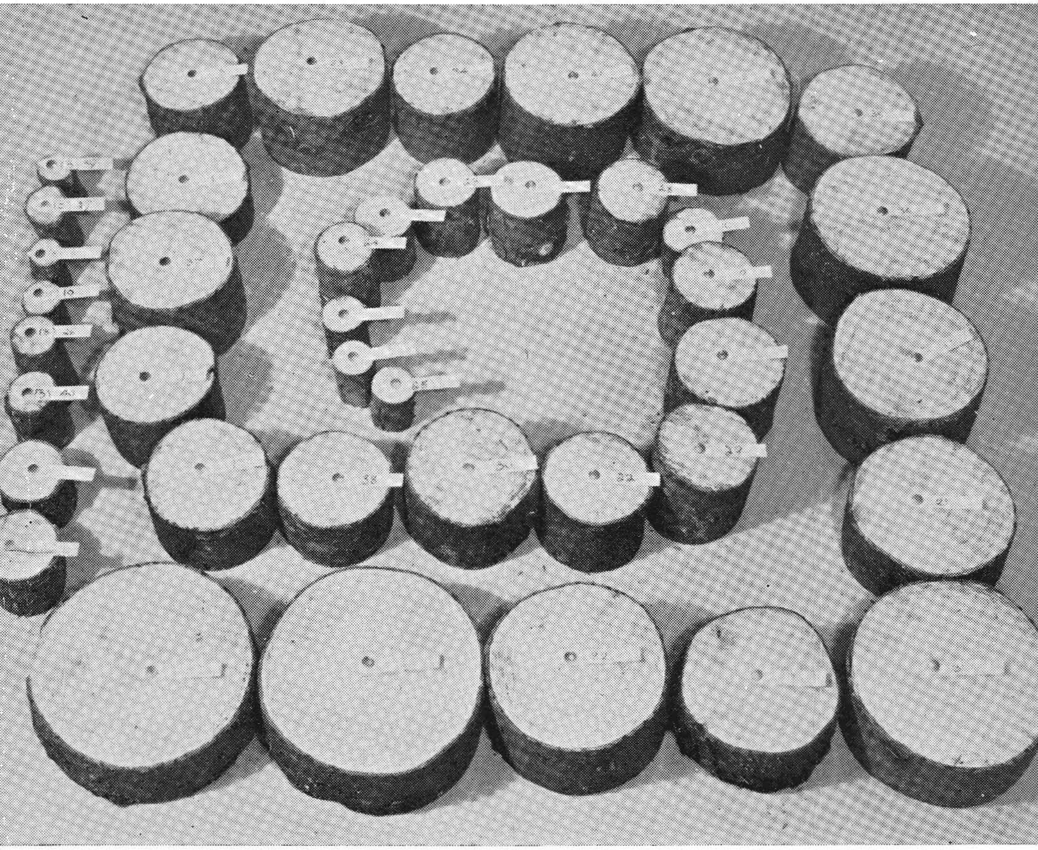

Journal of the Society
of Irish Foresters
Published Twice Yearly

IRISH FORESTRY

PEATLAND FORESTRY

Vol. XIX. No. 1 SPRING, 1962 7/6

CORRIGENDUM

In running title pages 33-55 for **Substitute** read **Substrate** where it occurs.

IRISH FORESTRY

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(The views expressed in the articles and notes in this journal are not necessarily the views of the Editor or of the Society of Irish Foresters.)

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IRISH FORESTRY

Volume XIX. SPRING, 1962 Number 1

Introduction

THE papers which follow were read at a symposium entitled 'Peatland Forestry', held in the Department of Extra-Mural Studies of the Queen's University of Belfast, on the 19th and 20th September, 1961. This symposium was the second of two such meetings which have been held in Belfast. In 1959 a course, originally designed simply to communicate to foresters in Northern Ireland the results of some ecological research carried out by the Botany Department of the University, was expanded to make it a comprehensive examination of the ecological basis for forestry in this country ('Forestry and the Land' Sept. 21-23, 1959). This course was attended by a large and representative body of those concerned with forestry in Ireland and it soon became clear that much of value to Irish Forestry might spring from such gatherings quite apart from anything which the formal programme had to offer. The 1961 symposium was arranged in response to many and repeated requests for another such meeting.

The particular objects of the symposium were to promote the exchange of ideas and information on the problems of peatland forestry, the research directed towards their solution, and the progress of peatland forestry in the British Isles. The contributors included three research officers representing the British Forestry Commission, the Forestry Division of the Irish Department of Lands, and the Forestry Division of the Northern Ireland Ministry of Agriculture. The seven remaining speakers were drawn from a number of research centres in Scotland and Ireland. Most of the papers have been revised for publication; some have been enlarged by the inclusion of additional material, some have been condensed and one appears in summary only as its substance is to be published elsewhere.

The administrative arrangements for both meetings were made by Mr. R. H. Semple, M.A., the Director of Extra-Mural Studies at the Queen's University of Belfast. Without his encouragement and active support the meetings would not have been held. His help, together with that of his staff, is most gratefully acknowledged. For the simultaneous publication of most of the papers under one cover we have to thank the Society of Irish Foresters.

R. E. PARKER.

The Problems of Peatland Forestry

An Introduction

R. E. PARKER,

Department of Botany, The Queen's University of Belfast.

I do not need to begin by persuading you that peatland forestry still has its problems. That so many of you have seen fit to attend this symposium is acknowledgment enough that there is a good deal about the growing and harvesting of trees on peat soils that we still have to learn. Forestry is a practical subject and its problems, in the first instance, are practical problems. They arise because of difficulties or failures in particular sets of circumstances and the form in which they are defined depends in part on the details of those circumstances and in part on the role and outlook of the persons recognizing them. For our present purpose we might consider separately the several practical problems which have arisen in the practice of peatland forestry but I am sure that satisfactory solutions to these problems will be arrived at all the sooner if we give priority at this stage to advancing our knowledge of the fundamental ecological relationships which lie at the roots not only of our failures but also of our successes. I propose therefore in this opening paper to consider the eco-systems with which we are dealing in the practice of peatland forestry in order to see if it is possible, on the basis of our present knowledge, to appreciate more fully the relationship between the practical problems already recognized and to anticipate some of the problems with which peatland forestry is likely to be faced in the future. In attempting the construction of a conceptual framework within which the practical problems might usefully be fitted I shall need to make some rather sweeping generalizations and to indulge in a certain amount of speculation. Since the more critical points which I shall make will be taken up and treated in greater detail in subsequent papers I shall not attempt here to indicate the source of all the information considered.

We have set ourselves during the next two days to deal specifically with peatland forestry so perhaps we should have at the outset some working definition of peatland itself. 'Peatland' is a term of convenience only with no generally accepted precise meaning. For survey purposes it has been found convenient to regard as peat soils those with a surface organic layer of more than twelve inches deep but I feel that we cannot expect the natural problems of peat soils to be bounded by such arbitrary limits. I would prefer to begin at any rate by defining peatland as land on which there is a superficial layer of organic matter within which the roots of the vegetation that it carries are entirely or almost entirely confined.

