types in which calluna is abundant or dominant, and Japanese larch is at least equal in rate of growth to the spruces on some flush types and is superior to them on the heath-moorland transitional types. Its value as a soil improver has been minimised by the wide distances at which it has been planted.

Before leaving this subject, some additional observations concerning the effect of trees upon different types of vegetation may be appropriate.

Upon those types where " intense check " occurs there is no noticeable effect ; even mountain pine does not produce any change in the character of the surface vegetation. Reference has already been made to the production of sphagnum mounds in heath and similar types.

The effect of trees on vegetation is seen most markedly on and near areas which have been successfully planted, usually fresh-flush types. On rush-flush and on some molinia flushes under the dense shade of the older plantations of spruce, ground vegetation is almost absent, and what remains is represented by scattered mosses such as *Plagiothecium undulatum* and *Thujidium tamarascinum*. Under less dense canopy these mosses are more abundant and a few etiolated shade-bearing plants such as *Holcus*, *Molinia*, and *Aira flexuosa* may be found. Under still less dense shade these grasses, especially *Molinia*, and etiolated *Juncus articulatus*, occur along with a considerable variety of subsidiary plants. In molinia-flush under half shade the molinia forms large, well-developed tufts, among which other plants are infrequent. Where a flush type of vegetation under half shade adjoins other types where the trees are still in a condition of check, there is usually a certain transitional marginal zone of molinia, in which the trees tend to recover from check, and in turn provide shade under which molinia and its shade-enduring associates compete successfully with light-demanding heath and moorland plants such as ericaceous plants, scirpus and sphagnum spp. In this way the area of successfully growing woodland gradually extends. This kind of succession toward woodland becomes, however, more pronounced where deep and effective ditches occur.

Quadrats A and B (pp. 104-105) show the change which is occurring on a small flat area near Cruachan. This flat is surrounded by a belt of spruce on better land where growth is improving toward the centre, so that the whole flat, originally scirpus moor, will eventually carry a good crop of trees. On comparing Quadrat A with B it may be seen that scirpus and its associates have been largely displaced in the interval of five years by molinia and its associates.

Examples of this kind are not infrequent owing to certain counter-acting influences, of which absence of shelter is the most important. On more exposed sites the marginal trees usually suffer so badly from wind damage, and thereby growth-check, that they fail to have any effect on the flush vegetation. Again, where sphagnum mounds develop on the margin of flushes the sphagnum overflows, as it were, into the flush, and although it does not appreciably affect the trees on the flush, it prevents the extension of the flush vegetation which we have seen is necessary before satisfactory tree-growth sets in.

So far, examples of dense canopy have not been observed upon *Eriophorum vaginatum* flush. When canopy becomes moderately strong, however, ericaceous plants disappear, with the exception of *Vaccinium myrtillus*, and grasses such as *Molinia* and *Aira flexuosa* become more abundant.

The effect of existing plantations upon the character of the peat itself can so far be studied only on flush areas ; on other types of moorland, tree growth has been too feeble to have any effect. Only slight alteration in acidity has been found to occur, although on the whole it has been found that both Sitka spruce and common spruce increase the acidity of the surface peat. The mean *p*H value of soil samples taken under canopy is 4.2, while that of samples taken from places not under tree-cover, but otherwise comparable (for example, on rides) is 4.5. The principal changes brought about in peat under the influence of tree growth are recognisable by its general appearance. It becomes more mould-like or clay-like, and less sodden with water. If the original amorphous peat consisted of a thin layer overlying badly aerated peat of the same or any other kind, this lower peat loses water and becomes darker in colour and more consolidated, resembling, in general appearance, cheesy peat. As this process of change initiated by tree growth proceeds, the roots of trees can pass further downwards into the altered lower peat : this shows that, if canopy can be established, even the badly-aerated pseudo-fibrous peats become, in time, sufficiently aerated for the growth of tree roots. This fact is a strong justification for any extra labour or cost incurred in giving the young crop a good start, so that close canopy may be formed early, since, once this is achieved subsequent growth will be quite satisfactory.

THE SILVICULTURAL IMPROVEMENT OF PEAT AREAS

Since the high water-content of the soil is the direct cause of the growth of moorland vegetation and of peat-formation, it is obviously necessary that peat soils should be drained as thoroughly as possible before trees are planted in them. The first step to be taken in any drainage scheme is to determine the source of the excess water and, if possible, cut it off there, before it reaches the water-logged area. Additional drains which may be required within the area should provide sufficiently free outflow for water from the peat itself to promote aeration.

In climatic peat, however, the main source of excess soil-water is rainfall, and to dispose of this excess a regular system of collecting ditches must be laid down over the whole area. In this way all freely-moving water is more quickly removed from the surface, which has then a chance of becoming dry, by the ordinary processes of percolation and evaporation. The usual practice of laying down a system of surface ditches at short intervals, running gradually downward across the slope of the ground, is the most effective means of collecting surface water.

Such a system of surface ditches, however, cannot be expected to do more than collect and remove rain-water. Their effectiveness in removing superfluous water and so promoting soil aeration, depends not only upon the soil, but also upon the distribution of rainfall throughout the seasons. If a high rainfall prevails throughout the whole year, then any water removed by the drains is quickly replaced, and under these conditions, surface ditching is not sufficient to induce aeration in the soil.

The rate of water movement through the soil, and of its evaporation from the soil, depends also upon the character of the soil. In the case of peat soils it is obvious, on the one hand, that fibrous sphagnum peat, on account of its open texture, allows of rapid percolation and evaporation, and in rainless periods it therefore becomes well aerated to the depth of the surface ditches, while on the other hand pseudo-fibrous peat, owing to its jelly-like structure is so retentive of water, or resistant to percolation, that only superficial water reaches the drains. Otherwise its amount can only be influenced by evaporation.

It does not always follow that aeration takes place in all kinds of peat when the excess water is removed. In mineral soil the structure is rigid since the particles are quite solid, with the result that when the water held between and on these particles, is removed, air takes the place of the water and aeration is established. On the other hand, the material of which some kinds of peat is composed is soft and plastic with the result that it shrinks and collapses as the water is removed, and no spaces being left for the entrance of air, aeration does not take place. If the peat is not too soft and pliant, such as the fibrous peat formed by the more rigid of the sphagnums, air spaces are left and aeration proceeds. The more compact kinds of fibrous peat, such as that of *Eriophorum vaginatum* are prevented from shrinking into an airtight mass by the rigid fibres they contain, and when water is removed, air-spaces are formed through the shrinkage of the softer matrix in which the fibres are embedded, with the result that improved aeration follows drainage. Amorphous peat, in which the particles are fairly rigid, responds readily to drainage.

The following field observations indicate relative effectiveness of drains in producing aeration in different kinds of peat. It has been found that when

Eriophorum vaginatum peat is drained by ditches 18 inches deep, the surface layer becomes darker in colour to a depth of about 4 inches, within a distance of 5 feet from the drain after a period of 2 years, which is a sign of improved aeration.

Fig. 2 shows, diagrammatically, the result produced by an 18-inch ditch in pseudo-fibrous scirpus peat. The ditch was cut during the winter and by

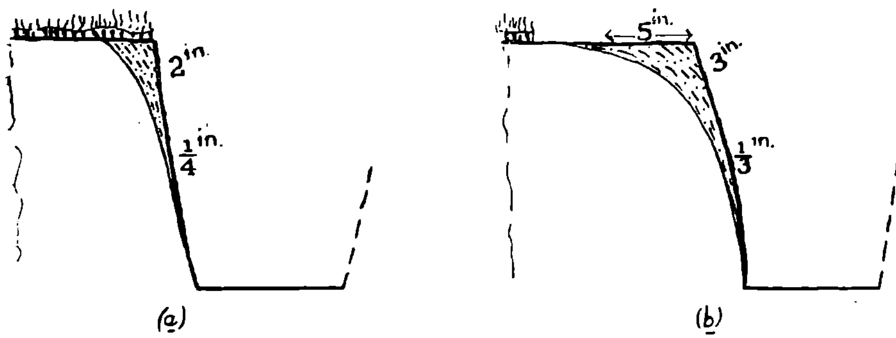


FIG. 2

the end of the following summer, aeration, as shown by the darker colour, had not penetrated more than about a quarter of an inch into the surface wall of the ditch, but along its edge the darker colour was traceable to a depth of 2 inches (Fig. 2*a*). As observation is difficult below the herbage, the surface turf was cut off at certain places. Fig. 2*b* indicates the effect of ditching on aeration a year after the first observations were made. The maximum depth of aeration at the edge of the ditch was just 3 inches, it gradually diminished from this point until at 5 inches from the edge of the ditch the darker zone was only one-third of an inch in depth or the same as it was on the wall of the ditch, and beyond 5 inches from the edge of the ditch this figure remained constant, which shows that the effect of the ditch on aeration is practically negligible. These observations, based on colour, were confirmed by determinations of oxygen requirement, which was found to be the same below the level of the ditch and at a point 3 inches below the surface of the peat at 3 inches from the edge of the ditch.

From oxygen-requirement determinations it was also found that the result of ditching in darker cheesy peat is only slightly more pronounced.

On pseudo-fibrous and cheesy peats, therefore, ditching has only a slight local effect in improving aeration. At the same time, however, ditches do reduce the water content as may be seen from the following table;

TABLE XIII

WATER CONTENT OF PEAT AT VARYING DISTANCES FROM A DITCH, EXPRESSED AS PERCENTAGE OF THE WEIGHT OF DRY PEAT

	(*a*)	(*b*)	(*c*)
1.	270	297	319
2.	261	299	338
3.	273	306	310
4.	250	289	315
5.	281	289	327
6.	263	308	330
Average ...	266	298	323

In the Table, column (*a*) gives the water content of deep scirpus peat at 3 inches from a ditch, the samples being taken at intervals of about 6 feet along the ditch ; columns (*b*) and (*c*) give the water contents of parallel samples at 1 foot and 3 feet respectively from the ditch. The peat samples were taken at a depth of 3—4 inches below the moss covering.

The data show that near the ditch the water content is reduced by at least 17½ per cent. of the original quantity, presuming that to have been the same as the present water content at 6 feet from the ditch. It is therefore concluded that while ditching may and usually does reduce the total amount of water held by pseudo-fibrous peat it does not directly improve the aeration of the peat as a whole for tree growth. Its main purpose lies in the removal of surface, *i.e.*, rain-water. The increased local aeration, described above as occurring at the edges of ditches, combined with the reduction in the water content of the peat, is sufficient to cause improved growth of trees near the ditches, but is insufficient to affect the peat as a whole.

It follows, therefore, that some other method of aeration must be attempted before successful plantations can be formed upon the pseudo-fibrous peat of western Scotland.

Deep drainage is the most obvious of these methods of improvement, but final evidence regarding its effectiveness is not as yet available in this country.

From a cutting up to 10 feet deep, made through deep peat some years ago at Inch Righ, near Onich, Argyllshire, no evidence of improvement could be obtained ; the vegetation was the same, as far as could be determined, within and without the area affected by the trench, but exact records of the vegetation before the trench was made were not available. Determinations of the water content of the peat showed nothing definite.

Evidence from natural streams, peat hags, or from surface ditches, which have become deeper through erosion, is somewhat inferential. In these the marginal vegetation may differ in two directions from that of the adjacent moorland. It is either essentially the same as that of the adjacent moorland, as has been already described in the case of peat hags, or it changes in character in the direction of the flush types. Where no real change in vegetational composition occurs, plants like calluna and molinia become more abundant and more vigorous. The effect of the stream or deep ditch is not essentially different from that of surface ditches and neither aeration nor tree growth are markedly improved. Except that the water content of the peat at 3—6 inches from the bank of such streams is usually lower, there is no evidence that any improvements in the condition of the peat has resulted from their presence. These conditions are usually found in larger areas of scirpus vegetation and deep peat, where the stream water is derived wholly or chiefly from moorland, and also at higher altitudes.

On the other hand, at low altitudes, in valleys, or in narrow flats bordered by sloping ground, the presence of a stream or the deepening of ditches by erosion is usually accompanied by definite alteration in the adjacent vegetation. Sometimes the change is very local, sometimes it affects a wider area. The change consists in the replacement of the scirpus types of vegetation by types in which molinia and other flush plants are abundant. An outstanding example occurs in a small valley N.W. of Cruachan Bothy. This is now largely covered by *Molinia* and *Juncus articulatus*, with local patches of *Eriophorum polystachion* and *Sphagnum medium*. The surface peat is distinctly amorphous, but the underlying peat is yellow scirpus peat. It is concluded that as a result of the deep central ditch, surface rain-water is drawn off rapidly and mineralised water from the adjacent slopes is allowed to pass freely over the surface and thus aerate and fertilise the valley as a whole, producing the flush type of vegetation. Similar effects have been observed in other localities ; for example, the writer was informed that at Corrour the natural deepening of surface ditches on a similar site had been followed by the displacement of a scirpus facies by molinia, and the molinia flush type had developed over a fairly large area. This change, when once started, proceeds more rapidly when trees are planted on the ground, since the shade they cast favours molinia. This has already been indicated on page 61 and shown in Quadrats A and B.

The conclusion is therefore reached that, apart from certain special localities, deep ditches produce only slight changes in the vegetation and in the character of the peat in which they are formed. These changes are of little immediate silvicultural importance unless the vegetation already includes flush plants, such as molinia, which are enabled by the withdrawal of water and subsequent aeration of the surface peat to compete successfully with the less satisfactory moorland plants, such as scirpus and compact spagnums.

At the same time it is recognised that a considerable time is required for deep ditches to exert their maximum influence. In the less rainy and less humid climate of Sweden up to 20 years have been found to be necessary. For this reason, deep ditching experiments have been laid down in areas throughout Scotland to obtain data on the point.

For immediate purposes, however, it is necessary to attempt aeration of the peat by some means other than simple drainage. The two principal factors which prevent the aeration of peat when it is drained are the surface moss, sphagnum, which is structurally adapted for the retention of moisture, and the nature of the peat itself, as already described. The character of the surface mosses depends to a considerable extent upon the ground vegetation in general ; for example, the open character of the herbage in high-moor favours the growth of short, compact, light-demanding sphagnum ; the shelter afforded by tufted calluna encourages the growth of *Sphagnum acutifolium* in mounds, and molinia, in its robust caespitose form, may eliminate sphagnum altogether by the shade which it casts and by the abundant litter which it deposits during the dead season of the year.

Surface aeration may therefore be improved by any means which promotes the growth of plants like molinia, and since shade-casting plants are also shade-bearing, such plants are favoured by the close growth of taller plants, like shrubs or trees, on moorlands in which they occur. These woody plants might be of little use as timber producers, but their value as soil improvers would warrant their use as nurse species. These are the motives which underlie the use for example of mountain pine as a soil-improving nurse crop. The only trees used by the writer which have given satisfactory results are the spruces. Most other species which have been tried are too slow in growth to provide sufficient shade, though Japanese larch and *Pinus contorta*, turf-planted and manured with basic slag, are now giving promising results on certain of the Forestry Commission's areas in the West of Scotland. On the basis of the above observations it can be laid down as a definite rule that the felling of trees or the slashing of scrub, growing naturally upon peat, is not a good practice (without very good reasons). By so doing light-demanding heath and moorland plants are favoured at the expense of the shade-bearing soil-improving species.

It also follows that by adopting as close a planting distance as possible, the growth of the soil-improving plants is favoured and the chances of success are greatly increased, especially on transitional vegetational types when the difference between success and failure hangs in the balance.

Many small experiments have been made with a view to testing the effects of various chemical agents in destroying or altering moorland vegetation. These substances included manures, such as sulphate of ammonia, nitrates, superphosphate and potash salts. The results were negatived as far as the vegetation was concerned. In the season following the application of those manures, Sitka spruce was planted, and after four years no difference in vegetation or in the growth of the spruce could be detected, in the treated as compared with untreated plots. Any injury to the vegetation was of a temporary nature. Negative results were also obtained when the vegetation was removed from the surface by hand.

Under certain conditions improvement of herbage follows burning, as, for example, when calluna mixed with molinia is burnt over, the molinia survives and grows more strongly in the following season, while the calluna is checked for several years. A similar result follows the burning of *Eriophorum vaginatum*, in which calluna and other ericaceous plants are abundant. Improvement in the growth of young trees after burning is not, however, so marked in *Eriophorum* ground as in molinia ground.

The removal of surface herbage by screefing the surface is productive of more harm than good, since the depressions formed collect water and act as centres for the growth of sphagnum. Trees planted in these depressions show poorer growth than where the ground has not been screefed.

The above experiments and observations are of somewhat limited application, and do not offer much help in the improvement of the climax vegetation and of the less amenable kinds of peat. The method of turf-planting referred to below is also a means of eliminating the effects of surface herbage and is of more general application.

The second factor which limits aeration depends, as already stated, upon the structure of the peat itself, some kinds of which shrink on drying, instead of becoming porous and allowing air to replace water which has been removed from it.

In the surface turf this property of shrinkage is not so well marked as in the deeper layers, since anaerobic disintegration has not yet begun and the plant remains still retain some rigidity, while the living plants also help to prevent shrinkage. Hence when the surface turf of pseudo-fibrous peat is exposed to the air such peat as it contains becomes readily aerated, and, as already mentioned, once aeration is established the peat becomes more porous and sponge-like and loses its gelatinous texture ; that is to say, air can penetrate more easily and abundantly. In its natural position under a mat of water-logged moss it is cut off from contact with the air and no change by aeration can happen. The advantages of turf-planting are largely dependent upon this fact.

Turf-planting as usually carried out is a form of the well-known " Belgian system " of establishing forests upon peat areas. Turfs cast out during the formation of collecting ditches, are arranged in rows, face downwards, between the ditches and spaced at the requisite planting distances. On these inverted blocks of turf the trees are planted.

From the present aspect the advantages of this method of treatment are :—

(1) The up-turned turf raises the plant above the wet surface and this, together with the collecting ditches, provides intense local drainage.

(2) Surface herbage is, at least temporarily, eliminated on the turf in which the young tree is planted.

(3) At the junction of the up-turned turf and the ground surface, the double layer of herbage and turf forms a zone of temporary aeration.

(4) The decay of the peat and of the underlying herbage liberates supplies of plant food materials which would otherwise be unavailable.

These advantages obtain only in a modified degree in regions of high rainfall like the west of Scotland and on the poorer types of peat. The intense drainage effect is not so satisfactory as is usually supposed. The turf, although well aerated at times, as is shown by the reduced oxygen-requirement, is not continuously supplied with an adequate amount of air. The formation of an impervious crust upon its surface tends to exclude the air from the turf as a whole. Only this surface crust is fairly well aerated and, as pointed out by E. V. Laing (Forestry Commission Bulletin No. 13, *Studies on Tree Roots*), the adventitious roots lie just below the aerated surface and soon spread out into the living ground vegetation. On scirpus ground and on the poorer kinds of peat, tree roots do not usually reach the zone of aeration resulting from the double layer of herbage, and tree roots placed there usually rot away, so that there is not much evidence that aeration is effective at this position.

The advantage of increased food supply also may not actually amount to much. The nutrient material contained in a block of peat of the usual dimensions even if wholly available to the tree would not be sufficient to support its growth for more than a few years, and analysis shows that only a small proportion of the nutrient material is liberated from turfs even after several years.

The conclusion is therefore reached that the chief benefit derived from turfing, apart from aeration, lies in the temporary elimination of vegetation from the surface of the turf. This conclusion is also suggested by the fact that turfing produces the best results in those types of vegetation in which conditions of aeration and food supply are already moderately satisfactory, for example, on flush types and on some transitional types.

The improvement in the growth of trees planted on up-turned turfs when compared with those planted direct on the ground vegetation in the better kinds of peat, and the temporary improvement which results from turf-planting on the poorer kinds, are proof enough of the value of turf-planting as a standard method of planting trees in peat. The temporary advantage obtained by turf-planting in poor peat is usually quite obvious ; the plants on the turfs are taller and deeper green as compared with the smaller size and yellow green colour of those planted in the usual way.

Effect of Solutions of varying pH upon Peat

Since pseudo-fibrous peat becomes aerated only to a slight degree by exposure to air in the form of turfs, an investigation was made into the conditions which might modify its gelatinous, plastic structure to which its retentiveness and resistance to aeration is due. If, for example, the gelatinous matrix could be made to coagulate upon the fibres, as occurs in peat of drier regions as a result of regular aeration, then water and air would move more freely through the peat, or again the peat as a whole might be caused to become granular like amorphous peat with similar results as regards aeration.

In substances similar to pseudo-fibrous peat the degree of gelatinizatioy (or inversely coagulation) is affected by the acidity of the water which then contain. The effect of immersing peat in water of varying pH value was therefore determined.

Cubes were cut from the interior of a very homogeneous uncracked block of air-dry pseudo-fibrous peat, all being of the same dimensions (1 centimetre cube) and weight. These were allowed to absorb water at different *p*H values ranging from *p*H 2.5 to *p*H 10. The required *p*H values were produced by using dilute sodium acetate-acetic acid mixtures. Increase in weight, *i.e.*, the amount of water absorbed, was determined after drying the surface of the cube with filter-paper. During absorption, the acidity of the water changed, as was to be expected. *p*H value was therefore determined after absorption of water had taken place, and is recorded as " final value." This is considered to be of more consequence than the *p*H value of the water at the beginning of the experiment.

The results are recorded in Table XIV and are shown graphically in Fig. 3.

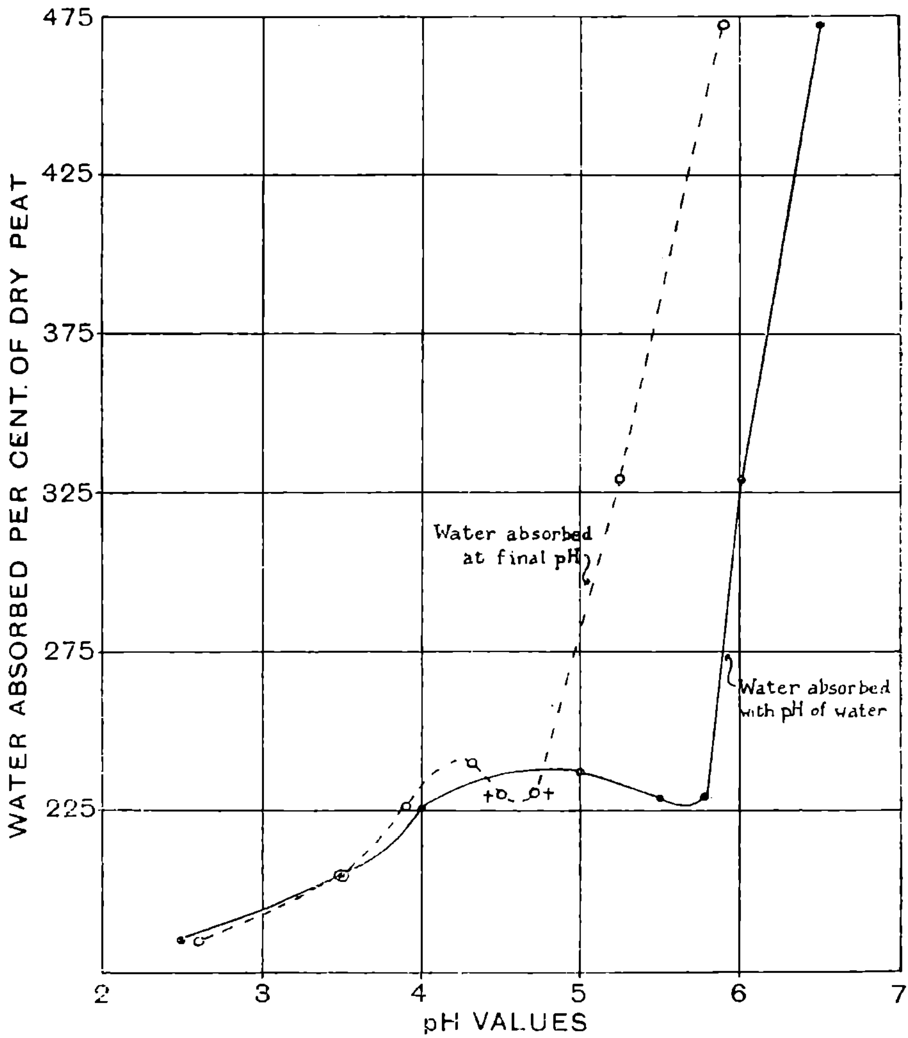


FIG. 3.—Effect of pH on absorption of water by peat

Ordinary distilled water was used for one pair of cubes, and the result is recorded in the last line of the table. The *p*H value of the water, 4.8, is due to carbon dioxide present as an impurity. As compared with the sodium acetate-acetic acid solution of the same *p*H value, there is no difference in water absorption, that is to say it is the *p*H value which determines the degree of absorption.

TABLE XIV

*p*H Values		Water absorption percentage of dry weight		
Of Liquid	Final Value	1	2	Average
2.5	2.6	183.3	187.7	185
3.5	3.5	202.5	203.4	203
4.0	3.9	224.3	227.0	225
5.0	4.3	234.2	235.7	236
5.5	4.59	227.6	227.8	228
5.75	4.79	226.8	229.1	228
6.0	5.3	330.0	323.3	327
6.5	5.9	470.3	471.6	471
7.0	6.5	553.0	549.0	551
10.0	9.0	576.0	565.0	570
4.8*	4.1	229.6	229.3	229

* Distilled water alone

The results show that the greater the acidity the smaller the volume occupied by the wet peat ; that is to say if acid were applied to the peat, it would shrink. This shrinkage, however, applies to the peat as a whole, and no signs of crumbling could be detected in the peat. Application of acid to peat in the field produced hardening of the surface only, after which aeration proceeded more slowly than if the peat had not been treated with acid.

It may be seen from the graph of the results that swelling of the peat becomes much more rapid at *p*H value 4.5 to 4.7 († †) and over. At *p*H 6 swelling is accompanied by the liberation of dark brown " Humus " from the peat. This substance is derived from the gelatinous matrix. In the laboratory it can be readily washed from small pieces of peat by alkalis, but field application of this treatment is impossible owing, in part, to the large quantity of alkali required and, in part, to the swelling at the surface of the peat, which prevents the dissolving liquid from penetrating beyond the surface.

The Coagulation of Peat by various Reagents

The structure of gelatinous substances is also affected by different salts dissolved in the water which they retain. Attempts to determine the effect of these by the method described above, were unsuccessful. Salts of sodium, ammonium and potassium caused slightly increased shrinkage in acid solution, and no difference could be detected as compared with the effect of the sodium used to produce the higher *p*H values in the above solution. With other salts, insoluble compounds were formed upon the surface of the blocks of peat and prevented further penetration of the peat by the salt.

The effectiveness of any reagent in causing coagulation of the gelatinous matrix of fibrous peats has frequently been determined by comparing the rate at which water passes through the peat before and after treatment with the reagent. The peat is fitted tightly into a cylindrical glass container, or a flanged glass cylinder is pressed upon the surface of the peat, and the rate at which water passes downward through the peat is measured. These and similar methods of measuring percolation cannot be used in dealing with pseudo-fibrous peat. Since percolation is extremely slow, water passes more rapidly between the peat and the walls of the glass container than through the peat itself, and intimate contact between the peat, as a whole, and the agent of coagulation can be obtained only by breaking down the peat into small fragments.

For this reason the peat was first passed through a mincer ; it was then shaken up with the coagulating solution, distilled water being used for comparison. Sufficient peat was treated with each reagent to give, on settling from the solution, a depth of 1 foot in a glass cylinder of 1 inch diameter. The lower end of this cylinder was covered with a thin cloth sieve. After allowing sufficient time for complete settling, the water above the peat was adjusted to a depth of 1 foot and maintained at that level, while the rate of percolation was determined by measuring the quantity of water which passed through the peat in a given time. One day was adopted as the standard period and daily determinations were made during 15 days.

As it had been observed that frost altered exposed peat on hag walls very noticeably, the tests were repeated, but, after being shaken up together, the peat and solution were frozen and allowed to thaw before the rate of percolation was determined.

The results are given in Table XV, in which (*a*) shows the effect of the coagulating solution alone, and (*b*) the combined effect of solution and freezing. The last two columns show the result of drying the peat before shaking it up in the liquid. The reagents were used at equivalent concentrations of solution, determined by the solubility of quicklime in water. They were : sulphuric acid—H_2SO_4, lime water—$Ca(OH)_2$, ammonia—NH_4OH, ammonium chloride —NH_4Cl, and ferric chloride—$FeCl_3$, of which the last was also used with dried peat.

TABLE XV

RATE OF FLOW OF WATER THROUGH PEAT TREATED BY VARIOUS ELECTROLYTES AND BY FREEZING

(Figures in inches per day, for a cylinder of peat one foot in length, under pressure of one foot of water)

No. of day	Distilled water		H_2SO_4		$Ca(OH)_2$		NH_4OH	NH_4Cl	$FeCl_3$		Peat dried	
	Not frozen	Frozen									Without $FeCl_3$	With $FeCl_3$
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(a)	(a)	(b)	(a)	(a)
1	0.57	5.04	0.60	98	0.50	65	0.43	0.54	0.5	60	3.90	0.83
2	0.49	4.72	0.31	80	0.50	29	0.31	0.40	0.2	31	2.10	0.68
3	0.47	3.54	0.28	52	0.48	28	0.28	0.32	0.2	30	0.98	0.57
4	0.33	3.35	0.28	43	0.28	28	0.24	0.24	0.2	29.5	0.83	0.35
5	0.24	3.11	0.28	39	0.24	27.5	0.18	0.21	0.2	29.5	0.59	0.35
6	0.20	2.95	0.24	35	0.22	27.5	0.16	0.20	0.2	29	0.47	0.35
7	0.20	2.76	0.22	33	.200	27.5	0.15	0.20	0.2	27.5	0.35	0.35
Average, 8th to 15th ...	0.20	1.96	0.20	24	0.20	22.3	0.12	—	0.2	20.8	0.28	0.28
15	0.19	—	—	9	—	10.1	—	—	—	8.3	—	0.20
Rates of Increase of Drainage due to the above methods of Treatment												
Day.	Unit Multiplied					(Untreated peat taken as unit)						
5th	1	13	1.17	165	1	110	0.75	1	0.8	125	2.5	1.5
7th	1	14	1.10	160	1	140	0.75	1	1.0	140	1.8	1.8
Average, 7th to 15th ...	1	10	1.00	120	1	110	0.60	1	1.0	100	1.4	1.4

It may be seen that, as time goes on, the rate of percolation diminishes until for some days a fairly constant rate is maintained. For several reasons it is concluded that this slowing down is due to the gradual blocking up of the pores between the coarser grains by the finer material carried downward by the movement of water. It might also be due to slight subsidence of the peat as a whole, although no such subsidence could be detected by measurement of the depth of the peat.

Treatment with coagulating agents alone was found with one exception to have little effect on the rate of percolation of water through peat. The irregular effects shown during the first few days may be set aside as indicating only that the peat has not completely settled. The exception, ammonium hydroxide, causes an appreciable diminution in the rate of flow. This is due to the alkaline reaction of the solution, which causes swelling and partial solution of the humus of the peat, as already described, when the *p*H of the treated peat rises above *p*H 5.6. Sodium and potassium hydroxides act in the same way.

When peat had been frozen in distilled water, the rate of percolation was increased, so that, compared with peat which had not been frozen, the quantity of water which drained through was 10 times greater from the 7th to the 15th day.

When peat which has been treated with a coagulating agent other than the hydroxides referred to, is subjected to freezing, the rate of percolation is increased by 100 times or more. This increase is greatest with acid, but the difference between the various reagents is not marked after the first few days.

Drying the peat before treatment produces only a slight increase in the rate of percolation.

Although the rate of percolation of water through unaltered pseudo-fibrous peat cannot be determined from this experiment in which the peat was broken down, preliminary work showed that movement of water through the unaltered peat was distinctly slower than in peat which had been passed through a mincing machine. Even when the peat has been broken down percolation is still extremely slow. For example, as Table XV shows, only one-fifth of an inch of water passed through 1 foot of peat in one day under a head of 1 foot of water.

Field Experiments on Peat

These investigations were followed by a field experiment on an area of *Eriophorum vaginatum—Calluna* peat. Heaps of broken-down fibrous peat were mixed with (1) sulphuric acid, (2) quicklime, (3) ferric hydroxide, (4) superphosphate, (5) basic slag, and (6) sulphate of ammonia, while one heap was left untreated as a control. The heaps were examined from time to time.

Sulphuric acid and superphosphate were found to act in a similar manner. In the first season during dry weather the heaps treated with these reagents became dry more rapidly and completely than the untreated heap. After the first season it appeared that only the surface crust was drying moderately quickly, while the interior was wetter than the untreated peat.

Peat treated with ferric hydroxide showed no difference from untreated peat.

Quicklime produced a blacker colour in the peat and caused the surface to crumble down to mould, an effect which wore off after the first season, so that in the second season it could be distinguished from untreated peat only by its blacker colour and a somewhat higher amount of amorphous material as compared with fibre.

The effect of basic slag was similar to that produced by lime, but the changes were more permanent. Within two seasons the changes in the treated heaps resulted in the production of a hard, friable, amorphous peat, of a black mould-like appearance.

Sulphate of ammonia caused a more intense darkening in the colour of the peat during the first six months, but at the end of a year there was no difference in colour between the treated and untreated heaps.

During the first season all the heaps remained free of plant growth. In the following spring, first the slagged and then the limed, followed by the untreated heap, were colonized by green algae and mosses, while seedlings of grass began to appear on the slagged and limed heaps. Sitka spruce was then planted on all the heaps, but it quickly died on those to which sulphuric acid, superphosphate and sulphate of ammonia had been applied. On the heap treated with ferric hydroxide and on the untreated heap the young trees showed little or no growth for two years. On the limed heaps the rate of growth fell off from 3½ inches in the first year to 2½ inches in the second, and the growth of mosses like *Bryum capillare* threatened to preclude aeration. On the slagged heap the rate of growth was 3½ inches in the first year and 8 inches in the second.

Spruce planted the following spring to replace those which had died in the first year also failed upon those heaps which had been treated with acid and with superphosphate. At the time of writing (four years after the experiment was started) those heaps are covered with moss ; they have settled down almost to the level of the surrounding surface and are quite unaerated. The other heaps show good aeration ; those treated with ferric hydroxide and sulphate of ammonia, as well as the untreated heap, have remained unaltered in appearance ; the limed heap presents a granular surface, but shows no internal alteration, while the slagged heap is definitely granular throughout.

It is therefore concluded that sulphuric acid and superphosphate which contains acid, are ineffective in producing aeration, since even before the acid is washed out the peat becomes compacted and loses any advantage which may have been gained by the original shrinkage due to the acid. Sulphate of ammonia is not much more effective in promoting aeration. Iron, though it makes the peat more rigid and less liable to collapse into a non-porous mass, does not promote decomposition. The action of lime is to increase decomposition slightly and chiefly at the surface. Basic slag is the only reagent used which was capable of producing sufficient change in the physical conditions of the peat to bring about its decomposition into an amorphous form.

Coagulation of Peat Humus

The extent to which aeration occurs in peat is determined largely by the condition of the gelatinous " humus " substances which surround the fibres, as has already been stated.