The problems which are encountered in attempts to grow tree crops on peat soils stem from the imperfections of the peatland environment which for the sake of convenience we might consider under two headings; firstly, the imperfections of the peat itself as a substrate for tree growth; and secondly, the imperfections of the climatic component of the environment. Let us first consider the edaphic limitations, those of the peat itself. The peculiarities of bog peat as a rooting medium for trees will be dealt with in some detail in several of the subsequent papers; what I would like to do here is simply to attempt a broad comparison between bog-peat soils and mineral soils to see if some hint emerges as to the main defect or defects of bog peats as forest soils. Perhaps the most striking point of contrast lies in the high organic matter content of the peats. This however would not appear to confer any serious disadvantage in itself if we may judge from the generally high fertility of drained fen peats. The quantitative comparison of peat soils and mineral soils is complicated by this great difference in organic matter content. The active constituents of mineral soils are diluted by large amounts of relatively inert mineral material and those of peat soils by large amounts of carbon-rich organic matter and water. In the face of these major differences comparisons of absolute amounts of the active constituents, e.g. available plant nutrients, are likely to be of less value than comparisons of ratios between them. Of the many ratios which might give a clue to the imperfections of acid peat soils perhaps the one most worthy of consideration is the carbon/nitrogen ratio of its organic matter. The C/N ratio for the organic matter of base-rich mineral soils in moist temperate regions is usually about 10. The humus of acid mineral soils such as podsols often has a value of about 20 but on sites showing unsatisfactory tree growth the ratio may be 30 and more. The ratio for bog peats varies a good deal from one peat type to another but it is usually more than 30 and values well above 40 have been reported. Under conditions of high C/N ratio, N and P are present mainly as complex organic compounds and are not readily available to the planted trees. The N and the P of the peat become available only through the activity of micro-organisms which bring about the decomposition of the organic matter and liberate these nutrient elements in much simpler molecular or ionic forms. Despite the physiological limitations which have been demonstrated for a number of known mycorrhizal fungi some of them at least may play a part in this process as well as the free-living micro-organisms. High values for the C/N ratio are associated with low concentrations of total N and total P. The primary reason for these low concentrations in peat is the low rate of organic matter decomposition. A higher rate of decomposition would increase the N and P percentage by bringing about a disproportionate loss of C as carbon dioxide. The low N percentage probably also results in part from the very low rate of nitrogen fixation. The total base content and the amounts of the individual bases present vary a good deal from one type of peat to another, particularly according to the extent to which the peat, during its growth, was influenced by mineral-rich drainage water. The ratios between the amounts of the individual bases present also vary a good deal, but comparisons between base-rich soils and bog peats show that for bog peats the following ratios are considerably higher:

$\frac{\text{monovalent bases}}{\text{divalent bases}}$, $\frac{Mg}{Ca}$, and $\frac{Na}{K}$. If we include in our comparisons the corresponding ratios for leached, acid, mineral soils we find that these like the C/N ratios, are generally intermediate, resembling those for the bog peats but rather less extreme. From these considerations we might expect acid bog peats to present similar problems for tree growth as do poor mineral soils but in a more acute form. In as much as peat soils are characterized by the marked accumulation of organic matter we might suspect the most acute problems to arise in connection with the availability of N and P.

We know that our planted trees will make considerable demands on the site for the several macro-nutrient elements N, P, K, Ca, and Mg. Although the initial requirements for Ca are low the long-term demands for this element are considerable because Ca to a greater extent than the others is immobilized in the wood. This tendency becomes particularly important where forest produce is removed from the site. The trees also require S, Fe, Mn, Zn, Cu, B, Mo and perhaps other elements in small quantities. How are these demands to be met? The peatlands most likely to present problems of nutrient supply would appear to be those least influenced by mineral-rich drainage water. It is these which have the very high C/N ratios, the lowest base contents, and the most extreme base ratios; so I think that an understanding of the nutrient economy of these sites both in their undrained state and when ploughed and planted with coniferous trees would be particularly valuable.

It now seems clear that the nutrient supply of the living vegetation of an ombrogenous bog is drawn from two different sources. One source is the atmosphere from which measurable amounts of nutrients arrive dissolved in the precipitation, as both organic and inorganic dust, and possibly also as gaseous ammonia. The other source is the peat and less thoroughly decomposed plant residues within the root range of the bog plants. Over a particular period the nutrients incorporated within the living plants will be in part nutrients freshly arrived from the atmosphere and in part nutrients which have already been incorporated within the living plants on the bog in a previous season or seasons. Not very much is yet known about the nutrient relationships of the individual bog species but it is clear that most of them can absorb nutrients from substrata in which they are present at high dilutions and concentrate them within their various organs. In our seasonal climate most bog species show a marked alternation between periods of growth and periods in which there is a reduction in the amount of living material above the surface. Some of the nutrients absorbed in a particular growing season are shed with the leaves and other parts lost in the following winter and are available for re-absorption by the roots of the same or of different plants during the next season. Some are retained within the perennating parts of the plants and re-cycled within the same plant during the next growing season. The combined effect of the reception of atmospheric nutrients at the bog surface, the re-cycling of nutrients between the plants and the peat surface, and the re-cycling of nutrients within the bog plants themselves is to concentrate the nutrients at the peat surface; in the living plants, in the litter, and in the surface peat. Profile analysis have repeatedly confirmed this generalization and shown that it applies particularly to K and P. Nutrients are lost from the system in two main ways. Some nutrient material is lost to the site altogether by being leached from the plants or from the peat and removed in drainage water. Still more is lost, to the living vegetation of the bog surface, by being built into the peat layer which because of further peat accumulation is passing out of root range.

What happens when the equilibrium of this system is disturbed by ploughing and tree planting? The draining and provision of an inverted peat ribbon enriched with a little mineral phosphate and a double layer of freshly dead vegetation give the planted trees an opportunity while they are still small and have poorly-developed root systems of competing on something like equal terms with the established bog species. After a few years of active growth the young trees, by shading and perhaps also by root competition, reduce the vigour of the bog plants around them and then kill them out. As the bog plants die and pass on to become 'organic matter' further supplies of nutrients become available to the trees, especially K and P. Peat accumulation ceases and the combined effects of drainage, transpiration of the stand, and tree root growth stimulate microbial activity and increase the rate of peat decomposition with further liberation of nutrients, particularly N and P. Practical experience is as yet too short for us to know and the relevant quantitative data is as yet too scanty for us to forecast with much confidence the long-term prospects of such a stand, but an optimistic account of their future might run as follows.

The continuing demands for nutrients made by the developing stand are met by further peat decomposition supplemented by the excess of the supply of atmospheric nutrients over the leaching losses. Additional N may become available through the fixation of atmospheric N. As the trees get older increasing quantities of nutrients are returned annually in needle and branch fall, branch rootlet renewal, and by crown leaching, to the peat surface where they are available for re-cycling. N, P, K and Ca are all involved in this process. Re-cycling of nutrients also takes place within the trees and with the gradual rise in proportion of wood to foliage, and with the initiation of heartwood formation, the importance of this internal re-cycling increases. In this process N, P, and K are again involved but the Ca which increases in concentration in the ageing timber is locked away until the tree itself in due course falls to decay on the forest floor. In this way, probably at about the stage of full crown development the overall annual nutrient requirement of the stand falls to a low level, low enough to be met by the annual supply of atmospheric nutrients together with any N fixation.

It would appear possible then that such a stand might be established on poor peatland and that it should maintain itself much as the native bog vegetation maintains itself by the concentration of the site nutrients at the surface and the continuous re-cycling of nutrients both within the plants themselves and between the plants and the peat surface. This is the most optimistic view and it requires some qualification before we leave it. Whether such a system as this could be established and maintained for a full rotation in the humid climate to which most of our peatland is subjected is very doubtful but if it could then it seems clear that it would be necessary to plant the most oligotrophic tree species available to us, namely lodgepole pine, a species which persists on undrained muskegs in Western North America. The quantitative data which we have already indicates that in such a system as we have envisaged tree growth rate would probably be severely limited by the supply of one or more nutrient elements, so it is possible that even though the trees might remain alive and continue to grow their growth rate would be very low. Our concept of the peatland forest self-maintaining in respect of nutrients takes no account of the removal of produce. Any nutrients removed in produce would have to be made good through the decomposition of more peat or through the addition of the appropriate minerals from outside. It is true that the deeper peats represent a considerable capital of plant nutrients but this capital is not easily realized. The N and P are only released on the decomposition of the peat itself. The basic nutrients are generally at very low concentrations as so for supplies to be maintained a very large volume of peat must be progressively exploited. It should be remembered here that these nutrients are not evenly distributed in depth. We have noted already how K and P in particular are markedly concentrated near the surface. Thus, continued exploitation of the peat in depth will not yield proportionate returns.

Peatland forests consist of more than peat and trees. There are clearly two other components of the ecosystem which are of major importance. One is the living vegetation of the bog surface which while alive provides both shelter and competition for the planted trees and when dead constitutes an important source of nutrients. The other is the microbial population of the peat itself through the agency of which all decomposition and nutrient release take place. Later contributions will illustrate the role of these in some detail; for the moment I should like simply to mention two particular kinds of interaction.

On many sites Sitka spruce passes into a state of 'check' a few years after planting. This condition has been attributed to N starvation, the result of unsuccessful competition with *Calluna*. It is true that *Calluna* where present in the original bog vegetation rapidly exploits the new rooting zone produced by ploughing, but whatever the role of *Calluna* here the trees are certainly N deficient. Although we know this, the problem of early 'check' of Sitka spruce is still with us. Top-dressing with nitrogenous materials alone has been disappointing, responses have been slight and short-lived. Our young peatland forest does not react as a simple two-phase system. It has been standard practice in some parts to apply repeated dressings of phosphate to checked spruce and this treatment has clearly not been without some effect. Recent work both here and in Scotland has shown that heavy dressings of phosphate to checked spruce not only produce a marked growth response but also an increase in the N content of the foliage. In short, nitrogenous materials alone do not effectively correct the trees' deficiency of N but heavy dressings of P do, giving the same response as combined dressings of N and P. Phosphatic materials then in some way increase the trees' uptake of N from the peat. We do not yet know whether the phosphate acts by stimulating the trees in some way or by promoting the activity of the peat micro-organisms, in either N fixation or peat decomposition. Culture work with spruce seedlings * recently carried out in Sweden has produced no evidence for an internal relationship between P and N levels which would explain the behaviour of the trees growing on peat. A worker in Germany has more recently found that the addition of phosphate to raw humus samples from poor pine and spruce stands results in an increase in microbial activity as indicated by increased carbon dioxide evolution. These observations give at least a little support to the suggestion put forward some years ago by Mr. McEvoy, and now generally subscribed to, that the P acts by promoting peat decomposition and N release. If this suggestion is correct we probably have peat soils in which the P level although not limiting the growth of the planted trees directly is doing so by limiting the activity of the soil micro-flora and thus keeping the trees' N supply at a deficiency level.

The disappointing results from top-dressing with nitrogenous materials and the prohibitive cost of heavy applications of either mineral phosphates or organic manures containing both N and P, has directed attention to the possibility of using the much cheaper ground limestone to accelerate peat decomposition with the more rapid release of N and perhaps also of P in available forms. At first sight this might appear to be just a simple extension of the practice, currently employed in Europe, of using lime to 'activate' the raw humus of acid mineral soils. Two liming experiments here in Northern Ireland have served to remind us that the results of liming on peat are far from simple. In one experiment Sitka spruce trees were limed (at 2½ tons of ground limestone per acre) at the time of planting in the Spring of 1957, the liming being in addition to a number of different N and P treatments. After three growing seasons a colour difference was apparent; the trees on the limed ground were a healthier green than those on the unlimed ground. This suggested a higher N level in their foliage and in turn more rapid mineralisation of the peat N. At the end of the fourth season measurements of current leader lengths revealed highly

* Norway spruce.

significant positive responses to liming, but only on the plots which had received no phosphate, i.e. 'Control' and 'Nitrogen only'. Lime had markedly reduced the 1960 growth when combined with several of the phosphate dressings. There is evidence here of increased N release but the response took several years to appear and was accompanied by an undesirable side effect.

Another trial involved a plantation which was growing on peat only about one foot deep and which at 18 years old had been brashed but not thinned. Ground limestone (at 2 tons per acre) was applied broadcast in the Spring of 1958. Diameter growth was followed by means of vernier bands and no growth response to liming has been detected even after four growing seasons. Needle samples were taken from branches of the topmost whorl in December 1960, three seasons after treatment. Analyses showed that the effect of liming had been to increase the Ca content of the foliage and to reduce the levels of the other cations, i.e. K, Mg, Na, and Mn. The mean N level in the foliage of the limed trees was also slightly lower but the difference was not significant at the 5% level. It is clear however that the lime did have some effect on the activity of the microbial population of the peat. In Spring the peat surface of the limed area becomes soft and appears highly humified but in Autumn it becomes densely felted with abundant basidiomycete mycelium. It is very conspicuous also that within the limed area the *Lactarius* sp. which is the apparent mycorrhizal associate of the spruce in the planation very rarely forms sporophores. Several workers in the last few years have confirmed by the experimental incubation of peats and raw humus materials with lime that lime does stimulate microbial activity and bring about a narrowing of the C/N ratio but these changes are not always accompanied by an increase in the mineralisation of N. There may be losses of ammonia gas, or of gaseous N resulting from denitrification, but one thing seems clear, that the addition of lime to organic materials of high C/N ratio is likely to be followed by a protracted period during which the N remains unavailable to the rooted plants because it has been incorporated within the protoplasm of the expanded microbial population.

We have so far been concerned mainly with the ability of poor peat soils to provide the nutrients necessary for continued tree growth and have seen that a great deal depends on the establishment and maintenance of conditions which favour the decomposition of organic matter. Another approach to the problem of nutrient supply is at least theoretically possible. The absolute amounts of nutrients required by forest crops are relatively small and it might be considered worthwhile to supply these in fertilizer applications, regarding the peat, more or less, as an inert rooting medium. Unfortunately although generally poor in available plant nutrients the peat soil and the native vegetation which it carries, as some of our examples have shown, are far from inert and one cannot ensure that the addition of an element in available form to the peat-forest system will result in the passage of that element into the growing trees when and where it is required.

We have seen how the most important chemical inadequacy of bog peat lies in its poverty of available plant nutrients and you will be aware that in looking for tree species for planting on poor peatland sites consideration is given to the tolerance of different species for low nutrient levels. Perhaps the most important physical defects of peats are related to their very high water content. We might expect therefore to see trees planted which are tolerant of water-logged soils. In practice we don't, another approach is adopted, that of lowering the water content of the peat by drainage operations and thereby increasing its oxygen content. Peats vary a great deal in their response to these operations. It seems that at one extreme we have the coarsely fibrous, very slightly humified *Sphagnum* peats, from which a good deal of water actually runs when drainage channels are first cut. At the other extreme we have the several kinds of more highly humified peat which are highly colloidal and jelly-like in nature. In these drainage operations would seem to act mainly by facilitating the shedding of subsequent precipitation, the actual lowering of the water content of the peat being due directly to surface evaporation and transpiration of the rooted vegetation. The physical condition of the peat is of direct importance to growing trees in two ways. The degree to which drainage operations succeed in converting the peat into a porous aerated mass determines the extent of root penetration, and this in turn determines both the volume of peat which the tree roots can exploit for nutrients and it also determines, to a considerable extent, the stability of the growing trees. Perhaps these points are best illustrated by means of two examples.

During the last few years in Northern Ireland we have had the opportunity of studying the results of draining and planting a number of very wet ombrogenous bogs. These sites have included areas which before draining carried a mosaic of moss hummocks and pools of open water or were wet flats with *Trichophorum, Narthecium,* and *Eriophorum vaginatum* rooted in an almost continuous *Sphagnum* carpet. The earliest plantings on such sites were of lodgepole pine alone but in areas more recently drained Sitka spruce has also been tried. Great changes have taken place; the peat has drained readily and growth even of the spruce has been remarkably good. The root systems of the trees are exceptionally well developed and there are obvious signs of nutrient release. The *E. vaginatum* and *Narthecium* have responded with a great increase in vigour and the *Narthecium* has flowered profusely; here and there thriving plants of *Holcus lanatus* (Yorkshire Fog) and of *Chamaenerion angustifolium* (Fireweed) have appeared. What will be the fate of these plantations? At the moment they are flourishing and perhaps with some attention to the main drains as the surface peat consolidates they will continue to thrive. There are several reasons however why we should not take this outcome for granted. Incubation work with *Sphagnum* peats has demonstrated an early flush of N mineralization out of proportion to their low N percentage. Evidently it is to this and to the physical conditions which allow them to exploiit rapidly an unusually large volume of peat that the planted trees are responding. It is difficult to see how these relatively favourable conditions can be maintained. Precocious root growth must surely advance the onset of inter-tree competition and early N release leave the substrate in the long run all the more N deficient.