In carrying out the experiments described above, it was observed that the different reagents used act upon this " humus " in different ways. For example, the alkalis tend to dissolve it, forming a dark brown liquid. In order to obtain further information on this point, the " humus " was extracted from pseudo-fibrous peat ; it was then subjected to a series of tests, which showed that the degree and kind of coagulation of this humus depends upon the substance used and the acidity of the liquid in which coagulation takes place. Acidity promotes the precipitation of humus from the extract. Sodium, potassium, ammonium and magnesium cause precipitation only in an acid medium. In an acid extract iron causes precipitation only when present in small amount, but in an alkaline liquid an excess of iron is required. Aluminium acts similarly to iron, except that at and above the neutral point no precipitation occurs. Calcium differs from all the other substances used. It can cause precipitation at all degrees of acidity tested, from *p*H 2.5 to *p*H 9.0, that is to say, from strongly acid to distinctly alkaline.

The precipitates formed in the presence of acid and the salts of iron and aluminium, are light and cloudy in appearance (flocculent) and are usually brown in colour. Those of the alkalis and of magnesium are intermediate in appearance and colour, while those of calcium are granular in appearance and are, especially in an alkaline liquid, darker in colour. When dried, the flocculent precipitates form a flaky mass, the granular precipitate from lime forms a crumbly powder.

The effect of alkaline lime upon soluble humus of peat may explain in part the black granular appearance which lime and basic slag produce in peat, but it does not offer a complete explanation of the changes produced, especially by basic slag. All attempts to reproduce in the laboratory the granular mould-like form to which peat is reduced by the application of slag in the field, have failed, and one is forced to the conclusion that more than direct physical and chemical changes are involved, *i.e.*, the alteration is produced in the peat by the activities of micro-organisms which, finding the slagged peat a suitable medium for their growth, alter the character of the peat-forming material as a whole.

That this is so is indicated by Table XVI which shows the condition of the organic matter of the peat obtained, at the end of the third year after treatment, from the heaps referred to on page 72 *et seq.*

Portions of peat from these heaps were treated with sodium hypochlorite which completely dissolved away or destroyed the darker coloured " humus " substances, leaving behind only the fibrous residue composed of cellulose and similar substances, which is recorded in the table as " fibre." The " humus " can be separated into two parts : (1) that soluble in ammonia, representing the more thoroughly humified material ; (2) that insoluble in ammonia, which is more resistant to further decay. Of these the first was determined directly by extraction from the peat in a Soxhlet apparatus with 5 per cent. ammonia, and subsequent precipitation with acid. The portion insoluble in ammonia was determined by difference, from the total organic matter in the peat. (All values represent organic matter per cent. of total organic matter dried at 100° C., and were determined by ignition).

TABLE XVI

——	Fresh Peat	Weathered Peat	Weathered after treatment with—		
			H_2SO_4	Ca $(OH)_2$	Basic Slag
1. Fibre	97.9	96.6	96.8	83.6	67.7
2. Ammonia soluble ...	1.3	1.7	1.4	8.5	13.9
3. Insoluble in ammonia	0.8	1.7	1.8	7.9	18.4

The results obtained show that both untreated peat, and peat treated with sulphuric acid have, after weathering for three years, practically the same composition as fresh peat, and that only small increases in the proportion of "insoluble" humus have taken place.

Considerable humidification, however, has occurred as a result of the treatment with lime, and especially with slag. This suggests that the principal result of the addition of basic slag is increased micro-organic activity, and that the chemical changes produced in the limed and slagged peat are not due directly to the chemical action of the manure since humidification requires the intervention of bacteria and fungi.

In summation of the position as regards the improvement of aeration by chemical methods, it has been found that, although successful results are not impossible of achievement, the chief problem in the laboratory as in the field lies in the difficulty of obtaining close contact between the ameliorating substance and the peat as a whole. Where precipitating agents come into contact with the peat an impervious crust is formed so that they do not mix with the peat. The crust formed quickly becomes incorporated into the general mass of the peat or is grown over by moorland plants and the temporary advantage is lost. In order to obtain the necessary intimate contact between manure and peat, the peat must be thoroughly broken down and the fibrous material, or the small lumps resulting from this treatment, must be mixed with the manure. The ameliorating agent must be of such a nature as to harden the peat in such a way that the temporary loose structure obtained by cultivating is maintained. Acids and acid-forming manures are of no use for this purpose, lime and other calcareous basic manures have been shown to be quite effective. The most marked change, however, produced by any ameliorant is that brought about by basic slag, where not only does the peat remain open in texture, but it also decomposes rapidly owing to the action of micro-organisms. This effect has been produced by no other manure except basic slag (including others of fundamentally the same nature). Ground mineral phosphate is similar in this respect to lime rather than slag, and it has been observed that the effect of different slags upon aeration, and the growth of trees, is not proportional to their phosphate content.

The Improvement of Tree Growth in Peat

A large number of small field experiments have been carried out in relation to the manuring of trees on peat. As a test plant, Sitka spruce has been used with few exceptions.

These experiments have been carried out on the east of Scotland near Aberdeen, on fibrous peat of the *Calluna-Eriophorum vaginatum* or *Calluna* vegetational type, and most of the experiments included sections of wetter basin peat with *Eriophorum polystachion*, *Erica tetralix*, and *Narthecium* abundant, along with much sphagnum (*S. medium*, *S. centrale*, *S. imbricatum*) and a few true mosses, *e.g.*, *Aulacomnium palustre*.

The quantity of manure used has been based upon the plan that the manure should be applied as a "fairly heavy" dressing per acre, as the term is used in agriculture. The standard amount of each applied per turf (or plant) was such that if the planting space were 4½ by 4½ feet the total amount per acre should be : Basic slag, 10 cwts. ; sulphate of ammonia, 5 cwts. ; sulphate of potash, 2 cwts. ; and lime (as carbonate), 20 cwts., with equivalent amounts of other manures. In earlier experiments these quantities were doubled, but, except for slag, the smaller quantities gave about the same results as the larger.

The results of these experiments may be summed up shortly as follows* :—

(1) Unless aeration of the peat is improved by suitable and thorough drainage, no manurial treatment is of any use. Intensive aeration by thorough breaking up of peat and piling it into heaps is, under east coast conditions of rainfall, sufficient to enable trees ultimately to grow upon otherwise unplantable peat, although check occurs for about five years, and during that period there is great danger of death from frost, or occasionally drought, and other factors not inherent in peat soil. When slag is added to such heaps growth is immediate and without check. Under western conditions of rainfall at Inverliever, heaps of peat broken up in this way become so quickly re-colonized by moorland species that the resulting benefit of improved aeration is lost. The method is scarcely practical even in the east without special mechanical implements. As a method of ordinary aeration, the turf-method of planting has nearly always been used.

(2) The time of application of manures in relation to time of planting has been found to be of little consequence as a rule. Strongly acid manures (*e.g.*, superphosphate) are apt to be injurious even when applied the year before planting. Very soluble manures may kill the plants unless applied some months before planting or in very small doses, in eastern conditions at least ; *e.g.*, sodium and calcium nitrate, ammonium and potassium sulphate. Chlorides (potassium chloride) are more permanently harmful than sulphates. Apart from this, it is of no importance whether the manure is added during the planting season or during the previous or subsequent seasons (except in the case of nitrate, which is easily washed away), provided that :—(*a*) If applied before, the manure does not cause the rapid growth of incrusting mosses, which would cause growth check before the young tree is large enough to prevent invasion by its shade (an effect of slag and lime) ; (*b*) if applied at the time of planting the pure manure is not brought into direct contact with the roots ; (*c*) if applied after planting, the manure be mixed with the broken surface of the turf. If laid on the surface it is liable to cake and be washed away without penetrating the peat, if mixed with the surface it is held there and gradually penetrates the turf. Lime-containing manures placed in a mass on or in the peat become caked and insoluble, if mixed with peat and placed in a pit in the turf, the mixture becomes hard and insoluble, with the result that the manure remains undisturbed for many years ; this has been determined by analysis of sections of manured turf. It is therefore as a whole unavailable to the plant after a short time. In practice it is considered that the most advisable method of using manures is to mix them with the surface of the turf a short time before planting.

(3) Nitrogenous manures give a better green colour the year after planting, growth is not appreciably increased, and the colour advantage is generally lost in the second year. Calcium nitrate is only slightly better than sulphate of ammonia ; sodium nitrate is less effective or shows no improvement. Organic nitrogenous manures, such as dried blood and fish meal, act similarly to sulphate of ammonia.

Potash manures—sulphate of potash, wood ashes, potassium phosphate and peat ashes in larger quantity produce a small temporary improvement in colour in the second year after planting, or they may have no effect (as is

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* Experiments carried out by the research staff of the Forestry Commission on *Scirpus* peats in the west of Scotland support on the whole the writer's conclusions, but there is some evidence to show that ground mineral phosphate and other phosphates may be as effective as basic slag in promoting the growth of spruce.—*Ed.*

always the case with peat ash). Magnesium sulphate and magnesium carbonate have not, as yet, brought about any improvement in growth or appearance —that is, during the three years the experiment has been in progress.

Phosphatic manures :—Only basic slag has been fully tested, but, at the best, other phosphates (ground mineral and pure tricalcium phosphate, ground bones and bone meal) are much inferior at the end of three seasons to basic slag. Ground mineral phosphate with lime shows an improvement as compared with ground mineral phosphate alone ; superphosphate injures the plants, even a year after application. The results do not vary with the phosphate content of any phosphatic manure.

Calcium manures :—Quicklime or carbonate of lime of various origins are similar in effect ; on turfs the improved effect of heavy dressings falls off after the second year, and only about 1 in 10 plants have recovered from check in five years. Calcium sulphate (commercial crude gypsum) is equal in effect to calcium carbonate, but not better.

Experiments in which mixtures of two manures have been used instead of a single manure have so far shown no difference from either of the manures used singly. These experiments have run for only three years and cannot as yet be fully assessed.

(4) Broadcasting of manure (slag) has not been found so satisfactory, either in promoting tree growth or in altering the character of the vegetation, as the local application of manure in turfs. For example, as part of the experiment described immediately below, two strips of ground, 24 by 5 yards, were selected, one of which was broadcast with ½ cwt. of lime and the other with ½ cwt. of basic slag. In three years no increase was measurable in the rate of growth of trees which were on the ground before the manure was applied, nor could any difference be found in the composition of the vegetation, although the vegetation as a whole was more vigorous.

Since amorphous peat and good tree-growth are usually associated with flush conditions, an attempt was made to produce an artificial flush by collecting water in a ditch, in which manure had previously been placed. The water was then allowed to spread out over the slope below. The experiment is illustrated by Sketch IV.

At Inverliever, near Cruachan, two ditches (AB and BD) were cut horizontally, 10 feet long, about half-way up a slope and in such a position that the areas below the ditch were separated by a low ridge (BXZ) ; the turf from the ditch was placed in an inverted position along the lower edge of the ditch, and at intervals along this line of turf a few openings were made, through which water collecting from above, into the ditches, might flow fairly evenly over the ground below. Into one ditch was put ½ cwt. of basic slag and into the other ½ cwt. of lime. The peat was fairly shallow, and for some distance below the ditch the vegetation was, in 1925, dominated by scirpus of rather robust character, sometimes forming definite tussocks, with short calluna throughout (not indicated in sketch), and here and there below the ditch, but more abundant and extensive above the ditch, were clumps of calluna. In addition, molinia occurred as single plants or small groups at a frequency of 1 per 9 square yards. The ground mosses were, below the ditch, mainly low pads of *Sphagna Acutifolia*, with equal amounts of hypnaceous mosses ; above the ditch somewhat higher mounds of sphagnum predominated. Above the ditches and to the right were rush flushes in process of being invaded by calluna and scirpus. The subsidiary plants have not been indicated owing to the size of the area.

There were 29 spruce plants on the area of 96 square yards shown in the sketch. Some difficulty was found in measuring the actual heights of these, owing to their small size and to the development of adventitious roots, and from their spacing it was apparent that replanting had taken place so that the plants were not of equal age. Instead, therefore, of taking the heights, the average lengths of shoot in the years 1923-24 and 1924-25 were measured in 1925. In 1928 the lengths of shoot of the three previous years were measured. The results are shown in Table XVII, together with the average 1923-25 growth.

Table XVII

INCREASED LENGTH OF SHOOT PRODUCED BY "FLUSHING" THE GROUND WITH LIME AND SLAG

Number of Plant on Sketch		Length of Shoot in cm.				(1928—1923–25)
		1923–25	1926	1927	1928	—Decrease +Increase
a.	1 ...	2.1	2.9	3.3	4.5	+ 2.4
	2 ...	1.1	1.1	0.9	0.7	— 0.4
	3 ...	3.2	2.3	2.0	1.5	— 1.7
	4 ...	3.0	2.5	1.9	1.2	— 1.8
	5 ...	4.1	3.3	2.7	1.5	— 2.6
b.	6 ...	1.0	1.0	1.2	1.5	+ 0.5
	7 ...			Frosted shoot.		
	8 ...	1.5	1.5	1.8	2.5	+ 1.0
	9 ...	1.2	1.4	2.7	4.0	+ 2.8
	10 ...	1.0	1.0	1.3	2.0	+ 1.0
	11 ...	1.0	1.0	1.1	1.5	+ 0.5
	12 ...	2.1	2.0	2.0	2.0	— 0.1
	13 ...	1.5	1.5	1.7	2.0	+ 0.5
	14 ...	1.4	1.4	1.4	1.0	— 0.4
c.	15 ...	1.6	1.5	1.0	0.7	— 0.9
	16 ...	2.5	2.5	2.5	2.2	— 0.3
	17 ...	2.7	2.6	2.3	2.2	— 0.5
	18* ...	2.24	2.24	2.13	2.0	— 0.24
	19 ...	2.3	2.0	2.0	1.5	— 0.8
	20 ...	1.6	1.4	1.1	0.6	— 1.0
	21 ...	3.2	3.0	3.0	2.5	— 0.7
d.	22 ...	2.7	2.9	5.5	10.5	+ 7.8
	23	1.8	2–0	4–3	6.2	+ 4.4
	24 ...	3.5	3.7	4.8	9.5	+ 6.0
	25 ...	1.0	1.0	1.3	2.0	+ 1.0
	26 ...	2.9	2.7	3.3	5.5	+ 2.6
	27 ...	4.7	4.1	4.1	4.0	— 0.7
	28 ...	1.5	1.5	3.3	4.4	+ 2.9
	29 ...	3.9	3.8	3.4	3.3	— 0.9

* Mean of two shoots

The plants have been grouped into four lots : (*a*) Those above the ditch; in which progressive check is evident, with the exception of No. 1, which is breaking out of check under the influence of flush conditions. The low relative increment of No. 5 is due to its previously moderately good growth, now followed by check, as scirpus invades the flush in the margin of which it stood ; (*b*) those below the slagged ditch ; (*c*) those upon the ridge ; (*d*) those below the limed ditch. Plant No. 7 had had its leader injured, probably by frost, but its leaves were as healthy and green in colour as were those of most of the plants which showed increased growth.

The experiment is not considered to be conclusive. At the same time, it shows that the application of mineralised water in some such way is a possible method of improvement of peat ground, since the growth of the plants on the area under the influence of the ditches is at least improving. From the lower portion of the sketch it is apparent that this improvement is being accompanied by improved vegetational conditions, as evidenced by the great increase in quantity and luxuriance of molinia and other species on the slope below the ditches and down which the water passes. The turfs themselves are so strongly colonised by grasses as to be specially sought out and cropped by deer.

The use of mineral soil as a peat ameliorant has not been attempted to any extent, since it is felt that, apart from its use in small quantities as in the Belgian turfing system, the cost would be prohibitive. That a layer of soil or even of mineral debris is of value in improving peat, requires no experimental proof, since in various areas where roadmaking has been carried out or where landslips have occurred this effect is to be seen in the improved growth of tree crops ; for example, at Achnashellach an example may be seen where road workers have thrown or blasted a large quantity of earth and fine rock debris over an area of the adjacent moor. On and near this area molinia flush vegetation has since developed. Evidence of the value of earth-falls in valley slopes has frequently been observed in several areas. On the other hand, in many areas occasional surface wash from higher ground is regularly incorporated in small amounts in peat without affecting its character at all.

It is probable that the main effect of using soil as in the Belgian system, when applied to our west coast conditions, is that it brings about the inoculation of the peat by humidifying organisms, as is indicated by the insistence in Belgium that good quality soil only is useful. In most of the field experiments which have been examined it was found that mineral soil of a poor description has usually been made use of, and it cannot be said to much advantage. Experiments by the writer, including the use of good soil as a peat improver, are not sufficiently advanced for assessment to be made. The chief possibility of using mineral soil for peat improvement is in connection with the shallow transition types where, in the course of ordinary planting operations, mineral subsoil (unleached) has been observed to produce a temporary beneficial effect when spread over the turf.

The position with regard to the improvement of tree growth on peat ground in the west of Scotland may be summed up as follows :—

Basic slag is the only manure which has been found to produce a marked improvement in tree growth on peat, and in order to obtain this result the slag must be applied to the turfs in which the trees are planted, since broadcasting is ineffective. Slag and even lime applied over a number of years through the medium of flush water has an appreciable effect upon tree growth on bad ground, but the method is of limited practical value. There is little evidence that soil is of much value when applied to trees planted in turfs, although numerous examples are to be found of the effectiveness of soil spread over the surface of peat ground.