At the other end of the peatland spectrum we have the more highly humified flush peats, often rather shallow, and usually considerably enriched with bases and with P by the passage of water which has had access to the sub-soil or rock below. These sites too show a marked response to draining; the vegetation exhibits a great flush of growth which is no doubt associated with a release of nutrients. If the trees escape being swamped by rank grass in their first few years they grow well and continue to do so for several decades. Although the short-term effects of drainage and tree planting on the physical properties of peat are rather variable the long-term effect seems always to be much the same. The rapid growth of the trees is associated with continued decomposition of the peat and the formation of an amorphous black residue. After about twenty-five years or so the main tree roots lie exposed on the peat surface and the maximum rooting depth is reduced to a few inches. The amorphous peat residue erodes very easily, on flat sites it tends to accumulate in the drains and cause general water-logging and on slopes to be washed away altogether. The trees naturally become very susceptible to windthrow, and it is not surprising that the gales of the last few years have taken a heavy toll of such plantations. In plantations which do remain standing it is often possible to detect a marked falling off in height growth rate. The deterioration in the physical condition of their rooting medium may be thought enough to account for this but we now know for one such site that in addition the levels of N, P, and K in the peat residue are very low indeed. It would seem then that except for a period of a few years we cannot have the best of both worlds; we can either have a rooting medium which is physically favourable but which cannot continue to provide an adequate nutrient supply or we can have a medium in which continuous decomposition provides the nutrients but at the same time destroys the peat itself as a suitable rooting medium.

The climatic limitations of the peatland environment are naturally less specific than the edaphic ones; after all, peat soils and mineral soils occur side by side in the same climate. Peatland forests however are particularly susceptible to adverse climatic conditions because of their peculiar soils. The blanket peat areas, whether they are on the hills or along our western sea-board are subject to frequent gale-force winds. One could scarcely argue 'a priori' that peatland forests must be more susceptible to wind damage than those established on mineral soils in the same climate. In fact the reverse has been argued for Western North America. But it does seem that the methods of site preparation, establishment, and thinning used to date have not been particularly successful in establishing wind-firm plantations. Present practice is directed mainly towards the creation of a crop in which the trees are individually wind-firm. Perhaps some fresh thinking is required here. It may be better to accept very shallow rooting as inevitable and plan for collective stability of the crop based on the strength and resilience of the intact tree root mat. We might be wiser to plan for a short rotation, to plant at wide spacing, not to thin, and to put up with rough produce.

We have seen that for the afforestation of peatland to succeed conditions which favour decomposition of the peat must be established and maintained. In this connection it is as well to remember that the very existence of peat on a site indicates that in the past over a very long period of time the rate of organic matter production exceeded that of its decomposition. Afforestation then must succeed in reversing this tendency. In dry climates peat formation is closely related to drainage impedance but in the 'blanket-bog climate' of our hills and Western seaboard it is largely independent of it. We can expect therefore that under these wetter conditions drainage operations alone might fail to halt peat formation and that greater efforts might be required to tip the scales in favour of decomposition. There is a good deal of evidence that this is indeed so. We have considered how a slow-growing plantation of an oligotrophic free species might be established on poor peatland and maintain itself on the supply of atmospheric nutrients. The indications are however that this would not be possible in the extremely humid climate of our blanket bogs. In many of our peatland plantations, planted without ploughing between 20 and 30 years ago there are many patches ranging from a few hundred square yards to several acres in extent on which the growth of the trees has been greatly retarded. The most extreme condition is represented by trees a few feet high growing only an inch or so a year. These trees typically stand among tall *Calluna* which being ungrazed and unburned for several decades is 'leggy' and forms an incomplete canopy. In the partial shade cast by the *Calluna* and the stunted trees there are accumulating large hummocks of several *Sphagnum* species. Quite clearly hand draining and turf planting have failed here to tip the scales in favour of organic matter decomposition. Surrounding each of these acutely retarded patches there is usually a zone in which the trees have become established and have grown well enough to have been brashed and even thinned. Here there has been a period of complete elimination of the bog vegetation followed by some peat decomposition, but with increasing light intensity resulting from the forestry operations, or as on many sites simply by precocious needle fall, fresh vegetation is developing on the forest floor. Unlike the cover of grasses, ferns, and brambles which develops under vigorous stands planted on base-rich flush peats and moist mineral soils the new vegetation of this marginal zone consists of rapidly growing mounds of *Sphagnum* often set in a thick spongy carpet formed by several pleurocarpous mosses. Apart from any active role which the *Sphagnum* may have in suffocating the tree roots or interrupting the vital nutrient cycle of the stand its presence is certainly symptomatic of a return to conditions of organic matter accumulation.

We have seen how the acid peat of our bogs is poor raw material for a forest soil and we have seen how the windiness and wetness of our climate only serve to make more difficult the satisfactory establishment and maintenance of forest growth on our peatlands. Most of us however would probably agree that the barren peatlands present to us a challenge which must be answered. On exactly how it should be answered in terms of both practical forestry and of research there is still room for much difference of opinion, and I expect we shall be made well aware of this before the close of this symposium.

The Indicator Value of Vegetation in relation to the Afforestation of Peatland in Northern Ireland

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Introduction.

Peatland in Ireland can be classified into two major groups, Raised bog and Blanket bog; the latter can be further subdivided into low-level and high-level bog, depending on altitude (Barry, 1954). Afforestation of the peatland has been concentrated mainly on areas of blanket bog; in Northern Ireland it has been restricted almost entirely to hill blanket bog (Parkin, 1957) but, in the Republic of Ireland, large areas of low-level bog in the West have been acquired and are being planted (McEvoy, 1954).

Within these two categories of blanket bog, any further subdivision for afforestation purposes must be based on more detailed and precise characters than those on which the original grouping was based. For obvious reasons, the most reliable index of site potential for tree growth is the performance of trees actually growing on the site in question, or at least one very similar to it. Unfortunately, owing to the recent date of most planting on blanket bog, this approach is of little value. Of the limited number of other site characteristics available, the one most used in the past, and that used in current forestry practice, is the vegetation of the site prior to planting (Anderson, 1961; Fraser, 1933; Gimmingham, 1949; Parkin, 1957).

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* Now, Chemical Research Division, N.I. Ministry of Agriculture.

Factors Affecting the Indicator Value of Peatland Vegetation.

The use of vegetation as an index of the potential of peatland for afforesation involves at least three basic assumptions, namely:—

(1) That peatland vegetation can be described and classified accurately.

(2) That the distribution of peatland vegetation types is related to variation in environmental factors, and that differences in vegetation can thus be used to indicate consistent differences in environmental factors.

(3) That the differences in environmental factors thus indicated can be measured and are significant for tree growth.

In the first part of this paper, some of the principles underlying these assumptions and some of the factors qualifying their acceptance are discussed briefly; in the second part a summary of the results of an investigation dealing with the relation between the vegetation and nutrient content of peatland in Northern Ireland will be presented.

1. *Description and Classification of Peatland Vegetation.*

A criticism often levelled against the use of vegetation as an index of site conditions is that the high level of human interference so modifies the natural vegetation, that the description and subsequent classification of geographically separate areas of vegetation is practically meaningless. This argument has force when the areas concerned have been subjected to essentially different types, or degrees, of human interference. Owing to the poverty of unfertilized peatland, however, its ability to support sustained grazing is severely restricted, and most areas of peatland in Ireland support a uniformly low density of grazing animals. Since the intensity of burning is related to the grazing density, this factor, too, varies little between different areas. The effects of interference on areas of similar vegetation, then, can be regarded as being relatively uniform throughout fairly large regions. Interference is an important factor in modifying peatland vegetation, and must be recognized as such, but it does not invalidate its description and classification.

From the descriptive point of view, interference introduces a complication, but one which can be surmounted without undue trouble. Its most serious effects will be discussed later.

A further difficulty in describing and classifying vegetation arises from the fact that many natural plant communities do not have sharp, well-defined boundaries. More often, the transition between communities is gradual, the variation between them in many cases being continuous. This is particularly true of peatland vegetation with its small flora. Only along lines of flushing is peatland vegetation generally sharply contrasted.

In attempting to describe and classify peatland vegetation, the obvious and most fruitful approach is to concentrate initially on those types of vegetation which show the greatest floristic uniformity throughout the region being studied. Thus, within a region, a number of discrete vegetation types, each readily definable by reference to actual uniform areas, or stands, of vegetation in the field, are recognized, and studied in detail. Types intermediate between the recognized types are noted but not investigated fully. Although the total area occupied by the intermediate types may equal, or even exceed, the area occupied by the main types recognized, their exclusion from the initial classification is justified by the fact that their floristic compostion is so variable that they cannot be adequately defined, nor, therefore, classified. The study of the main recognized types, however, forms the basis of a framework within which the intermediate vegetation types can later be fitted.

It will be noted that in such a scheme of classification there is only one unit—the vegetation type or noda (Poore, 1955). No attempt is made at this stage to establish a hierarchical system of classification.

2. *Relationship between Peatland Vegetation and Environment.*

The vegetation occupying a site is determined by the interaction between the environment of that site and the tolerances of the species capable of reaching it. In general, when the environment changes to the extent that it lies outside the range of tolerance of the species present the specific composition of the vegetation will change. This change in vegetation following change in environmental factors is the principle underlying the use of vegetation as an indicator of environmental conditions. Unfortunately several factors modify, to a greater or less degree, the straightforward plant-environment response.

The effect of such factors is to complicate the use of vegetation as an index of site potential and some of the more important will be discussed below.

(a) *Interference.*

Interference, in addition to being an important factor affecting the classification of peatland vegetation, modifies the relation between peatland vegetation and its environment. However, as has already been mentioned, interference can be regarded as a factor common to similar vegetation types within relatively large areas, so that, other things being equal, similar environments within an area will support similar vegetation types. Different vegetation types, of course, are not subjected to the same degree of interference. The degree of interference depends to a great extent on the 'palatability' and inflammability of the vegetation. *Juncus*—grass flushes are subject to a much greater degree of interference than the poorer *Trichophorum—Calluna* vegetation types; the important point is that the grazing intensity on, for example, *Juncus*—grass flushes is uniform over wide areas, and, therefore, that interference does not disturb the equilibrium between vegetation and environment in different areas.

Probably the most apparent effect of interference on peatland vegetation is the reduction in the total number of plant species. In areas subject to frequent interference, species susceptible to grazing and fire damage are gradually eliminated. The vegetation of the area is then composed of a relatively small number of interference-resistant species, with the result that although there may be little change in the environments of the different sites in the area, the vegetation on them will have changed. In particular the differences between the vegetation on the separate sites will be smaller due to the fewer number of species occupying the same range of site conditions. This effect is made more apparent by the fact that many of the species which are sensitive to environmental change are among those which are lost by interference. Thus, the effect of continued interference with the vegetation of an area is to impair the precision with which vegetation can be expected to indicate changes in environmental conditions.

Although small differences in environmental conditions may not be apparent from the vegetation, larger differences, e.g. those which evoke a response from the less sensitive species, will still be indicated. Although the precision of the method is reduced, its reliability would be affected only if interference had the effect of causing a similar vegetation to develop on basically different sites or *vice versa*. Fortunately there is no indication of this.

It cannot be expected, of course, that the vegetation occupying a site immediately after a major disturbance such as fire, ploughing, fertilization, etc. will provide a reliable indication of the more typical environmental conditions of that site; rather will the vegetation reflect the effect of the recent interference. Such relatively short-term changes in vegetation can be misleading, but fortunately the effects of a recent major interference of the type indicated are easily recognized, and the significance of the subsequent vegetation changes can be interpreted in the light of this knowledge.

(b) *Tolerance of Species.*

The importance of strain or ecotypic differences in forest trees (*Pinus contorta* is an excellent example) in their response to environmental factors has long been realized. It is now known that different ecotypes of a species, e.g. *P. contorta,* will behave quite differently in the same environment. That similar genetic differences do not exist in very tolerant species such as *Calluna* etc. is difficult to believe. Unfortunately it is not at present possible to recognize the different ecotypes of the common native species but until this is remedied the indicator value of such species must remain low.

(c) *Migration Barriers.*

It is perhaps a platitude to state that plants can only grow on a site if first their seed or other means of dispersal can reach it. The existence of barriers to species migration, however, often imposes strict limitations on the actual flora of a region and, although two sites in separate areas may be essentially similar, the vegetation on them may be different owing to the inability of the same species to reach both. Such limitations are unlikely to affect the flora of Irish peatland, but migration barriers such as the English and Irish Channels have undoubtedly had an historical influence on Irish vegetation.

The time required for species migration must be taken into account when considering sudden short term changes in vegetation, e.g. the changes following ploughing and fertilization of different areas, and in studying the colonization of newly-exposed bare ground. For this reason, the absence of a species should not, in itself, be used to evaluate site conditions.

(d) *Compensation Effect.*

The phenomenon by which one factor of the environment apparently compensates for other factors, and can allow a species to exist in an environment normally thought outside its range of tolerance for these factors, has an important bearing on the environmental response of certain species. A compensation effect is often apparent in the extension of a species into an apparently unsuitable climatic region owing to its occurrence on a base rich parent material. Similarly, the altitudinal zonation of vegetation is often modified by compensating edaphic factors.

The occurrence of *Schoenus nigricans,* which is restricted to base rich sites in England and Continental Europe, on the ombrogenous bogs in West Ireland has been quoted as an example of mild climatic factors compensating for adverse edaphic conditions (Bellamy, 1959; Gorham, 1953). The mechanism of this apparent compensation is still in doubt but the mildness of the climate and the high base saturation of the peat, caused by the high salt content of the atmosphere, have both been suggested as causes, and probably both are involved.

The difference in nutrient status of the peat supporting *S. nigricans* in the extreme west and in Loch Navar forest in County Fermanagh might be given as an illustration of compensation and of the dangers inherent in the use of a single species as an indicator of site conditions. At Loch Navar, *Schoenus* is restricted entirely to Ca-rich flush sites, whereas in Mayo it occurs on the open bog plane. The figures shown below indicate the magnitude of the difference in nutrient content, and thus potential for tree growth, between the two areas.

Comparison of Nutrient Status of Typical *Schoenus nigricans* sites in Co. Mayo and in the Lough Navar Area of Co. Fermanagh.

		Total Ion Content (mgs./100 gs. dry wt.)				
Location	*pH*	*Na*	*K*	*Ca*	*P*	*Fe*
* Glenamoy, Co. Mayo (Profile 1)	4.6	58.0	50.0	78.0	22.0	37.0
* Glenamoy (Profile 2)	4.8	80.0	44.0	82.0	18.0	70.0
† L. Navar, Fermanagh	4.6	24.2	62.0	1,301.5	46.7	1,501.3

* The figures from Glenamoy are due to Walsh & Barry (1958).

† The figures from L. Navar represent the mean values from 15 sites.

(e) *Inertial Effect.*

A time lag always occurs between change in environmental conditions and response of vegetation. With some species this interval is greatly extended so that they sometimes continue to exist on a site long after conditions have ceased to be optimal, or indeed 'normal' for their growth. In the sequence of bog development from eutrophic to oligotrophic conditions certain species, e.g. *Phragmites communis* and some *Carex* species, which are characteristic of the early nutrient-rich conditions, occasionally persist through to the later stages of development under a quite different nutrient regime. In such a case the depauperate condition of the persisting species and the vegetation associated with them usually prevents a wrong conclusion about site conditions being drawn from their presence.

Owing to its nature, the relation between peat and the vegetation it supports is very close in certain respects. In contrast with mineral soils, the nutrient status of peat, except where it is influenced by mineral-rich flush water, is largely determined by the mineral constitution of the plants growing on it, and of those which have contributed to its accumulation. The physical characteristics of the peat are similarly conditioned by the vegetation. Several workers have recently shown that the plants growing on peat concentrate and retain large amounts, relative, that is, to the amounts in the peat, of mineral elements within their structure (Goodman and Perkins, 1959; Malmer, 1958; Newbould, 1960). This retention is most marked for the elements Potassium and Phosphorus. Owing to this reservoir of nutrients embodied in the vegetation it would seem useful to regard the peat and its associated vegetation as a unit when considering the nutrient status of peatland in relation to afforestation.

3. *Tree Growth in Relation to Vegetation Type.*

The growth of trees on different vegetation types can be expected to vary in response to two distinct sets of factors—those caused by the direct action of the vegetation *per se* and those environmental factors causing the distribution in the vegetation types, i.e. the factors indicated by the vegetation.

Of the direct effects of the vegetation, one of the more important is undoubtedly the effect of competition between the native vegetation and the trees, although other factors such as litter toxicity, different rhizophere populations etc. must all be considered. Elucidation of the mechanism of this competition effect is not yet complete, but it has been shown that competition for nutrients, in particular for Nitrogen, is a very important aspect (Leyton, 1954; Weatherall, 1953). In this context, the specific composition and degree of vigour of the vegetation must be determined in assessing the potential of the site for tree growth. *Calluna* is one of the more aggressive species in this respect, and its relative abundance and vitality can be critical in the early stages of tree growth.