Where peat is shallow and especially where the surface vegetation includes less *Scirpus* and more *Molinia* and *Eriophorum vaginatum* (*e.g.*, in the transitional types and *Eriophorum* flush), the balance may be swayed in favour of young trees by intensive drainage and turf-planting with slag as a peat ameliorant and phosphatic manure, but on deep peat and especially where *Scirpus* is abundant, this treatment is local in its effects and thus of temporary benefit, and the trees are unable to compete successfully with the ground vegetation. In order to establish plantations, the vegetation must be altered or the peat itself improved by direct methods. Since no suitable soil-improving nurse tree or shrub has yet been found which might indirectly improve the soil by changing the surface herbage, it seems to the writer that the most hopeful mode of attacking the problem is by intensive mechanical cultivation of the surface of the peat after draining. In this way the peat is thoroughly aerated, and aeration may be maintained by manuring with basic slag, which gives the young crop the necessary initial impetus.

Many subsidiary points throughout this bulletin do not require further emphasis in this connection, such as the necessity for close planting and the laying out of planting schemes so as to afford the young crop the maximum shelter from wind, with its corollary, the advantage of establishing one block for shelter before further planting is commenced.

SUMMARY

Over a considerable area of the west of Scotland the growth of trees is unsatisfactory as a result of the presence of a layer of peat upon the surface of the ground. The growth of moorland vegetation and the consequent accumulation of peat result from the cool temperate oceanic climate of the region. The character of the vegetation and of the peat in the region is determined chiefly by the nature of the topography and mineral soil.

The principal types of vegetation, as exemplified by the Inverliever forest area, are described systematically. The climax type is scirpus moor, but transitional (pre-climax) types of moorland vegetation cover the greater proportion of the area. The effects of past exploitation upon the vegetation are discussed, and the conclusion is reached that grazing by sheep and regular burning of surface herbage have increased the area of peat ground especially peat of the worst kind.

The different kinds of peat are classified upon a broad pedological basis, within which further divisions are made according to their structure and vegetational origin. Edaphically, the main groups of peat show well-marked differences ranging from good quality amorphous flush peat on the one hand, which is similar in its characters to a wet humose mineral soil, to pseudo-fibrous peat on the other hand, in which excessive moisture, lack of air, low nutrient content and slow response to drainage all militate against successful forestry. All peat of the west of Scotland has a high acidity and lime-requirement, but variations in acidity do not appear to influence tree growth.

The growth of trees (chiefly Sitka spruce and Norway spruce) upon peat indicates that the chief limiting factor to growth in bad peat is lack of air in the peat, as a result of which tree roots are confined to the surface turf or herbage in which available food supplies are lacking, and where the turf is shallow these surface roots are subject to extremes of moisture and of temperature. Where the turf is deeper and more open in texture, growth-check is not so intense, but close canopy is not formed in a reasonable time and a considerable proportion of the trees is injured or killed by non-edaphic factors such as wind ; ultimately the whole crop becomes completely checked. The most important cause of secondary check in the growth of trees is the rapid growth of sphagnum above their roots, which takes place in the moderate shelter provided by plants like heather or by slowly growing, widely spaced young trees. Close planting is therefore advocated as a means of reducing the time required for the formation of close canopy, especially on ground in which rapid sphagnum growth is likely to take place. The rate of growth of trees from type to type, as well as the growth of individual trees within any one type of vegetation, is correlated with the actual plants among which the young trees are planted.

The improvement of bad peat ground necessitates better drainage and aeration, and alteration of the vegetation toward the flush types. With few exceptions, ordinary ditching is quite ineffective in producing aeration, while, upon deep scirpus peat, even deep ditching may produce little improvement after many years. The rate of water-movement through pseudo-fibrous peat is so very slow that steps must be taken to break down its gelatinous structure. This may be accomplished by chemical ameliorants which, however, can act effectively only where the ameliorant and the peat are thoroughly mixed

together. Basic slag is the most satisfactory ameliorant as, in addition to its direct action, it indirectly decomposes the peat to amorphous humus by providing suitable conditions for bacteria.

The planting of doubtful peat ground may be successfully carried out after thorough drainage by turf-planting, using basic slag as a peat-improving manure, but on bad peat ground more drastic measures are required, and the surface conditions must be altered over the area as a whole. This may be done in one or other of the following ways :—(*a*) by the establishment of a less exacting, soil-improving cover species of which none of these tried so far has proved satisfactory ; (*b*) by extending the areas already influenced by flush water with or without the assistance of manure ; (*c*) by proper mechanical cultivation of the surface combined with drainage and manuring.

APPENDIX I

Maps and Meteorological Data

MAP I, p. 84

The area in which the detailed work of investigation was carried out is enclosed by Loch Awe on the one side and by lines drawn from Rudha Barain to Cnoc Feadaige, Monadh Meadhonach, Barmaddy and Dalavaich; in greater detail from the boundary line to Cruachan, where the earliest enclosure took place.

(Reproduced from Geological Survey Map.)

MAP II, p. 85

The distribution of high rainfall areas in Great Britain. Reproduced from the Royal Meteorological Society's Average Annual Rainfall Map (1881–1915). Areas having a rainfall of 1,000 mm. (40 inches) and over are shaded.

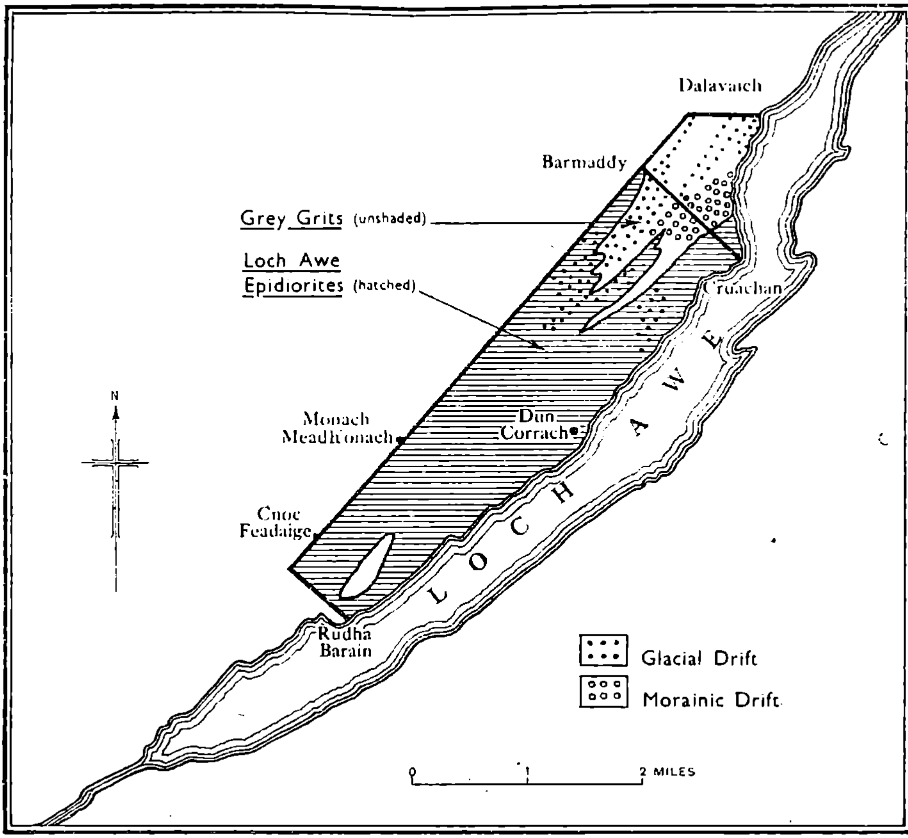
MAP III, p. 86

Map of N/S (rainfall over saturation deficit) isopleths.* Under 400: Diagonal dashes. 400–500: Blank. 500–750: Horizontal lines. 750–1,000: Diagonal lines. over 1,000: Vertical lines. The last area coincides generally with the areas in which moorland soils are the most generally developed soil types.

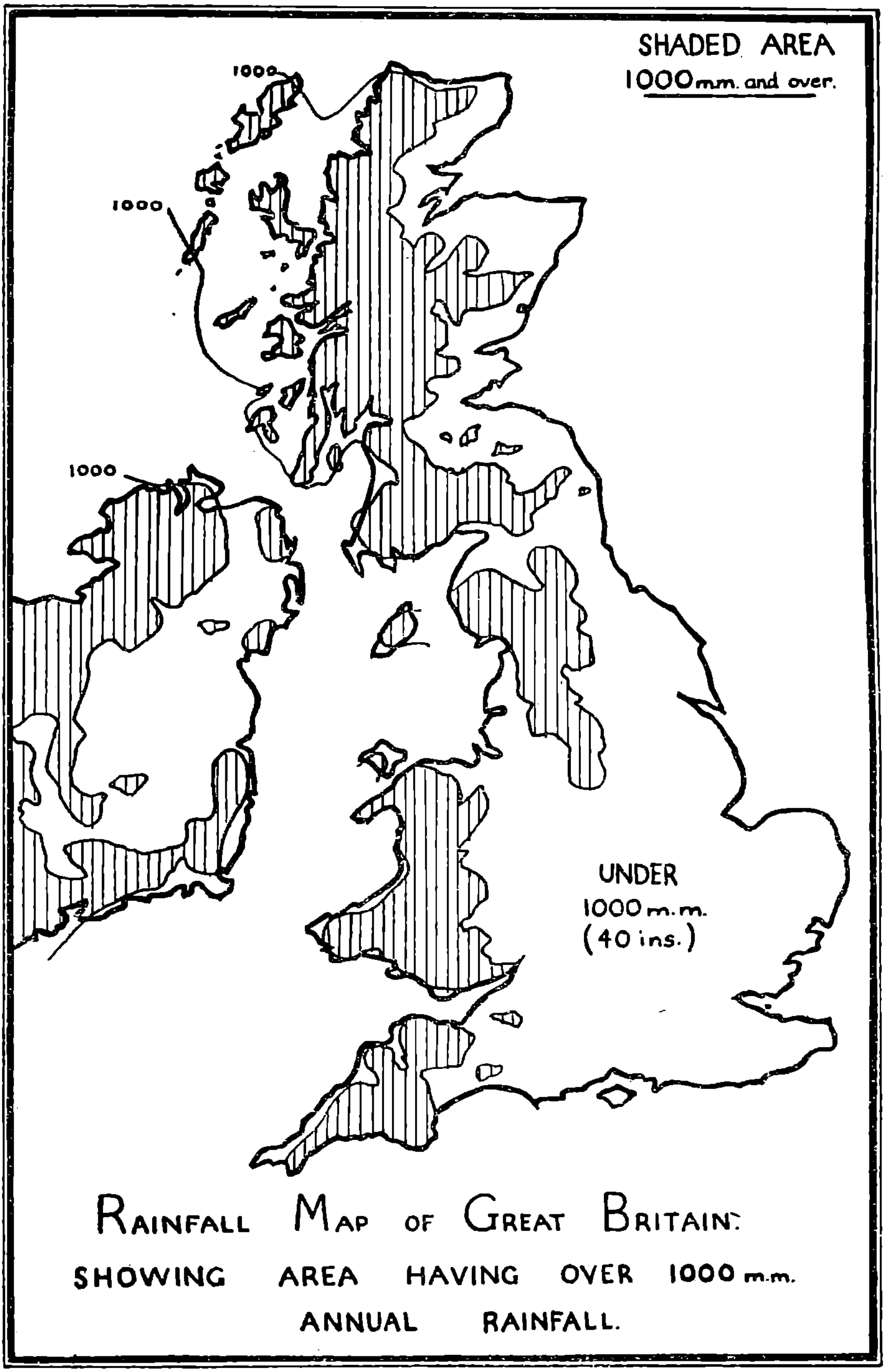
METEOROLOGICAL DATA

Table on page 87.

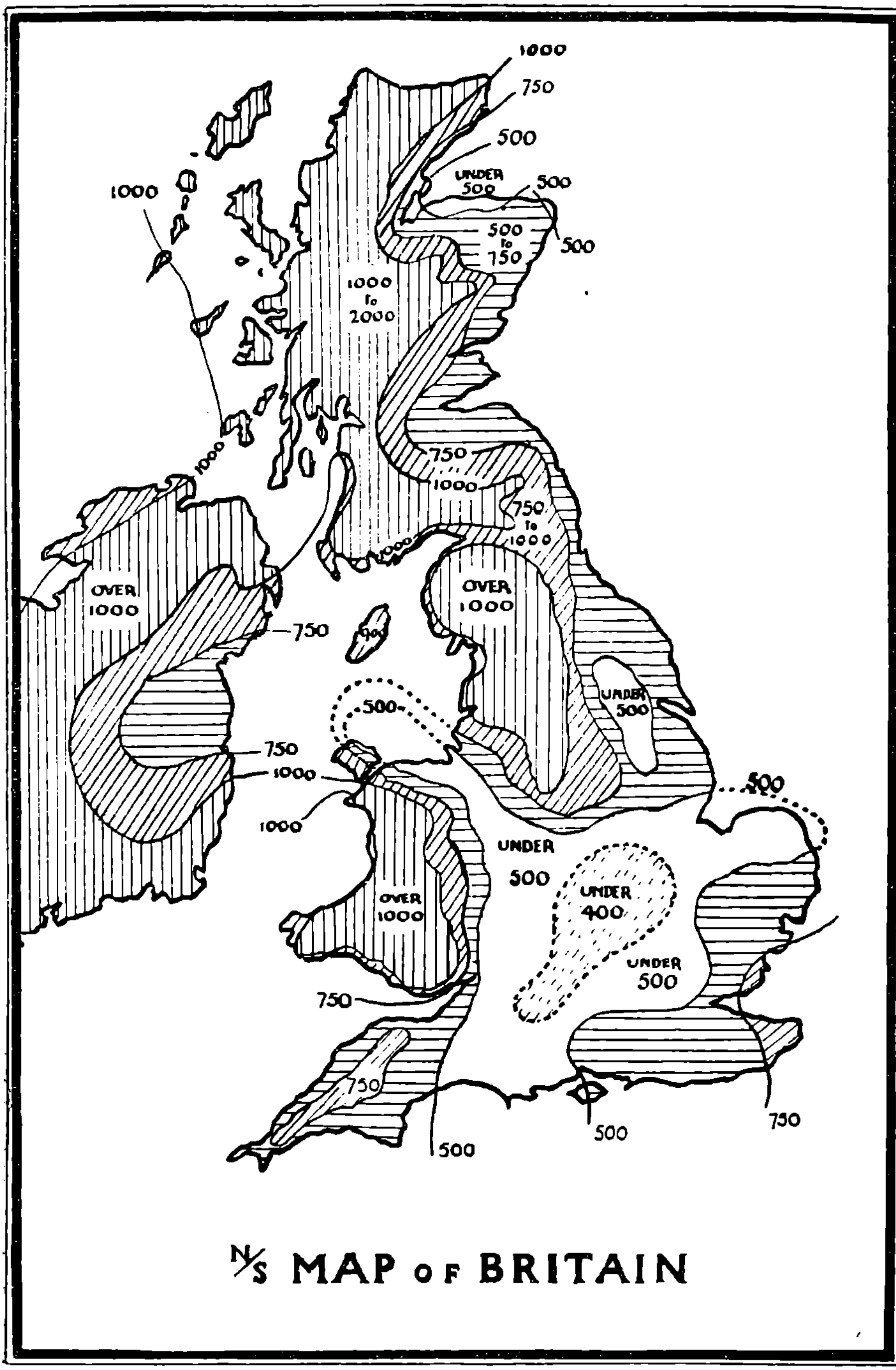
* For an explanation of isopleths see pages 8-9.


Dalavaich
Barmaddy
Grey Grits (unshaded)
Loch Awe
Epidiorites (hatched)
Cruachan
N
Monach
Meadh'onach
Dun
Corrach
Cnoc
Feadaige
LOCH AWE
Rudha
Barain
Glacial Drift
Morainic Drift
0
1
2 MILES

MAP I


SHADED AREA
1000 mm. and over.
1000
1000
1000
UNDER
1000 m.m.
(40 ins.)
RAINFALL MAP OF GREAT BRITAIN:
SHOWING AREA HAVING OVER 1000 m.m.
ANNUAL RAINFALL.

MAP II



MAP III

(See APPENDIX I for explanation of symbols)

METEOROLOGICAL DATA—INVERLIEVER

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Rainfall in inches (0.5 ins. interval)												
Ford, 1916–26 Mean	8.0	6.0	4.5	4.5	5.0	4.0	5.5	6.5	7.0	8.0	8.0	8.0	74.5
Ford, 1916–26 Maximum	12.0	8.0	10.5	7.0	8.0	5.5	9.5	8.0	12.0	13.0	13.5	13.5	94.5
Ford, 1916–26 Minimum	6.0	3.0	0.5	3.0	3.5	2.0	4.2	5.0	4.5	4.0	2.0	4.5	60.0
Cruachan, 1916–24—Mean ...	10.0	7.5	6.5	5.0	4.5	4.0	6.0	6.5	8.5	9.0	10.0	11.0	88.0
	Distribution of Sunshine												
Days on which 0.6 or less of the sky at Ford was clouded ...	10	9	8	13	13	10	10	8	8	10	10	10	119
	Temperatures in Degrees Fahrenheit												
Ford, 1916–26 Mean Temperature ...	36	37	38	43	52	53	56	56	51	45	40	37	45
Ford, 1916–26 Mean Maximum ...	41	45	45	52	61	64	67	66	59	53	46	42	53
Ford, 1916–26 Mean Minimum ...	32	31	31	33	41	42	45	46	42	38	34	31	37
Cruachan, 1916–24 Maximum ...	40	41	44	50	61	64	67	63	58	52	44	41	52
Cruachan, 1916–24 Minimum	31	30	30	33	41	42	44	46	41	37	35	34	37
Annual distribution of ground frost. Average number of nights per month on which frost was recorded on grass at Ford	20	19	22	15	5	2	2	2	10	12	20	20	150
Number of nights (over four years to 1925) at Cruachan on which 36° F. was reached (an index to the probable frequency of frost on the higher ground)	30	31	32	25	15	6	2	2	9	17	23	31	223

APPENDIX II

Plant Lists

EXPLANATORY NOTE.—The plant lists do not include all the species occurring upon the various types of vegetation, but only those which, from their frequency or some such cause are considered to be of some value in the characterisation of the type concerned.