A vigorous and highly competitive native vegetation may be the most important single factor in the establishment of trees on certain sites, but the relatively poor growth of trees may not be an accurate reflection of the ability of the site to sustain timber production once the competitive effect is overcome. For instance, early tree growth on sites poor in nutrients may be better, due primarily to the absence of vegetation competition, than on sites with a more adequate nutrient supply but more vigorous vegetation. In later years, of course, the position will be reversed.

Since the environment of a site is holocoenotic and reacts as a complex, integrated system, vegetation should strictly be used as an indicator of total environment, not as an idicator of particular, arbitrarily selected factors (of the environment). From this, it is apparent that the only logically correct method of using vegetation as an indicator of site potential for tree growth is to relate the growth of trees directly to vegetation type, i.e. to record the growth of trees on the different vegetation types. Such a method obviously demands long term investigation. It is possible, however, to as it were, short-cut this procedure by relating vegetation to specific environmental factors which are thought to be significant for tree growth on deep peat.

It is now quite clear that the factors of greatest significance to initial tree growth on deep peat are:—

(a) Competition from the native vegetation.

(b) Deficiency of mineral nutrients, particularly Phosphorus.

(c) Deficiency of aeration resulting from excess water.

Any investigation of the indicator value of peatland vegetation should, therefore, be directed towards establishing an association between the vegetation types recognized and those environmental factors indicated.

The results of such an investigation are presented in the second half of this paper.

Relationship between vegetation and peat nutrient content in certain forest areas in Northern Ireland.

During the last few years, an investigation into the relation between vegetation and nutrient content of the peat from certain areas of peatland in the course of afforestation has been carried out by members of the Botany Department of Queen's University, Belfast. Of the forest areas studied, two, Beaghs and Ballypatrick, are situated in North Antrim and one, Lough Navar, is in South-West Fermanagh. All three occur on deep peat.

The classification of the vegetation was based on the detailed examination and description of small areas, or stands, located within the main vegetation types recognized. Transitional types were noted but not examined in detail. At each site described, samples of the peat from immediately below the litter layer were collected and taken back to the laboratory for chemical analysis. In this way, it was hoped to determine some of the factors governing the distribution of vegetation types, and to investigate the value of vegetation in indicating site potential for tree growth.

The detailed results will not be presented here, but some of the conclusions may be of interest.

Altogether, a total of ten distinct vegetation types were recognized in the three areas. Initially, the types were classified into the categories A, B and C depending on whether they occurred on unflushed, slightly flushed or strongly flushed sites. It became apparent later, however, that, although the distinction between unflushed and strongly flushed sites was real, those peats thought to be slightly flushed showed relatively little difference from certain of the unflushed types. Due to the nature of flushing, however, it is very difficult to establish the importance of its influence except when the flushing water is richly charged with mineral ions. When the peat is influenced by flush water of relatively low mineral content, analysis of a sample collected at a particular point in time will not indicate any enrichment effect, even though this weak solution may have an important influence on the nutrient economy on the site over an extended period of time. Thus, despite the fact that the analyses give little indication of it, it is possible that some of the B types benefit from a slight flushing influence.

One fact that the results indicate is that, in general, there is no close correlation between peatland vegetation and the total nutrient content of underlying peat, except in those sites influenced by mineral rich flush water. This is not altogether unexpected, since even if the distribution of vegetation is controlled by the nutritional status of the peat, the availability, rather than the total conent, of nutrients will be the determining influence. This was realised at the outset of the investigation but there are several reasons for determining total nutrient content. In the first place, the concept of "availability" of nutrients was developed mainly in relation to agricultral practices on mineral soils. It has been found over a long period of trial and error, that a rough estimate of the amounts of nutrients which can be utilised by agricultural crops can be obtained by leaching the soil with various reagents and determining the amounts of nutrient elements removed in the leachate. This fraction is classified as 'available'. The method, although giving satisfactory results in practice, is entirely empirical and bears no direct relation to the actual nutrient uptake of the plants.

The relation between the total and available fractions of the nutrient content of peat, however, is much more complicated and the methods used in agriculture are of limited direct value. We know so little of the nutrient release in peat and of the uptake of nutrients by bog plants and trees that a great deal of fundamental research is required before predictions about the relative amounts of total and available nutrients in peat can safely be made. Further, with the establishment of forest conditions and the anticipated decomposition of the upper layers of peat, the total nutrients in the peat may well eventually become available to the trees and thus, in the long term, be the more fundamental criterion of site fertility.

Vegetation and Nutrient Content of Hill Blanket Bog in Northern Ireland.

Despite a general lack of positive correlation between vegetation and total nutrient content of the underlying peat, it is possible to distinguish three broad categories of hill blanket bog between which the differences in total nutrient content are likely to be significant for tree growth.

These three categories of peatland are listed below, while the mean analytical data are presented in the accompanying table (Table 1). The figures in this table represent the mean values obtained for the peat underlying the different vegetation types in each category; the data from the three areas studied have been combined in one overall mean.

Basic Categories of Blanket Bog in Northern Ireland.

A. Areas of very wet, unflushed peat occurring on flat, slightly convex or gently sloping ground.

B. Areas of drier, possibly slightly flushed peat occurring on moderate—fairly steep slopes.

C. Areas of peat strongly flushed with mineral-rich water of telluric origin.

Table I.

Mean Analytical Data relating to Peat from Different Categories

			Mean Ion Content (mgs./100 gs. dry wt.)				
Category	%M	pH	Na	K	Ca	P	Fe
A	90.02	3.37	30.53	26.64	142.27	31.69	88.78
B	89.14	3.18	31.03	28.64	188.41	61.50	140.42
C	84.09	4.62	29.06	72.86	843.28	78.79	2,224.28
Lon Mor	—	—	24.5	42.00	162.5	66.25	—

An interesting comparison can be drawn between the figures shown above for the total ion content of the main categories of blanket bog in Northern Ireland and those quoted by Binns (Binns, 1959) for the Lon Mor experimental area in Inverness-shire. This area is one of the British Forestry's Commission's main centres of experimental work on peatland afforestation and was originally selected as an area of typical deep basin peat of the poorest type. The figures in the last line of Table I. are the mean total ion contents (mgs./100 gs. dry wt.) of the upper six inch layer of an area of unplanted peat adjacent to one of the early F.C. experiments (Exp. 47. P. 28). The high total content of Potassium and Phosphorous in relation to the total content of Irish blanket bog might lead one to expect slightly different responses in this country.

Rather than give complete lists of the species occurring in the vegetation types recognised in the different categories of peatland only the more conspicuous, or those with some special indicator value will be mentioned. The effects of burning and grazing on the specific composition of the types will also be dealt with. The mean values of total ion content of the corresponding peat types are shown, for each type and area separately, in Table II.

Table II.

Mean Results of Analytical Data for Peat from Different Vegetation Types

(Total Ion Content (mgs./100 gs. dry wt.)

Area	Type	pH	M%	Na	K	Ca	P	Fe
Ballypatrick	A2	3.15	91.5	25.71	18.37	129.80	20.08	82.10
	A3	3.18	87.5	33.20	30.69	165.22	56.76	100.64
	A4	3.14	89.13	32.48	21.68	166.11	51.47	103.29
	B1	3.13	89.71	37.10	27.79	176.44	73.24	110.50
Beaghs	A2	3.20	91.64	31.05	20.98	136.80	30.90	124.50
	A3	3.00	89.08	26.28	20.88	190.08	51.16	103.18
	A5	3.15	89.46	29.00	26.50	161.90	46.39	120.66
	B1	2.98	89.69	29.07	29.86	132.31	94.74	148.66
	C1	4.88	80.86	30.57	60.60	679.00	108.40	3,576.30
L. Navar	A1	3.42	88.21	31.75	33.42	161.89	35.07	83.51
	A2	3.72	88.74	33.62	33.80	140.61	40.73	65.00
	B3	3.72	89.38	30.12	43.09	326.83	56.76	295.99
	C1	4.39	83.81	32.42	95.99	549.31	81.23	1,595.23
	C3	4.60	87.59	24.20	62.02	1,301.54	46.74	1,501.30

Category A.