In so far as they refer to non-moorland types, the lists have been constructed by ocular estimation and refer to Inverliever alone. Earlier ocular estimations of frequency on the moorland types were subsequently superseded by more accurate ecological determinations upon representative areas in the counties of Argyll, Inverness, Ross, Sutherland and, in some types, Dumfries, so that the data are representative of the west of Scotland in general.

The nomenclature used is that of the following works :

For flowering plants and ferns : Bentham and Hooker's *British Flora*, 1920.

For mosses (excluding the Sphagna) : *The Students' Handbook of British Mosses*, Dixon and Jameson, 1922.

For Sphagna : *Die Europaischen Torfmoose*, Roth, 1916.

For Liverworts : *The Students' Handbook of British Hepatics*, McVicar, 1912.

Those plants which are listed include constants (*i.e.*, those which invariably occur on the type), and those which are generally found, *i.e.*, those which have been found on 60 per cent. or more of those examples of the type from which the lists were compiled. The frequency symbols indicate the usual frequency of the plant in the examples as a whole, and are used as follows :—

D.—Dominant, *i.e.*, present in such abundance and of such a habit of growth as to determine the appearance (facies) of the vegetation during the vegetative season.

c.D.—Co-dominant, *i.e.*, present in such abundance as to affect the facies of the type but not the most important species in this respect.

a.—Abundant.

f.—Frequent.

c.—Common.

i.—Infrequent ; occasionally or rarely found.

l.—Locally, *i.e.*, occurring in some special phase in the type.

d.—Diffusely, *i.e.*, not forming compact masses or groups ; *e.g.*, a.d.—abundant, but scattered as a diffuse growth form over the area.

PLANT LISTS

I.—1. OAK WOODLAND

Trees

Dominant :
Quercus sessiliflora (*petraea*).

Co-dominant :
Fraxinus excelsior l.f.
Ulmus montana l.a.
Alnus glutinosa l.a.

Sub-canopy Trees and Shrubs

Prunus padus l.
P. spinosa l.
Pyrus aucuparia i.
Rubus fruticosus l.a.
Rosa canina l.c.
Corylus avellana l.
Hedera helix l.
Lonicera periclymenum c.
Salix aurita l.c.
S. cinerea l.i.

Ground Vegetation

Lychnis vespertina c.
L. diurna c.
Stellaria holostea l.a.
S. graminea l.a.
Arenaria trinervia f.
Hypericum pulchrum c.
Hieracium alpinum c.
Primula vulgaris f.
Lysimachia nemorum c.
Iris pseudacorus l.
Allium ursinum c.
Scilla nutans f.

Ground Vegetation—*continued*

Spiraea ulmaria l.c.
Geum urbanum c.
Chrysosplenium alternifolium c.
C. oppositifolium a.
Circaea alpina c.—l.a.
Epilobium montanum c.
E. anagallidifolium f.
Oenanthe crocata l.a.
Angelica sylvestris l.
Heracleum sphondylium c.
Galium verum c.
G. aparine l.a.
Asperula odorata l.a.
Valeriana officinalis c.
Petasites albus l.a.
Centaurea nigra l.c.
Juncus articulatus l.a.
Anthoxanthum odoratum l.
Agrostis alba f.
A. canina l.c.
Aira flexuosa c.
Molinia caerulea l.c.
Bromus spp. l.
Equisetum arvense l.
E. sylvaticum c.—l.a.
Pteris aquilinum l.
Scolopendrium vulgare l.c.
Asplenium trichomanes c.
A. filix-foemina l.a.
Aspidium filix-mas l.c.
Polypodium vulgare c.
Cystopteris fragilis c.

I.—2. Oak-Birch Woodland

Trees

Dominant :
Quercus sessiliflora (*petraea*).

Co-dominant :
Ulmus montana (*glabra*) l.f.
Betula alba (*pendula*) l.a. . (l.—D.).
Alnus glutinosa l.a.

Sub-canopy Trees and Shrubs

Prunus padus i.
Rubus fruticosus l.
Pyrus aucuparia c.
Lonicera periclymenum c.
Corylus avellana l.f.—a.
Salix aurita l.c.

Ground Vegetation

Viola palustris l.c.
Lychnis diurna c.
Arenaria trinervia c.—i.
Sagina procumbens c.
Hypericum pulchrum c.
Lathyrus montanus c.
Potentilla tormentilla c.
Chrysosplenium oppositifolium l.a.
Pimpinella saxifraga l.c.
Conopodium denudatum l.c.
Angelica sylvestris l.c.
Galium saxatile f.
G. verum l.c.
G. aparine l.
Scabiosa succisa f.
Solidago virgaurea l.c.
Achillea millefolium l.c.
Hieracium alpinum c.
Hypochaeris radicata c.
Leontodon autumnale c.
Vaccinium myrtillus l.a.
V. vitis idaea l.c.
Calluna vulgaris l.
Primula vulgaris l.c.
Trientalis europaea f.
Scrophularia nodosa c.
Veronica officinalis c.
V. chamaedrys l.c.
Melampyrum pratense l.f.
Teucrium scorodonia f.
Rumex acetosella c.
Myrica gale l.c.—a.
Scilla nutans l.c.
Juncus articulatus l.a.
J. squarrosus l.c.
Luzula pilosa c.
Anthoxanthum odoratum c.—f.
Agrostis spp. l.c.—a.
Aira flexuosa f., l.a.
A. caespitosa l.
Holcus mollis l.c.
H. lanatus c.—l.a.
Molinia caerulea c.—l.a.
Equisetum silvaticum l.
Pteris aquilina l.f.—a.
Blechnum spicant f.
Polypodium vulgare l.c.
Aspidium filix-mas. l.
A. dilatatum i.—l.c.
A. oreopteris l.c.

II.—1. Meadow Grassland (Typical grass phase, *i.e.*, local species omitted)

Ranunculus repens c.
R. acris c.—f.
Polygala vulgaris c.
Stellaria graminea c.
Sagina procumbens c.
Hypericum pulchrum c.—f.
Lotus corniculatus c.
Lathyrus montanus c.
Digitalis purpurea i.—c.
Veronica chamaedrys c.—f.
V. serpyllifolia c.
Euphrasia officinalis f.
Ajuga reptans c.—f.
Plantago lanceolata f.
Rumex acetosa c.
Orchis maculata i.—c.

Meadow Grassland—*continued*

Potentilla tormentilla c.—f.
Angelica silvestris c.
Heracleum sphondylium c.
Galium saxatile c.—f.
G. verum c.
Scabiosa succisa c.—f.
Achillea millefolium c.
Cnicus lanceolatus c.
C. palustre c.
Centaurea nigra c.—f.
Hieracium pilosella c.
H. alpinum c.
Hypochaeris radicata c.
Leontodon autumnale c.—f.
Primula vulgaris c.
(No mosses of importance.)
O. latifolia i.—c.
Luzula congesta c.
Juncus articulatus f.—l.a.
Anthoxanthum odoratum c.—f.
Alopecurus pratensis f.
Agrostis spp. f.—a.
Aira flexuosa f.—a.
Holcus lanatus f.—a.
Cynosurus cristatus c.
Molinia caerulea f.—a.
Dactylis glomerata f.—a.
Festuca ovina i.—c.
Bromus mollis i.—c.
Lolium perenne c.—f.

II.—2. HEATH-GRASSLAND (Typical grass phase—local species omitted)

Ranunculus acris c.
Viola riviniana c.
Polygala vulgaris c.
Lotus corniculatus c.
Lathyrus montanus c.
Potentilla tormentilla f.
Pimpinella saxifraga c.
Angelica silvestris i.—c.
Heracleum sphondylium i.—f.
Galium saxatile f.
Scabiosa succisa f.
Solidago virgaurea c.—f.
Gnaphalium sylvaticum i.—c.
Achillea millefolium c.
Senecio jacobaea c.
Cirsium lanceolatum c.
Centaurea nigra c.—f.
Hieracium alpinum c.
Hypochaeris radicata f.
Leontodon autumnale f.
Vaccinium myrtillus l.a.—f.d.
V. vitis-idaea i.
Calluna vulgaris i.—l.a.
(No mosses of importance.)
Veronica officinalis c.
V. chamaedrys c.—f.
Euphrasia officinalis f.
Thymus serpyllifolia i.—l.a.
Teucrium scorodonia f.
Plantago lanceolata c.
Rumex acetosa c.—f.
R. acetosella i.—c.
Orchia latifolia i.—c.
Juncus articulatus l.a.—c.
Luzula pilosa c.—l.f.
L. congesta c.
Carex binervis c.
C. panicea i.—l.f.
Anthoxanthum odoratum f.—a.
Agrostis spp. c.
Aira flexuosa a.
Holcus lanatus i.—l.a.
Molinia caerulea a.
Festuca ovina f.—a.
Nardus stricta i.—l.c.
Pteris aquilina i.—l.a.
Blechnum spicant c.

III.—1. HEATH recently developed on unstable soil

Dominant : *Calluna vulgaris.*

Species frequently scattered throughout the Calluna (f.d.).

Potentilla tormentilla.
Galium saxatile.
Scabiosa succisa.
Hypochaeris radicata.
Erica cinerea.
Vaccinium myrtillus.
Luzula campestris.
Carex binervis.
Aira flexuosa.
Blechnum spicant.

Less frequently, but usually to be found

Viola canina c.
Polygala vulgaris c.
Hypericum pulchrum i.—c.
Antennaria dioica l.c.
Leontodon autumnalis i.
Erica tetralix l.c.
Euphrasia officinalis c.
Listera cordata i.
Juncus squarrosus c.—l.f.
Anthoxanthum odoratum c.
Molinia caerulea l.c.
Lycopodium clavatum l.c.

Mosses

Dicranum scoparium c.
Rhacomitrium lanuginosum i.—c.
Brachythecium purum f.
Hypnum cupressiforme a.
Hypnum schreberi a.
Hylocomium splendens c.—l.a.
H. loreum c.d.

Liverworts

Plagiochila asplenioides c.d.
Lophocolea bidentata c.
Diplophyllum albicana l.a.
Frullania tamarisci l.c.

III.—2. Heath (podsolic)
Dominant : *Calluna vulgaris.*

Co-dominant and abundant species

Erica cinerea f.
Erica tetralix f.—l.a.
Vaccinium myrtillus c.—l.a.
V. vitis-idaea i.—l.f.
Scirpus caespitosus l.c.
Aira flexuosa i.—c.
Molinia caerulea i., l.
Nardus stricta i., l.
Juncus squarrosus c.

Species frequently scattered throughout

Polygala vulgaris c.
Potentilla tormentilla a.d.
Galium saxatile c.
Scabiosa succisa i.—f.
Solidago virgaurea c.
Hypochaeris radicata c.
Antennaria dioica i.—c.
Hieracium pilosella i.—c.
Euphrasia officinalis i.
Empetrum nigrum i.—a.
Narthecium ossifragum i.—f.
Eriophorum polystachion i.—c.
Carex binervis c.
Lycopodium clavatum i.—c.

Mosses

Polytrichum piliferum i.
P. juniperinum g.d.
Dicranella heteromalla i.—c.
Campylopus subulatus i.—c.
C. atrovirens i.—c.
Dicranum scoparium f.
Leucobryum glaucum i.—f.
Rhacomitrium lanuginosum c.
Aulacomnium palustre l.c.
Brachythecium purum a.
Plagiothecium undulatum i.
Hypnum cupressiforme a.
H. molluscum c.d.
H. schreberi a.
Hylocomium splendens a.
H. loreum f.d.
Sphagnum compactum i.—f.
S. rubellum l.c.—l.a.
S. acutifolium (a.g.g.) c.—a.

Liverworts

Pleurosia purpurea i.
Plagiochila asplenioides c.d.
Diplophyllum albicans c.—l.a.

V.—1. Transitional Scirpus-Molinia Moor
Dominant :

Scirpus caespitosus—chiefly in large vigorous tufts.
Molinia caerulea—chiefly in small tufts or in the diffuse form.

Co-dominant plants—frequently occurring or locally abundant.

Cardamine pratensis f.d.
Potentilla tormentilla f.d.
Galium palustre f.d.
Scabiosa succisa f.
Taraxacum paludosum i.—f.
Erica tetralix c.—l.a.
Vaccinium myrtillus i.—f.
Euphrasia officinalis c.—f.
Pedicularis palustris i.—f.
P. sylvatica l.f.
Myrica gale f.d.—l.a.
Empetrum nigrum i.—l.f.
Narthecium ossifragum f.—a.
Juncus articulatus l.a.
J. lamprocarpus l.f.
J. supinus i.—f.
J. squarrosus i.—f.
Eriophorum polystachion c.—f.
E. vaginatum i.—l.a.
Carex ampullacea l.
C. caespitosa l.c.
C. echinata l.f.
C. leporina l.c.
Anthoxanthum odoratum f.d.
Alopecurus pratensis l.
Phleum pratense c.
Agrostis spp. c.
Aira caespitosa l.a.
Holcus lanatus f.d.—l.a.
Festuca paludosa c.
Equisetum sylvaticum l.a.
Pteris aquilina i.—l.a.
Aspidium oreopteris i. l.a.

Very many subsidiary species are found

Mosses

Polytrichum juniperinum i.—l.c.
Campylopus subulatus f.
C. atrovirens l.f.
Dicranum scoparium f.
Funaria hygrometrica l.a.
Aulacomnium palustre f.—f.d.
Brachythecium purum a.
Eurynchium spp. c.
Hypnum cupressiforme i.—l.a.
H. cuspidatum c.—l.a.
H. schreberi c.d.—a.
Hylocomium splendens c.d.—l.f.
Sphagnum papillosum l.a.
S. centrale l.c.
S. compactum c.—f.
S. cuspidatum c.f.
S. molluscum c.d.
S. schliepachii l.c.
S. subsecundum c.—l.a.
S. acutifolium (seg.) a.
S. rubellum a.d.
S. acutifolium (a.g.g.).
Short forms a.

Where sub-shrub canopy is fairly dense, *e.g.*, under *Myrica gale*, the following additional mosses occur :—

Bryum capillare f.
B. spp. c.
Mnium hornum a.
M. affine c.
Mnium punctatum c.
Thujidium tamarascinum l.a.
Plagiothecium undulatum l.a.

V.—2. Transitional Scirpus-Calluna-Molinia Moor

Dominant :
Scirpus caespitosus—in definite tufts and diffuse growth.
Calluna vulgaris—in definite tufts and diffuse growth.
Molinia caerulea—chiefly in diffuse growth.
Narthecium ossifragum—diffuse but very abundant.

Subsidiary plants of usual occurrence

Polygala vulgaris i.—c.
Potentilla tormentilla a.d.
Drosera rotundifolia c.
D. longifolia l.c.
Hydrocotyle vulgaris l.
Galium saxatile c.
Scabiosa succisa o.—f.
Erica tetralix a.—c.
Vaccinium myrtillus i.—c.
V. vitis-idaea i.—c.
V. oxycoccus l.a.
Myrica gale i.—l.a.
Empetrum nigrum i.f.
Juncus articulatus (a.g.g.) l.a.
J. squarrosus i.—c.
Luzula campestris i.—c.
Potamogeton polygonifolius l.c.
Eriophorum polystachion f.—a.
E. vaginatum i.—f.
Carex ampullacea l.
Pteris aquilina l.

Mosses

Dicranella heteromalla c.d.
Dicranum scoparium c.d.
Rhacomitrium lanuginosum c.—f.
Aulacomnium palustre c.—f.
Breutelia arcuata l.c.
Brachythecium purum f.—a.
Plagiothecium undulatum i.—c.
Hypnum cupressiforme f.—a.
H.—molluscum c.
H. schreberi f.—a.
Hylocomium splendens f.—a.
H. loreum f.d.
Sphagnum centrale c.—f.
S. medium c.—f.
S. compactum c.—f.
S. lindbergii l.a.
S. cuspidatum l.a.
S. molluscum i.—c.
S. schliepachii l.a.
S. rubellum a.
S. acutifolium (seg.) a.
S. acutifolia (short red, brown and pale forms) a.d.

V.—3. Transitional Heath-Moor. Calluna-Scirpus Moor

Dominant :
Calluna vulgaris—in large clumps or tufts with
Scirpus caespitosus predominating in the surrounding opener herbage.

Subsidiary plants of usual occurrence

Ranunculus repens c. (d.).
Polygala vulgaris c.
Stellaria graminea c.
Hypericum pulchrum i.—c.
Rumex acetosa c.
R. acetosella c.
Myrica gale l.f.
Empetrum nigrum i.—f.

Subsidiary plants of usual occurrence—*continued*

Trifolium medium i.—l.ci
T. repens i.—l.c.
Lotus corniculatus i.—c.
Lathyrus macrorrhizus c.
Potentilla tormentilla a.d.
Galium saxatile f.—a.
Scabiosa succisa f.—a.
Solidago virgaurea c.
Senecio sylvaticus i.—c.
Centaurea nigra l.a.
Hypochaeris radicata c.
Taraxacum paludosum c.
Erica cinerea l.f.
E. tetralix c.—f.d.
Vaccinium myrtillus c.—l.a.
V. vitis-idaea c.—l.f.
Veronica officinalis c.
Euphrasia officinalis c.
Prunella vulgaris l.c.
Teucrium scorodonia c.
Ajuga reptans l.c.
Luzula campestris c.
L. pilosa i.—f.
Eriophorum polystachion i.—l.c.
E. vaginatum i. (—l.a.).
Carex binervis c.—l.a.
C. caespitosa c.
C. echinata i.—l.f.
Anthoxanthum odoratum f.—a.d.
Agrostis carina c.—l.f.
Aira flexuosa a.—l.D.
Holcus lanatus l.c.—l.a.
Arrhenatherum avenaceum l.c.
Molinia caerulea l.c.—l.a.
Dactylis glomerata l.c.
Festuca paludosa c.d.—l.c.
Nardus stricta l.i.—l.c.
Pteris aquilina l.f.
Aspidium oreopteris l.f.
A. dilatatum l. .
Lycopodium clavatum l.f.

Polytrichum commune l.f.
P. piliferum l.c.
P. juniperinum g.d.—l.c.
Dicranella heteromalla c.
Campylopus subulatus c.
Dicranum scoparium f.
Bryum capillare i.—c.
Brachythecium purum a.
Hypnum cupressiforme a.
H. molluscum c.

Mosses
Hypnum schreberi a.
Hylocomium splendens a.
H. loreum f.d.
Sphagnum lindbergii f
S. girgensohnii c.—a.
S. russowii l.a.
S. rubellum c.
S. warnstorfii f.
S. acutifolium f.
Short Sphagna of the Acutifolia group are frequent.
Sphagnum mainly confined to the opener spaces between tufts of heather.

Flush Types in Moorland

Flush types on mineral soil are not listed, being essentially similar to those of moorland.

VI.—1. Rush (*Juncus articulatus*) Flush

Dominant :

Juncus articulatus—in close to somewhat open formation, with or without the grasses listed as important or co-dominant.

Plants usually found in moorland rush flush

Ranunculus acris i.—c.
R. flammula l.f.
Cardamine pratensis i.
Viola palustris l.a.
Stellaria uliginosa i.—c.
Parnassia palustris l.c.
Epilobium montanum c.
E. palustre c.
Galium palustre i.—f.
Scabiosa succisa i.—l.f.
Taraxacum paludosum c.
Calluna vulgaris l.
Erica tetralix l.f.
Euphrasia officinalis i.—c.
Pedicularis palustris i.—f.
Rumex acetosa i.—c.
Myrica gale l., i.—f.
Salix cinerea i.—c.
Orchis latifolia i.—c.
O. maculata i.—c.
Iris pseudacorus—local.
Narthecium ossifragum l., i.
Juncus communis i.
J. articulatus.
f. lamprocarpus l.a.
f. supinus l.
Potamogeton polygonifolius l.
Carex echinota i.—l.f.
C. leporina i.
Anthoxanthum odoratum l.c.
Agrostis spp. c.—l.a.
Aira flexuosa i.—c.
Holcus mollis i.—c.
H. lanatus c.—l.a.
Molinia caerulea l.c.—l.a.
Equisetum spp. c

Mosses

Polytrichum commune l.o.
P. juniperinum c.—l.a.
Funaria hygrometrica l.a.
Bryum capillare c.—l.a.
Mnium spp. c.
Thujidium tamarascinum l.c.
Brachythecium purum f.—l.c.
Plagiothecium undulatum i.—c.
Eurynchium spp. f.
Hypnum schreberi f.—a.
H. cuspidatum l.a.
Hylocomium splendens c.—a
H. loreum c.
H. squarrosum c.
Sphagnum cymbifolium l.a.
S. papillosum l.a.
S. fimbriatum l.c.
A few other sphagnums are local and infrequent.

Liverworts

Many species, of which the following are frequent :—
Aneura spp.
Lophosia incisa.
Plagiochila asplenioides (abundant).
Leptocyphus taylori.
Lophocolea bidentata.
L. heterophylla.
Trichocolea tomentella.
Madotheca platyphylla.

VI.—2. TYPICAL MOLINIA FLUSH

Dominant :

Molinia caerulea in large strong tufts

Other plants usually occurring

Potentilla tormentilla i.—c.
Angelica sylvestris i.
Galium palustre i.
Scabiosa succisa i.—c.
Carduus palustris i.
Calluna vulgaris l., i.—f.
Erica tetralix l., i.—l.f.
Vaccinium myrtillus l.c.
Myrica gale l., i.—a.
Salix cinerea i.
Orchis latifolia i.
Juncus articulatus l.
Luzula campestris i.—c.
Scirpus caespitosus l.i.
Eriophorum polystachion l., i.—c.
E. vaginatum l.f.
Carex binervis i.—c.
C. caespitosa (a.g.g.) i.
C. echinata i.—l.f.
Anthoxanthum odoratum c.
Agrostis spp. i.—f.
Aira flexuosa i.—l.f.
Holcus lanatus l.f.
Festuca ovina l.c.

Mosses

Polytrichum spp. i.
Dicranum scoparium i.
Aulacomnium palustre l.i.
Bryum spp. l.i.
Mnium spp. l.i.
Thujidium tamarascinum l.i.
Brachythecium purum i.—c., l.a.
Plagiothecium undulatum l.i.
Eurynchium spp. l.i.
Hypnum schreberi g.d.
H. cuspidatum i.
Hylocomium splendens i.—c., l.a.
H. loreum i.
Sphagnum spp. (chiefly *papillosum*) i.l.

VI.—3. ERIOPHORUM VAGINATUM FLUSH

Dominant :

Eriophorum vaginatum in large tussocks ; subsidiary plants chiefly growing upon these. " local " species chiefly in depressed areas.

Commoner subsidiary plants

Viola palustris l.a.
Potentilla tormentilla i.—c.
Galium saxatile c.
G. palustre i.—c.
Scabiosa succisa i.
Calluna vulgaris f.
Erica tetralix f.—l.a.
Vaccinium myrtillus i.—f.
V. vitis-idaea i.—c.
V. oxycoccus l.c.
Euphrasia officinalis i.
Myrica gale c.
Empetrum nigrum c.—f.
Narthecium ossifragum c.—l.a.
Juncus articulatus (a.g.g.) l.
Scirpus caespitosus i., l.f.
Eriophorum polystachion c.—l.a.
Carex echinata i.—l.f.
Anthoxanthum odoratum i.
Agrostis spp. i.
Aira flexuosa i.—a.
Molinia caerulea i.—a.
Festuca ovina i.—c.

Mosses

Polytrichum juniperinum c.
Dicranum scoparium i.—f.
Aulacomnium palustre l.f.
Brachythecium purum f.—l.a.
Hypnum cupressiforme c.—f.
H. schreberi c.—a.
Hylocomium splendens c.—a.
H. loreum i.d.
Sphagnum centrale c.
S. compactum i.—c.
S. rubellum l.a.
S. acutifolium l.a.

VI.—4. Ferruginous Flush in Moorland

Vegetation in general similar to the non-flush type

Indicative plants often associated with Iron-flush or more abundant in Iron-flush than on the surrounding ground.

Ranunculus flammula l.a.
R. hederaceus l.a.
Viola palustris l.a.
Potentilla palustris l.f.
Parnassia palustris l.f.
Hydrocotyle vulgaris l.a.
Scabiosa succisa f.
Taraxacum paludosum c.
Menyanthes trifoliata l.c.
Erica tetralix c.—l.a.
Vaccinium oxycoccus l.f.
Myosotis palustris l.c.
Euphrasia officinalis a.
E. scotica f.—l.a.
Pedicularis palustris l.a.
Pinguicula vulgaris i.—c.
Myrica gale l.f.—l.a.
Empetrum nigrum l.c.
Orchis latifolia c.
O. maculata c.
Habenaria conopsea i.—c.
Narthecium ossifragum a.
Juncus lamprocarpus l.a.
J. supinus f.
Showing poor development.
Juncus squarrosus c.
J. bufonius c.
Luzula campestris c.
Potamogeton polygonifolius c.—a.
Scirpus caespitosus f.
Eriophorum polystachion f.
E. vaginatum i.—l.c.
Carex ampullacea i.—f.
C. binervis i.—f.
C. caespitosa (a.g.g.) c.
C. echinata i.—l.f.
C. leporina l.c.
C. pulicaris i.—f.
C. canescens i.—l.f.

Showing poor development:
Anthoxanthum odoratum c.
Alopecurus geniculatus l.c.
Agrostis canina l.c.
Aira flexuosa l.c.
Holcus lanatus l.c.
Molinia caerulea l.c.—f.
Festuca ovina i.—c.
Nardus stricta i.c.

Equisetum arvense l.f.
Lycopodium inundatum i.—c.

Mosses

Cynodontium bruntoni l.a.
Dicranella heteromalla l.a.
Campylopus subulatus l.a.
C. flexuosus l.a.
C. atrovirens l.a.
Funaria hygrometrica l.a.
Aulacomnium palustre a.
Breutelia arcuata l.a.
Bryum spp. f.
Mnium spp. l.
Brachythecium rivulare l.
Hypnum falcatum c.—l.a.
H. revolvens i.—l.a.
H. cuspidatum i.—a.
Sphagnum centrale f.
S. compactum f.—a.
S. rubellum c.—a.
S. warnstorfii l.c.—l.a.
S. acutifolium (compact forms) c.—a.
S subsecundum (forma) f.

VII.—1. Low-Moor is not listed (*cf.* Sketches I, II and III)

VII.—2. Sphagnum Flat Moor (Plants marked * confined mainly to margin of free water or hollows on which free water rests)

Main facies, open growth of higher plants in dense growth of *Sphagnum*, mainly *S. centrale* and *S. medium*.

Viola palustris l.c.*
Potentilla tormentilla f.
Drosera longifolia l.c.—a.
D. rotundifolia c.—a.
Hydrocotyle vulgaris l.c.*
Scabiosa succisa i.
Menyanthes trifoliata l.f.*
Calluna vulgaris i.—l.c.
Erica tetralix a.d.
Vaccinium myrtillus i.—l.f.
V. oxycoccus a.d.
Juncus articulatus l.
J. supinus c.*
J. squarrosus i.—c.
Luzula campestris i.—c.
Potamogeton natans var. *polygonifolius* l.c.*
Scirpus palustris l.*
S. caespitosus i.—c.
Eriophorum polystachion c.—a.
E. vaginatum i.—f., l.a.
Carex ampullacea c.—f., l.a.*
C. caespitosa i.—c.

Euphrasia officinalis i.—c.
Pedicularis palustris i.—c.
P. sylvatica c.
Rumex acetosella l.c.
Myrica gale l.
Empetrum nigrum c.—f.
Narthecium ossifragum g.a.
Juncus communis l.c.
f. stricta l.a.
C. echinata i.—l.c.
C. leporina i.—c.
C. pulicaris l.c.
Aira flexuosa i.
Molinia caerulea i.—c.

Mosses

Polytrichum commune i.—l.a.
P. piliferum l.
P. juniperinum l.
Rhacomitrium lanuginosum i.—c.
Aulacomnium palustre f.—a.
Breutelia arcuata c.—l.f.
Brachythecium purum l.
Hypnum cupressiforme l.
H. cuspidatum l.
H. schreberi i.—c.
Sphagnum imbricatum l.
S. cymbifolium l.
S. affine l.
S. papillosum i.—a.
Sphagnum centrale a.
S. medium a.
S. compactum l.f.—l.a.
S. squarrosum l.
S. cuspidatum l.c.—l.a.*
S. molluscum f., g.d.
S. schliephackii l.c.
S. russowii l.c.
S. rubellum l.c.—l.a.
S. acutifolium (agg.) l.a., g.d.
S. laricinum l.
S. platyphyllum l.*
S. subsecundum l.a.*

Liverworts

Pleurosia purpurea l.c.—l.a.

Many others are frequent among the mosses in this type, *e.g.* —

Metzigeria furcata.
Lophosia incisa.
Gymnocolea inflata.
Plagiochila spp.
Lophocolea bidentata.
L. heterophylla.
Cephalosia viticulosa.
Nowellia curvifolia.
Odontochisma spp.
Scapania spp.
Calypogeia spp.

These species are to be found generally, in types where sphagnum growth is slow

VII.—3. Scirpus-Calluna Transition from Low to High-Moor

Dominant :

Calluna vulgaris in somewhat small tufts.

Scirpus caespitosus in open (non-tufted) growth in a matrix of mosses.

Most usual subsidiary plants

Polygala vulgaris i.c.
Potentilla tormentilla c.
Drosera rotundifolia i.—f.
Scabiosa succisa i.—c.
Galium saxatile i.
Erica tetralix f.—a.d.
Vaccinium myrtillus i.—c.
V. oxococcus l.f.
Pedicularis sylvatica l.c.
Myrica gale i.—l.c.
Empetrum nigrum c.— l.f.
Narthecium ossifragum a.
Juncus articulatus l.
Juncus supinus i.—l.c.
J. squarrosus i.
Luzula campestris i.
Eriophorum polystachion c.—l.a.
E. vaginatum i.—c.
Carex binervis i.—c.
C. caespitosa (a.g.g.) i.
C. echinata, *C. leporina*, *C. pulicaris* } l.f. but not constant.
Aira flexuosa i.
Molinia caerulea i.—l.a.

Mosses

Polytrichum juniperinum l.c.
Dicranum scoparium c.
Rhacomitrium lanuginosum f.
Aulacomnium palustre c., l.a.
Brachythecium purum c.
Hypnum cupressiforme l.a.
H. schreberi a.
Hylocomium loreum g.d.
Sphagnum centrale c.
Sphagnum compactum l.f.
S. cuspidatum l., i.
S. molluscum c.
S. schliepackii l.i.
S. rubellum l.a.
S. subsecundum l.a.
S. acutifolium (agg.) a. (chiefly in the form of small short red, brown and pale yellow forms).

Mosses—*continued*

S. medium c. | *Pleurosia purpurea* c.—l.a.

VIII.—Scirpus High-Moor

Dominant :

Scirpus caespitosus / *Calluna vulgaris* } Short and open growth with little power of shading the surface of the ground.

Subsidiary species usually found

Polygala vulgaris i.
Potentilla tormentilla f.d.
Drosera longifolia l.i.—c.
D. rotundifolia c.
Scabiosa succisa i.
Erica tetralix g.d., l.a.
Vaccinium myrtillus i.—c.
V. oxycoccus l.
Myrica gale i.—c.
Empetrum nigrum f.d.
Narthecium ossifragum a.
Juncus squarrosus i.—c.
Eriophorum polystachion c.
E. vaginatum i.—l.c.
Aira flexuosa i.
Molinia caerulea i.—l.c.

Mosses

Dicranella heteromalla i.—c.
Campylopus subulatus i.—c.
C. flexuosus i.—f.
C. atrovirens l.c.
Dicranum scoparium i.—c.
Leucobryum glaucum i.—l.c.
Rhacomitrium lanuginosum g.d.—l.a.
Aulacomnium palustre i.—f.
Breutelia arcuata l.c.
Bryum spp. l.c.
Brachythecium purum f.—l.a.
Plagiothecium undulatum i.—l.c.
Hypnum cupressiforme c.—l.a.
H. revolvens i.—l.a.
H. molluscum c.—l.a.
Hypnum schreberi f.—l.a.
Hylocomium splendens f.—l.a.
H. loreum c.d.
Sphagnum centrale c.—f.
S. medium c.—a.
S. compactum c.—a.d.
S. cuspidatum l.c.
S. molluscum c.d.
S. schliepachii l.c.
S. rubellum a.
S. acutifolium (seg.) i.
S. acutifolia (short brown and light coloured forms) a.

Liverworts

Pleurosia purpurea f.—l.a.

APPENDIX III

Analytical Methods

(*a*) Oxygen Requirement

Method of Determination

Ferric ammonium sulphate solution (M/20) in N/20 sulphuric acid was finally adopted as a standard reducible solution. Sulphuric acid is necessary to prevent the removal of ferric ions as hydroxide through the hydrolysing action of the peat.

Five to ten grams of fresh peat of known water content are dropped into a conical flask containing about 100 c.c. of air-free water, in an atmosphere of carbon dioxide, all possible precautions being taken to prevent undue contact with the air. 50 c.c. of the standard iron solution is added, and the volume of the solution made up to a total of 200 c.c. It is well shaken, boiled under a reflux condenser for 10 minutes, and allowed to cool in an atmosphere of CO_2. If necessary, freshly-boiled water is added to the 200 c.c. level. Aliquots (50 c.c.) of the clear supernatant liquid are titrated with N/20 permanganate solution. Only occasionally was filtration necessary, when it was carried out under CO_2.

The results were calculated as grams oxygen required for the oxidation of the iron reduced by the action of 100 grammes of peat (air dry).

(*b*) Calcium Acetate Acidity

The method used was made as comparable as possible to the Hutchinson-McLennan lime-requirement method, but it was considered better to use fresh peat of known water content rather than air-dry, although calculations were made on air-dry peat.

Ten grams of peat are placed in a bottle of 500 c.c. capacity, together with sufficient water to make, with the water contained in the peat, 200 c.c. To this 50 c.c. N/10 calcium acetate solution is added, making 250 c.c. N/50 solution. After shaking vigorously for one hour the bottle is allowed to stand over-night, re-shaken for five minutes in the morning, filtered, and an aliquot portion titrated against N/10 sodium hydroxide (B.D.H. universal indicator used). The results, as expressed in the tables, are calculated in c.c. normal acid per cent. (this, multiplied by 0.05 is equal to mg. calcium carbonate, or multiplied by 0.05 multiplied by 1.75 is approximately equal to " lime-requirement " as determined by the Hutchinson-McLennan method, as was found by a parallel series of determinations).

(c) Hydrogen Ion Concentration Methods

Materials.—It was at first considered that only fresh material (*i.e.*, undried) should be used. Latterly it was found that little change occurred unless the material was stored wet for fairly long periods (6-12 months).