The vegetation characteristic of this category can be divided into two distinct types, separated on a vegetation basis by the relative abundance of *Trichophorum caespitosum,* and on a physical basis by differences in microtopography.

The first type, A1, is one of the most difficult sites to afforest successfully, due both to its poverty of nutrients and to its physical condition. The type occurs on peatland familiarly known as 'quaking bog' or one of the slightly drier phases of this bog type. It is well represented in all three areas studied, although at L. Navar it reaches its greatest development on the flatter areas just outside the forest boundary. A large part of the plateau on the east block of Beaghs forest is occupied by vegetation of this type, which, as a rule, occurs on flat or slightly convex ground. The surface shows a characteristic microtopography of alternating hummocks and hollows, the latter often filled with water, sometimes to a considerable depth. The vegetation forms a mosaic pattern related to the hummocks on which *Calluna, Erica tetralix, Trichophorum* and the small-leaved *Sphagnum* species are prominent. Round the edges of the pools and in the shallower hollows *Eriophorum vaginatum, Narthecium ossifragum, Menyanthes trifoliata* and the submerged and large-leaved *Sphagnums* are the most conspicuous species.

Owing to its extreme wetness this vegetation is seldom burned in its natural state but treading, especially by cattle, can cause damage to the peat structure resulting in a drying out of the surface and increased risk of fire damage. The effects of grazing are seldom severe.

As has been indicated, this type has a very low potential for tree growth but, if the temporary abandonment of an occasional tractor is accepted, and the areas drained, satisfactory growth should be possible given heavy, and probably repeated, application of fertilizer.

The other main vegetation type in this first category is dominated by *Trichophorum* and has been designated A2. The actual cover of *Trichophorum* on any one site is variable, and seems to depend on the wetness of the site and its past history of burning. Several species of *Sphagnum* are often very conspiuous and other associated species are *Eriophorum angustifolium, Erica tetralix* and *Narthecium. Calluna* is nearly always present, but not in a vigorous condition.

Repeated burning of this type appears to lead to the elimination of the *Calluna* and *Erica tetralix* and the establisment of a type of vegetation composed almost entirely of *Trichophorum* and a thick mat of *Sphagnum* species. Grazing seems to have a slight effect. *Carex panicea* is found in this type at L. Navar where it seems to become more conspicuous after interference, an observation which has also been reported for a different type of vegetation (Asprey, 1947). This species is not found in the same vegetation type at either of the North Antrim areas.

The nutrient content of this type is again very low, but the early growth of fertilized trees has so far been promising. This is probably due in some measure to the lack of competition from the native vegetation and it must remain doubtful if the peat is capable of supplying the nutrients required for a complete rotation.

It is interesting to note that the total nutrient content of the peat from both the vegetation types in this first category is considerably lower than the peat from the Lon Mor which Dr. Binns found so deficient after only thirty years of tree growth. Although there is not much difference between the values of Calcium for the two areas, the mean values of Potassium and Phosphorus on a dry weight basis for the Ulster blanket bog are approximately half those of the Lon Mor peat (Table I). Thus it appears certain that supplementary fertilization of the areas in this category will be necessary to secure even one rotation.

Category B.

The second category of peatland bears a number of very diverse types of vegetation. Broadly speaking, however, they can be distinguished by the relative abundance of three species—*Calluna, Eriophorum vaginatum* and *Molinia caerulea.*

The types dominated by Calluna reach their greatest development on the peats of North Antrim. At L. Naver, *Calluna* occurs in a dominant role only on the relatively freely drained, shallow peat on the top of escarpments. *Eriophorum vaginatum* also shows a greater vigour in the drier Antrim areas, but to a lesser degree than *Calluna,* while *Molinia* displays the opposite tendency, being decidedly more vigorous in Fermanagh. Whether this geographic distinction is due to climatic or geological factors cannot yet be confirmed, but probably both factors are involved.

At Ballypatrick and Beaghs the vegetation in which *Calluna* is the dominant species occupies a large area. In the type designated A3, *Calluna* occurs as a strong, bushy plant with a high degree of cover. *Eriophorum vaginatum* is a constant associate, single shoots often protruding above the *Calluna* canopy. *Erica tetralix, Empetrum nigrum, Vaccinium myrtillus* and *Deschampsia flexuosa,* along with *Potentilla erecta* and many of the common hypnaceous mosses are usually conspicuous. *Sphagnum rubellum* and *S. plumulosum* are almost always present, but only become conspicuous when the *Calluna* becomes old and degenerate so allowing a higher light intensity below its canopy.

The factor most likely to limit tree growth on this type is competition from the vegetation, especially for Nitrogen, rather than any nutrient deficiency in the peat.

The M% of the peat is low, the mean of the two Antrim areas being 88.3%. There is very little evidence to suggest that this type is influenced by flushing, in fact the opposite appears to be the case, the vegetation being most vigorous on the tops of ridges and similar situations where drainage is free. From this, it would seem that adequate aeration is the factor primarily controlling the distribution of this type of vegetation. The A3 type does not occur at L. Navar.

The effects of grazing alone are not severe, but burning leads to a radical change in the vegetation, the general effect resulting in a decrease in the dominance of *Calluna* and a consequent increase in the associated species, particularly *Eriophorum vaginatum* and, in certain cases *Trichophorum.*

Several variants of the type occur, and the transition between it and the previously described *Trichophorum* type seems to be continuous. *Eriophorum angustifolium* becomes more conspicuous on the wetter areas and this particular variant has been typified as A4 and A5 at Ballypatrick and Beaghs respectively. The nutrient content of these types is very similar to that of the A3 type and the presence of *Eriophorum angustifolium* does not seem to indicate any particular nutrient conditions, but probably reflects an increased wetness of the site.

Another type found only in the North Antrim areas is that in which *Eriophorum vaginatum* assumes a dominant role. In this type, B1, *E. vaginatum* occurs in tall, dense clumps. The distance between the clumps is variable and seems to be related to the intensity of sheep grazing and treading. Where this is low, the clumps are almost contiguous and the *E. vaginatum* cover consequently high. Associated species are *Calluna* and other Ericaceous species, *Deschampsia flexuosa, Anthoxanthum odoratum* and the herbs *Potentilla erecta and Galium palustre*. High grazing intensity leads to the development of a type of vegetation in which the clumps occur some distance apart. In such areas the proportion of mosses increases, *Polytrichum commune* and several *Sphagnum* species often becoming very conspicuous.

Burning leads to an increase in the dominance of *E. vaginatum* at the expense of the associated species. The relation between burning and the occurrence of the *Eriophorum* dominated and *Calluna* dominated types is obscure, but in intermediate types in which the species are co-dominant, burning appears to lead to the elimination of the *Calluna* and to the formation of a typical B1 type with a high *Eriophorum* dominance. Whether this is an irreversible change is not known.

Tree growth on this type has so far been satisfactory. Its nutrient content is similar to the A3 type except that the Phosphorus content is considerably higher. This latter effect is probably due to the retention of Phosphorus by the *Eriophorum* and its subsequent gradual release, but typical B1 sites may also benefit from a slight flushing influence. Competition between the trees and vegetation is less severe than in the *Calluna* types.

The type of vegetation in which *Molinia* is the most conspicuous species, the B3 type, is confined mainly to L. Navar, although a similar vegetation occurs at a few sites at Beaghs. The *Molinia* is usually accompanied by *Eriophorum vaginatum, E. angustifolium, Calluna* and *Erica tetralix. Carex panicea is* often present and again seems to increase with the severity of grazing and trampling. *Myrica gale* is found occasionally in this type but, although it has been stated that this species is a good indicator of nutrient rich conditions, the data from the Navar samples do not support this contention in that the sites on which it occurs are no richer than the other B3 sites. There may, however, be a flush influence at the sites on which *Myrica* occurs. Two species found, rather unexpectedly, in this type are *Trichophorum* and *Narthecium*. Both are present, however, in an unusually vigorous condition, due, presumably, to the higher nutrient conditions than those under which they are usually found.

The effects of burning and grazing do not appear to be severe and are reflected in the relative abundance of *Carex panicea*.

The Calcium and Iron content of peat from this type is higher than the corresponding types at Ballypatrick and Beaghs, but the content of Phosphorus is lower. Tree growth should be satisfactory.