The hydrogen electrode was originally used, but owing to difficulties indicated by several workers (length of time required for saturation, followed by drift of potential, and " poisoning " of electrodes), as well as the high dilutions frequently required when fresh material was used, it was replaced by the quinhydrone electrode, used against a saturated calomel electrode. The low *p*H values obtaining eliminated the main source of error associated with the use of the quinhydrone electrode. Saturated KCl was used as a neutral bridge with, as a rule, KCl agar bridge, although it was found that this was unnecessary if readings were obtained quickly. The electrodes were regularly tested by means of " buffer solutions."

Indicators were used in the field to test stream and drainage water ; in the laboratory some of the earlier work was carried out by colorimetric methods on dry peat only, but later the colours obtained were found to be quite unreliable, and the results rejected.

(d) Methods of Analysis

Except that in all cases the peat was ignited before extraction, the methods of minera analyses are those usually adopted (*see* Russel, *Soil Conditions and Plant Growth*) ; ammonia content was determined by distillation with magnesia, nitrate by extraction of the peat with water, flocculation of suspended matter with milk of lime, and reduction to ammonia by a copper zinc couple, while duplicates were tested by colorimetric methods. The ultimate analyses were, in all cases where small quantities were involved, duplicated colorimetrically by the methods described in U.S. Bureau of Soils, Bulletin No. 31. Although not mentioned in the text, since no general conclusions could be drawn from the results, except that their presence in amount was related to flushing or to the incorporation of mineral matter in the peat, traces or larger amounts of manganese, sulphide, sulphate, were usually found to be present ; luxuriant *Juncus articulatus* has invariably been found to contain more than traces of manganese.

The Base exchange method used is that of Gedroiz—*Thur. Opit. Agron.* 19, 226-244—air-dry peat being used.

APPENDIX IV

Illustrations

Sketches, Quadrats and Plates

Sketches I, II and III are referred to in text (p. 25 *et seq.*). Main inflow of water in I, from the right ; in II, from the top centre and from stream on the right ; seepage only, flows into III.

Outflow I—over a rocky lip on the lower left corner.

Outflow II—toward lower left corner.

Outflow III—main outflow to right centre into sphagnum flat (X) and over the lip of basin into the valley on the lower side of the sketch.

Sketch IV (*see* p. 102)—Vegetational symbols : see p. 99. The subsidiary species are not indicated in the upper part of the sketch. A B and B D represent the ditches ; A B with lime added, B D with slag. Area B X Z represents the watershed between the two ditches. The numbered circles represent the positions of the plants, the growth of which is listed in Table XIX. The lower half of the sketch represents in greater detail the vegetation developed in and below the ditches and turves under the influence of manure (1928).

Sketch V (p. 54 *et seq.*). Two diagrammatic sketches of the variation in height growth of trees occurring on transects over variable vegetation ; this is indicated by the most abundant plants. The first sketch is quite typical of narrow flatter terraces on the lower ground ; the second of the variation in tree growth which may be found in wider stretches of moderate natural drainage.

Quadrats A and B. The same quadrat at five years' interval. Showing the gradual displacement of high-moor vegetation (*Scirpus—Calluna*, etc.) by flush-like vegetation (*Molinia* dominant), produced by the shade of trees and by a deep drain. Plate X was taken in 1927 to the left of this quadrat.

Appendix IV—*continued*

The following are the symbols used in sketches and quadrats for the species occurring, except where otherwise mentioned :—

Potentilla tormentilla ╥╥
P. palustris Θ
Drosera rotundifolia Δ
Myriophyllum spicatum ξ
Nuphar pumila ω
Nymphaea alba ꝏ
Polygala serpyllacea ●
Galium saxatile ϒ
Scabiosa succisa ♀
Lobelia dortmanna ϙ
Menyanthes trifoliata φc
Calluna vulgaris C

(in tufts) Ⓒ

Erica cinerea X

E. tetralix ℰ
Vaccinium myrtillus V
V. vitis idaea ∇
V. oxycoccus 卐
Euphrasia spp. ⊙
Myrica gale ⑊
Salix cinerea ♆
Empetrum nigrum ᒣ
Narthecium ossifragum ♀
Juncus communis Ł
J. articulatus ⋕ or ⊧
J. lamprocarpus ǂ
J. supinus +++

Juncus squarrosus +
J. bufonius ≠
Luzula pilosa þ
Potamogeton polygonifolius ∞
Scirpus palustris ф

S. caespitosus ≡≡≡ ⁞⁞⁞

(in tufts) ⁂ *

Eriophorum polystachion ‡
E. vaginatum †
Carex ampullacea Ɇ
C. binervis Γ
C. panicea ɼ
C. limosa 7
C. echinata ɫ
C. leporina Υ
C. pulicaris ɸ
Agrostis spp. α
Deschampsia flexuosa δ
D. caespitosa D
Holcus mollis ƒ
H. lanatus ħ
Molinia caerulea M

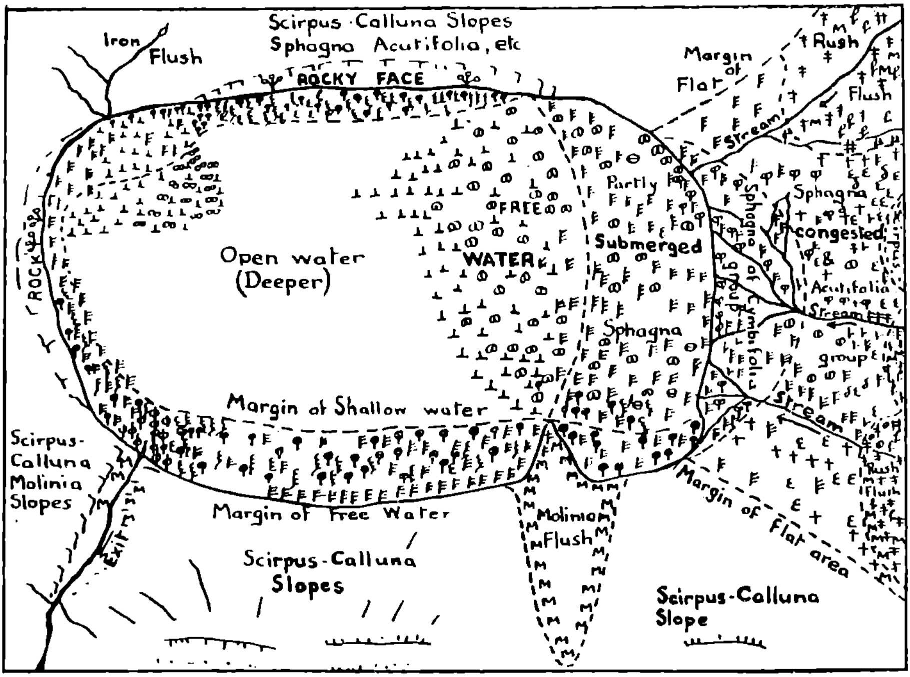
(in tufts) Ⓜ (MM MM)

Festuca ovina ƒ

(in tufts) (ff)

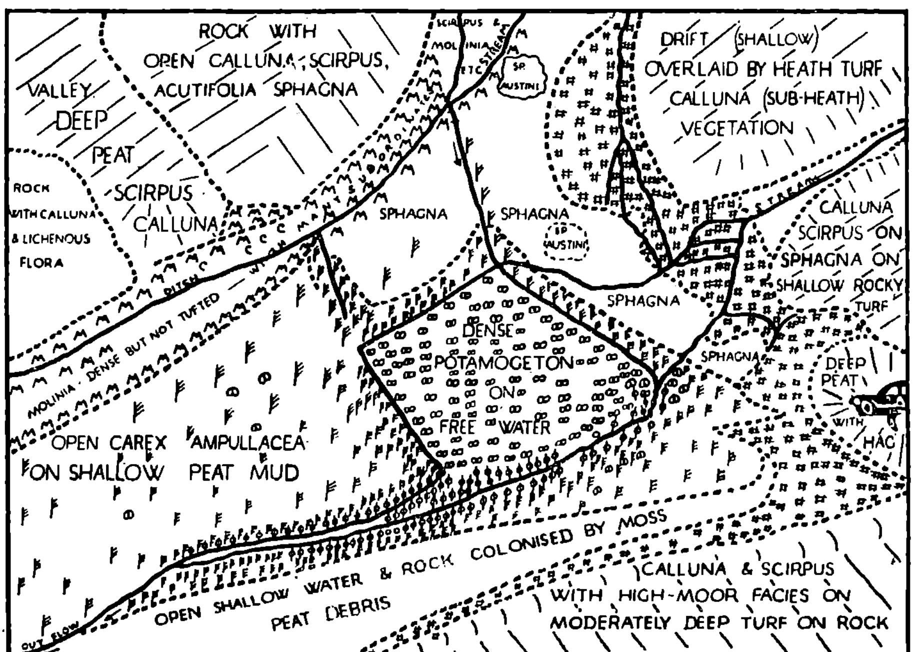
Nardus stricta χ
Equisetum limosum ⊥

NOTE.—In quadrats and sketches *S. papillosum* includes *S. centrale* as well as true *S. papillosum*.

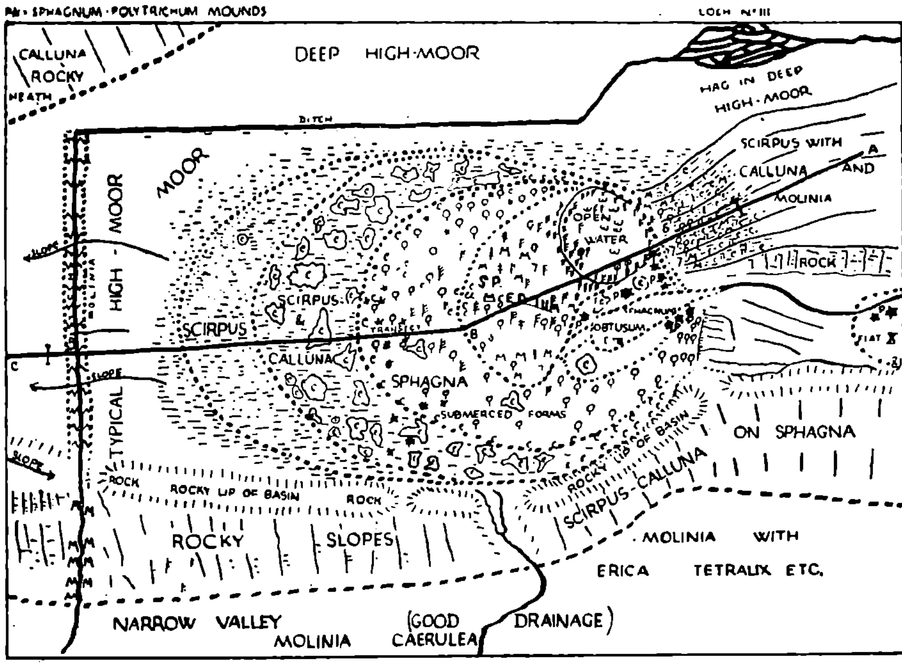


Sketch I

MAIN VALLEY

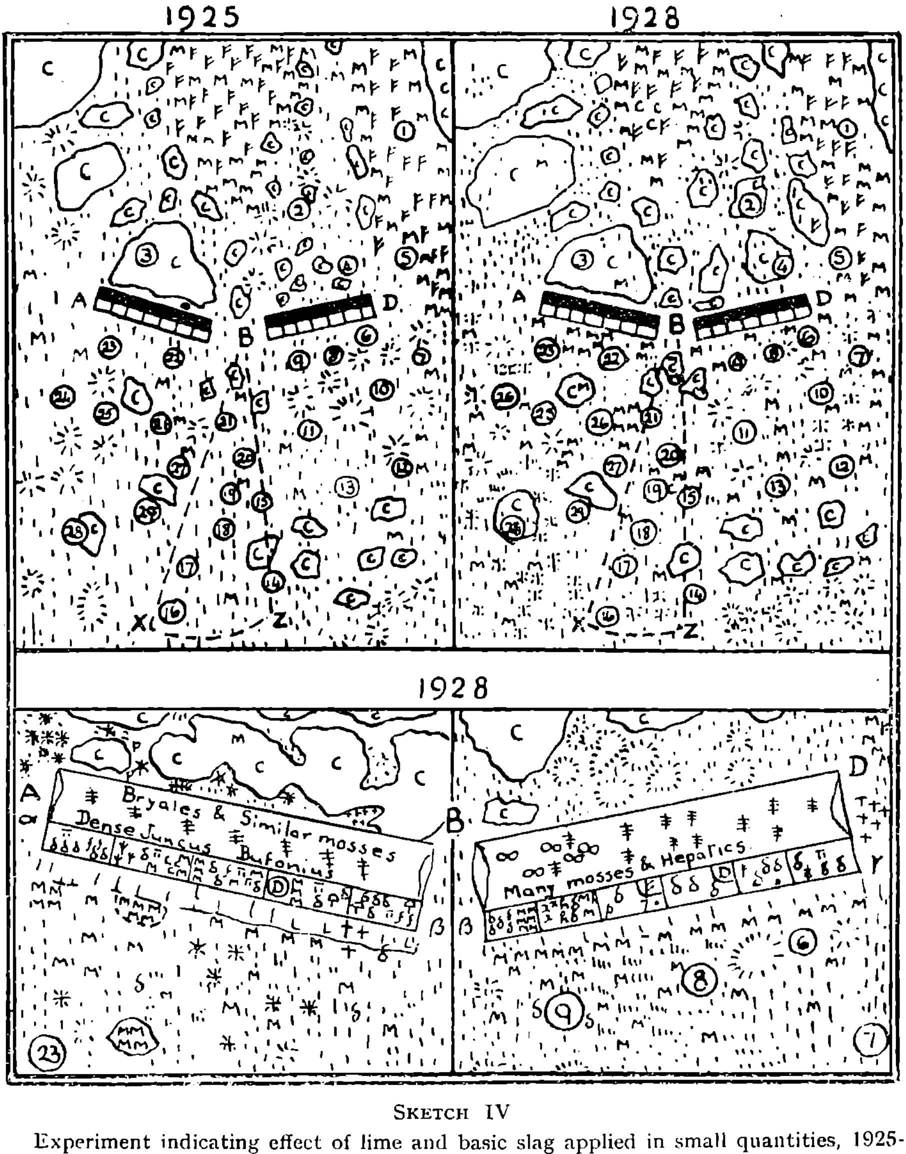


Sketch II



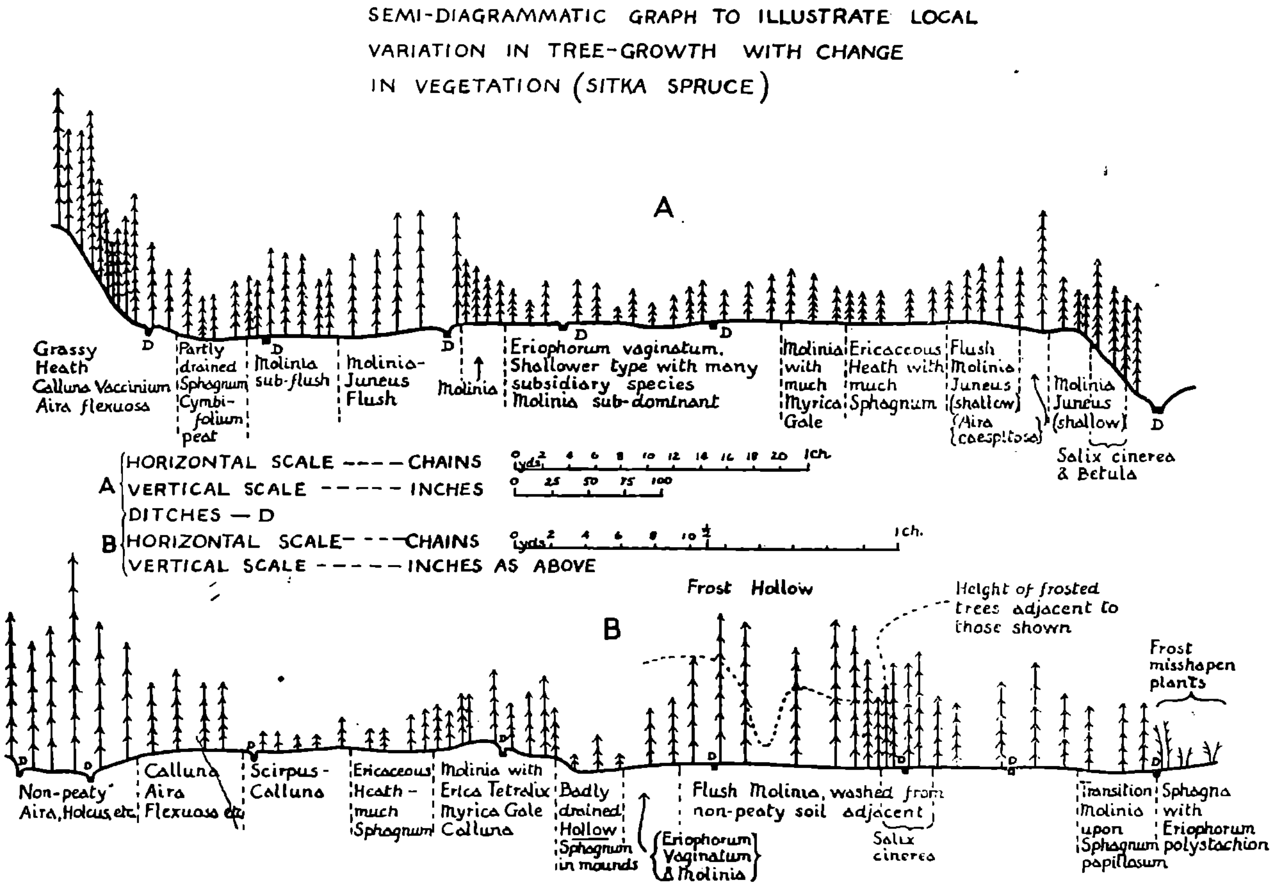
SPHAGNUM-POLYTRICHUM MOUNDS
LOCH No III
CALLUNA
ROCKY
HEATH
DEEP HIGH-MOOR
HAG IN DEEP
HIGH-MOOR
DITCH
SCIRPUS WITH
CALLUNA AND
MOLINIA
A
HIGH-MOOR
MOOR
OPEN
WATER
ROCK
SLOPE
MOLINIA
SCIRPUS
SCIRPUS &
CALLUNA
SPHAGNA
OBTUSUM
C
FLAT
SUBMERGED FORMS
TYPICAL
ON SPHAGNA
ROCKY LIP OF BASIN
SCIRPUS-CALLUNA
ROCK
ROCKY LIP OF BASIN
ROCK
ROCKY SLOPES
MOLINIA WITH
ERICA TETRALIX ETC.
NARROW VALLEY
MOLINIA
(GOOD
CAERULEA
DRAINAGE)

Sketch III

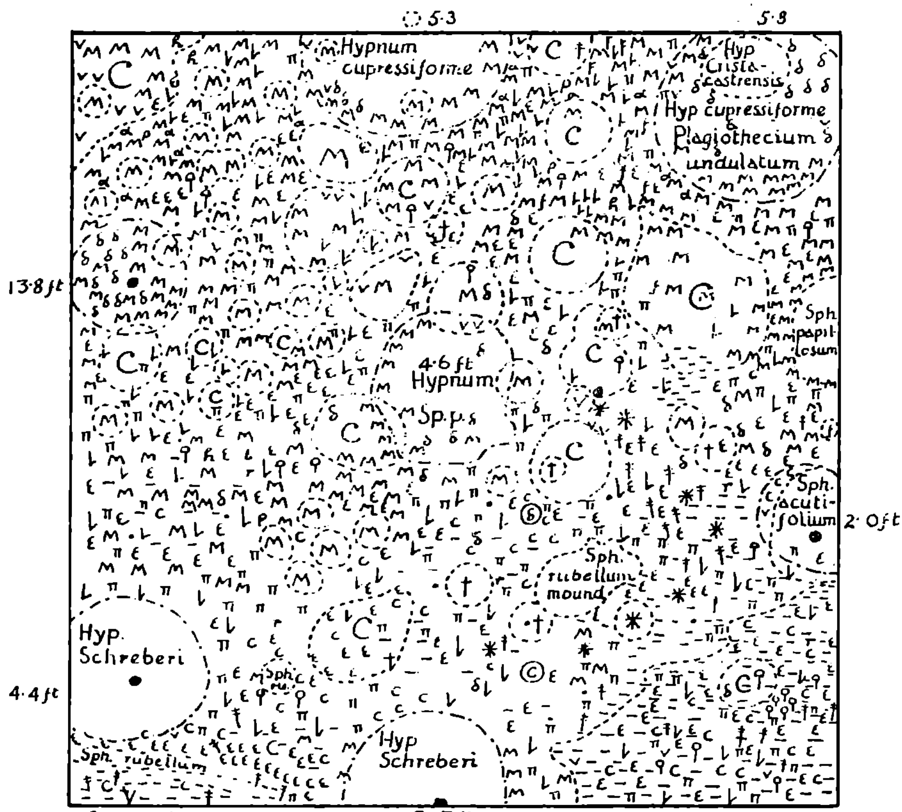


SKETCH IV

Experiment indicating effect of lime and basic slag applied in small quantities, 1925-1928.

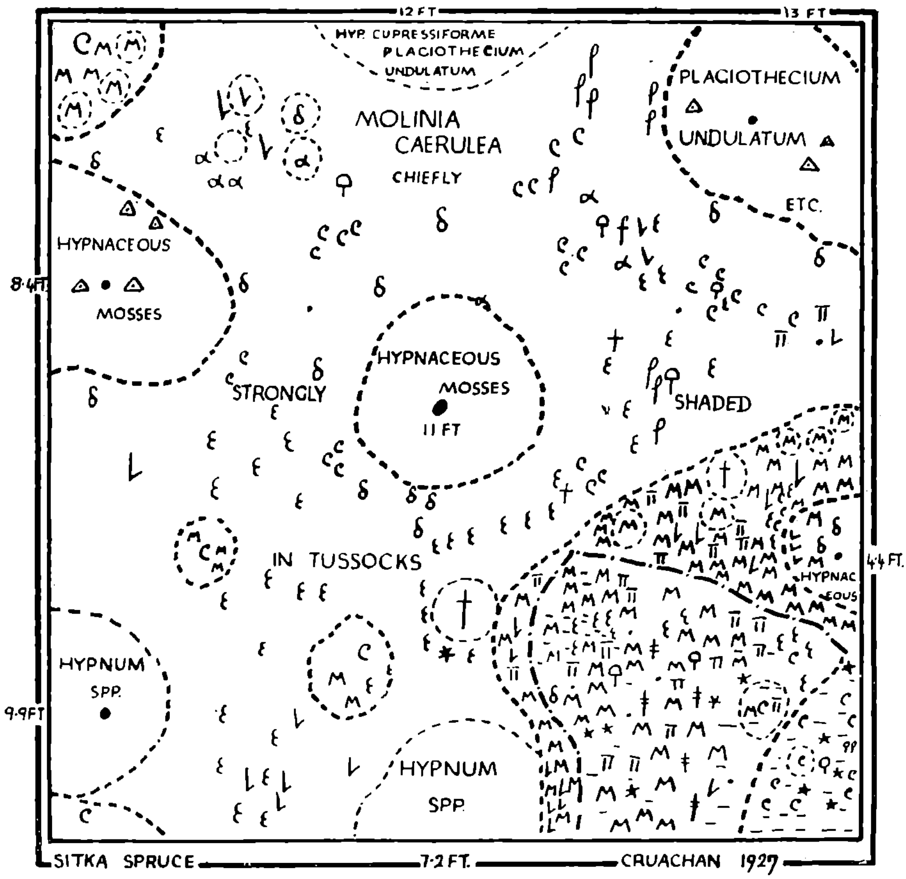

SEMI-DIAGRAMMATIC GRAPH TO ILLUSTRATE LOCAL VARIATION IN TREE-GROWTH WITH CHANGE IN VEGETATION (SITKA SPRUCE)
A
Grassy Heath Calluna Vaccinium Aira flexuosa
D
Partly drained Sphagnum Cymbifolium peat
D
Molinia sub-flush
Molinia-Juncus Flush
D
Molinia
Eriophorum vaginatum. Shallower type with many subsidiary species Molinia sub-dominant
D
D
Molinia with much Myrica Gale
Ericaceous Heath with much Sphagnum
Flush Molinia Juncus (shallow) (Aira caespitosa)
Molinia Juncus (shallow)
Salix cinerea & Betula
D
A HORIZONTAL SCALE ---- CHAINS
VERTICAL SCALE ----- INCHES
DITCHES — D
B HORIZONTAL SCALE ---- CHAINS
VERTICAL SCALE ----- INCHES AS ABOVE
0 yds. 2 4 6 8 10 12 14 16 18 20 1ch.
0 25 50 75 100
0 yds. 2 4 6 8 10½ 1ch.
B
Frost Hollow
Height of frosted trees adjacent to those shown
Frost misshapen plants
Non-peaty Aira, Holcus, etc.
Calluna Aira Flexuosa etc.
Scirpus-Calluna
Ericaceous Heath - much Sphagnum
Molinia with Erica Tetralix Myrica Gale Calluna
Badly drained Hollow Sphagnum in mounds
Eriophorum Vaginatum & Molinia
Flush Molinia, washed from non-peaty soil adjacent
Salix cinerea
Transition Molinia upon Sphagnum papillosum
Sphagna with Eriophorum polystachion

SKETCH V



(Marginal figures = height of trees in feet.
–.–.–.–encloses areas under strong shade.
Mosses are indicated where they predominate in ground flora)

QUADRAT A



(Boundary between areas fairly strongly and slightly shaded shown thus–·–···–)

QUADRAT B

APPENDIX V

Bibliographical Notes

Works of a general character to which reference has been made or to which attention may be directed are :—

HARDY, MARCEL. *Esquisse de la geographie et de la vegetation des Highlands d'Ecosse.*

TANSLEY. *Types of British Vegetation.* Cambridge, 1911.

For the principles of soil classification :—

RAMANN, E. *Bodenkunde.* Berlin, 1911.

RAMANN, E. (Trans. G. L. Whittles.) *Evolution and Classification of Soils.* Cambridge, 1928.

GLINKA, K. *Typen der Bodenbildung.* Berlin, 1913.

For the principles of peat classification and differentiation :—

WEBER, C. A. *Die wichtigsten Humus-und Torf-arten.* Berlin, 1908.

POST, L. VON. *Torvslag och Torvmarkstyper.* Stockholm, 1921.

SERNANDER, R. *Vara Torfmossar.* Stockholm, 1916.

DACHNOWSKI, A. P. *Peat Deposits in the United States.* (Soil Science, 10.) 1920.

Recent publications upon peat in this country have been few in number and have not, as a rule, had much bearing upon the subject-matter of this paper. The pioneer works of AITON—*Origin, Qualities and Cultivation of Moss Earth* (Glasgow, 1805), and of RENNIE—*On Peat Moss* (Edinburgh, 1807-10), although useful in indicating the cultural practice of that time, have mainly a historical value. Research in this country upon moorland (of sufficient definition to be helpful) is summed up in Tansley's *Types of British Vegetation*, and is illustrated by such papers as :—

PETHYBRIDGE and PRAEGER. *The Vegetation of the District lying south of Dublin.* ('Pro. R. Irish Acad.,' 1905.)

MOSS, C. E. *The Peat Moors of the Pennines : their Age, Origin and Utilisation.* ('Geog. Journ.,' 1904.)

LEWIS,—. *The Plant Remains in the Scottish Peat Mosses.* ('Trans. R. Soc. Edinburgh,' XXVIII, *et seq.*)

Numerous descriptive works on peat have been isued from time to time from many Continental peat-research stations. Many of these have a purpose and orientation similar to this paper. Only a few typical examples need be named :—

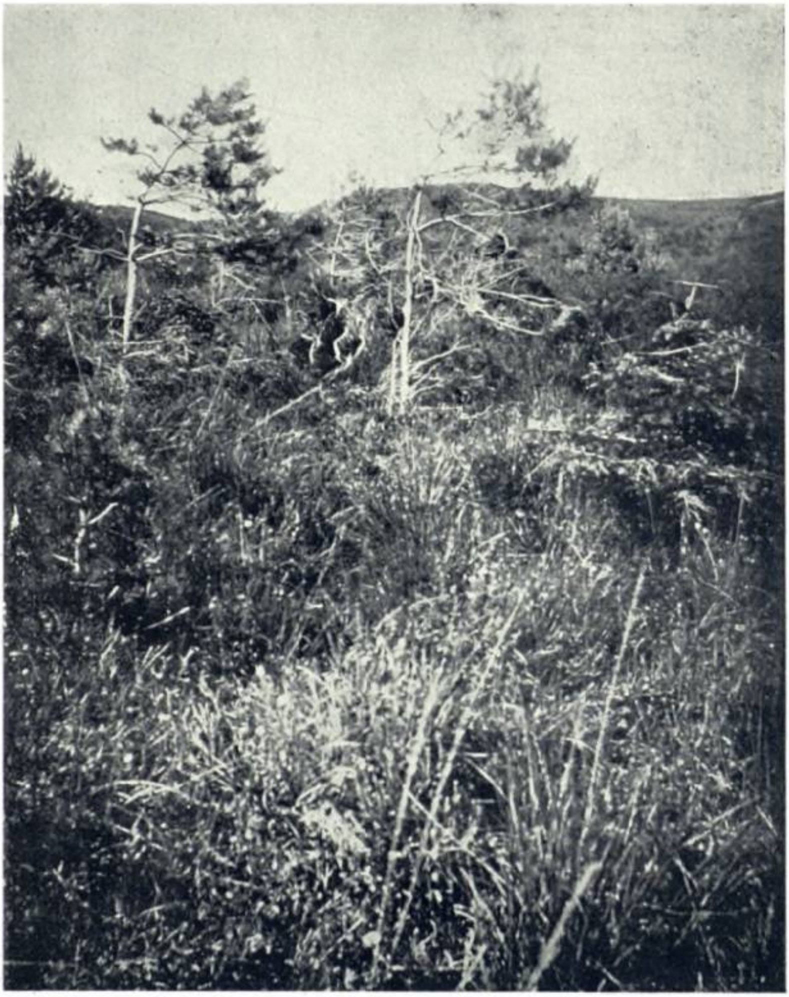
CAJANDER, A. K. *Studien uber die Moore Finnlands.* ('Acta. Forest. Fenn.'). Helsingfors, 1913.

FRUH, J., and SCHROTER, C. *Die Moore der Schweiz.* Bern, 1904.

POST, L. VON. *Uber stratigraphische zweigliederung schwedischer Hochmoore.* Stockholm, 1922.

DACHNOWSKI, A. P. *Peat Deposits of Ohio.* ('Ohio Geol. Survey Bul. 16.') 1912.

(1) The typical, loose mound-formation of *Sphagnum acutifolium* which develops on heath to moorland transitional types, especially when shelter is afforded by checked trees (here Scots pine). Calluna and sub-shrubs induce similar growth of sphagnum.

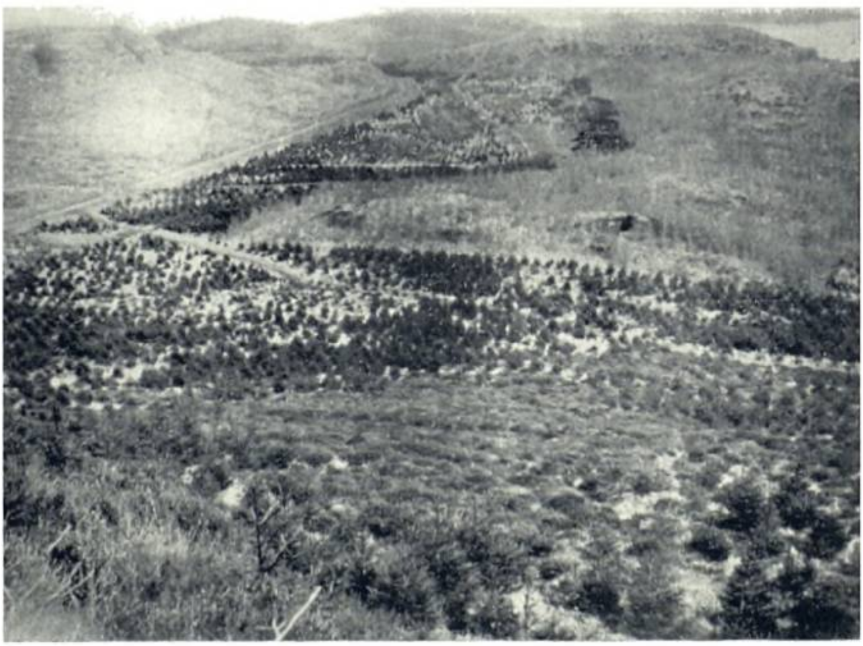


(2) Typical growth of Scots pine in moorland and sub-moorland conditions at Inverliever. Age 16 years. Vegetation *Eriophorum vaginatum* sub-flush with little *Molinia* and *Scirpus* and much *Erica tetralix*. The trees occupy a marginal position; the better plants appearing on the background are on a healthy drier ridge.

(3) A general view in the area investigated, looking north-east. The underlying peat of the valley bottom is Scirpus peat. Under the influence of the central ditch this is changing to Molinia and, especially toward the right centre of the photograph, better tree-growth is shown.

(4) Showing variation in growth of Common spruce which accompanies change from Molinia flush in the background to deep *Eriophorum vaginatum* (with Scirpus and Molinia) in the foreground ; in transition to Scirpus highmoor. Age of trees, 14 years.

(5) *Calluna-Eriophorum vaginatum*. The effect of fire. The dark foreground and the background show the normal appearance of the vegetation of "Highland" peat in the east of Scotland. The strip in the middle distance was burnt-over about three years before the photograph was taken, and shows the temporary dominance of *Eriophorum vaginatum*.



Heath grassland changing to moorland.
(6) The camera stands on grassy heath, and apart from semi-flush on the right hand of the foreground, there is shown the upward invasion of this by Scirpus-Calluna-Molinia; the middle distance is largely non-peaty (*Aira caespitosa*), but locally there is developed thin iron flush peat. The grass-heath to the left background is planted with larch, while in the centre is deep peat surrounded by a belt of flush Molinia. Age of trees, 9 years.

(7) A general view looking E.N.E. from Dun Corrach showing the general contour in this area, with alternate ridges and valleys (white patches are snow). The lightest areas are Molinia flush with at least fair growth of spruces; the light grey ground is variable, but on slopes and hollows is mainly dominated by Scirpus and the Cotton-grasses with or without Molinia.

(8) Ungrazed Scirpus High-moor, changing to flush (with Molinia) in the foreground. The rate of growth of Mountain pine on such conditions is seen from the specimens scattered throughout. About 10 years old.

(9) Degenerate Scirpus High-moor. "Peat Hag" showing the typical border of *Rhacomitrium lanuginosum* and fairly well developed clumps of *Calluna*. In the floor of the hag in the foreground, short *Molinia* and *Eriophorum polystachion* upon fragmental peat is being quickly displaced by Calluna from the collapse of the hag wall near the camera.

(10) Typical tufted Molinia developed along with progressing Sitka spruce as a result of drainage and the shelter of adjacent trees.

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