These three vegetation types, then, form a group whose nutrient content is intermediate between the very poor *Trichophorum/Sphagnum* peat and the nutrient-rich flush peats now to be described. The variation in the vegetation of the group is fairly wide, but most intermediate types can be referred to one of those described above and their potential estimated accordingly.

Although it has been indicated that the types differ with regard to their total content of the various nutrient elements, it seems unlikely, in view of the amounts of the same elements applied as fertilizer, that the differences will be significant for early tree growth. Certain of the differences, however, are statistically significant and may be important during the later life of the tree crop. This may be so with the higher Phosphorus content of the B1 type and the high Calcium content of L. Navar types dominated by *Molinia.*

Category C.

The heavily flushed peats are very different from those already described. This applies equally to their vegetation and chemical characters. The vegetation types in this category found on deep peat are those dominated respectively by *Juncus acutiflorus,* type C1 and *Schoenus nigricans,* type C3. Communities dominated by *Juncus effusus* occur on peat, but usually only where there is an appreciable admixture of mineral particles and the peat is shallow.

These extreme flush types are so readily recognized in the field, and so different chemically from the other types that, despite considerable differences between them, they will be dealt with as a single group.

To illustrate the magnitude of the differences between these and the other peat types some results from the figures of mean total nutrient content shown in Table II. may be quoted. The value for Calcium, for instance, is over ten times greater in the *Schoenus* type than in the A2 *Trichophorum* type and the mean value for Iron is over twenty times that for an unflushed type. Potassium content is two or three times as high in the *Juncus* and *Schoenus* flush types as in most of the others. Only the Phosphorus content fails to show such extreme differences. In the *Juncus* type it is higher than in any other, but the mean Phosphorus content of fifteen *Schoenus* samples is lower than the means of the three peat types in the intermediate category of peat. This fact may be very important for the growth of trees on *Schoenus* type peats, especially in view of the very high Iron content of the peat. Another noticeable feature of the nutrient content of these flush peats is the significantly higher Calcium content of the *Schoenus* as opposed to *Juncus* types.

Apart from the dominants, the species composition of the two types is similar. One very obvious point of difference, however, is the much higher density of vegetation in the *Juncus* type. Consequently, the associated species in the *Schoenus* type are more conspicuous. The common associates of both types are *Molinia, Calluna, Succissa pratensis* and *Prunella vulgaris,* the two latter species being found mainly at L. Navar. The grasses *Deschampsia flexuosa, Anthoxanthum odoratum* and *Holcus lanatus* are commonly present. The moss *Breutelia chryso-*

coma, a recognized indicator of base rich conditions, is found in both types at L. Navar but does not occur in the Antrim areas.

Schoenus nigricans does not occur either at Beaghs or Ballypatrick.

Neither type suffers greatly from burning and grazing. Although the intensity of grazing is as high as on any other type, its effects are not apparent due, presumably, to the fact that the fertility of the site allows the vegetation to recover quickly from grazing damage.

As far as tree growth on the flush types is concerned, the only nutrient element likely to be limiting is Phosphorus. This is particularly true of the *Schoenus* type and fertilization may not overcome this limitation. Owing to the very high Iron content of the peat, the formation of complex Ferro-phosphate compounds may fix the Phosphorus in a form unavailable to the trees.

The competitive effect of *Juncus* and its associated species can complicate the establishment and restrict the early growth of the trees, but, once this is overcome, growth should be good provided an adequate source of available Phosphorus is present.

Peatland Vegetation as a Source of Nutrients.

In view of the peculiar importance of the vegetation in the nutrient economy of peatland, it was decided to investigate certain aspects of the chemical composition of peatland vegetation. The entire aerial portion of the vegetation standing on 1 sq. m. at five sites located in each of the four main vegetation types at L. Navar was clipped and brought back to Belfast in large polythene bags. Separate whole plants were collected for root analysis. The clipping was done in August, i.e. at the time of greatest dry matter accumulation. In the laboratory, the vegetation was separated into species, dried and weighed prior to analysis.

The mean total dry weight varies from approximately 5,000 lbs./acre in the *Trichophorum* type to 9,000 lbs./acre in the *Juncus* type. The value for the *Schoenus* type is relatively low at 5,600 lbs./acre, while the average for the *Molinia* type is 8,000 lbs./acre. These figures may be more intelligible when expressed as being from 2½-4 tons per acre. A preliminary estimate of the dry weight of the *Calluna* dominated vegetation type at Ballypatrick is slightly over 10,000 lbs./acre.

Table III.

Nutrient Content of Four Site Types at Lough Navar, Co. Fermanagh

		Site content of total nutrients (Kgs./Ha.)				
Type	Component	Na	K	Ca	P	Fe
	Peat	43.76	43.52	184.85	53.77	85.01
A2	Shoots	4.81	19.09	11.71	2.44	1.24
	Roots	1.90	12.18	6.11	1.77	0.72
	TOTAL	50.47	74.79	202.67	57.98	86.97
	Peat	38.29	53.86	395.92	72.92	359.01
B3	Shoots	9.07	34.26	15.31	4.04	2.10
	Roots	1.77	31.36	7.60	2.59	0.61
	TOTAL	49.13	119.48	418.83	79.55	361.72
	Peat	57.72	219.36	786.85	147.39	3,795.90
C1	Shoots	25.51	42.68	23.92	6.45	1.17
	Roots	15.60	44.33	24.02	4.98	32.18
	TOTAL	98.83	306.37	834.79	158.82	3,829.25
	Peat	34.69	109.69	1,981.46	65.02	2,148.95
C3	Shoots	2.97	21.98	23.34	3.18	6.54
	Roots	3.41	28.94	19.37	3.19	1.59
	TOTAL	41.07	160.61	2,024.17	71.39	2,157.08

Samples of the vegetation from each type were analysed for total ion content, and the mean values of the nutrient content of both roots and shoots, expressed as Kgs./Ha. are presented in Table III; also included is the nutrient content of the corresponding peat type expressed as Kgs./Ha. to a depth of 10 cms. The total of these values provides an estimate of the Site Nutrient Content, i.e. the total amount of potentially available nutrients contained within the site at any one time. The amount of nutrients present in the site over a period of time will, of course, be greater than this due to the continual supply of nutrients supplied to the site via precipitation, flushing, air-borne particles, etc. and to any amounts added as fertilizer.

Unfortunately, complete results are not available for the North Antrim areas, but there is no reason to suppose that the relation between the nutrient content of the peat and vegetation will be essentially different from that shown for L. Navar forest.

The results in Table III illustrate the significance of the nutrients embodied in the vegetation for the initial growth of trees on peatland. Thus, the amounts of Potassium in the vegetation is approximately equal to the amounts in the upper 10 cms. of unflushed peat. Once canopy closure is attained and the vegetation suppressed, this supply of Potassium will be relatively easily available. Since trees growing on certain peats (Binns, 1959; Wright, 1959) have been shown to be deficient in Potassium content, the release of this element from the vegetation may be an important factor in determining the initial success of a tree crop on unflushed peat.

The amounts of the other elements in the vegetation, though comprising a smaller proportion of the total than Potassium, may be equally important in the early stages of tree growth, since the double layer of vegetation below the plough ribbon is one of the first sources of nutrients to be exploited by the developing tree roots.

It is thus apparent that the natural vegetation has a twofold effect on the establishment of trees on peat. In the first place, there is a direct competitive effect, both in the physical and nutritional sense, between the vegetation and the trees; this can be critical where species such as *Calluna* and *Juncus acutiflorus* are vigorous. Secondly, the nutrients embodied in the vegetation can, when they become available, provide a considerable stimulus to the growth of the trees.

An important source of nutrients available to trees growing on peat is that provided as fertilizer at time of planting. At the present rate of application in Northern Ireland (2 oz. basic slag/tree) the amounts applied are approximately 15-20 Kgs./Ha. of Phosphorus and 40-60 Kgs./Ha. of Calcium. One effect of this fertilization is that the magnitude of the differences between the nutrient content of the peat from different vegetation types becomes proportionately less. When comparing the values of nutrient content of different types this must be borne in mind, for, although the level of statistical significance will remain unaltered since the treatment is common to all types, the significance of relatively small differences to the trees will be reduced.

Summary and Conclusions.

In the first part of this paper, some of the considerations affecting the use of vegetation as an index of site potential for tree growth on peat are discussed. The second part deals with an investigation into the relationship between the vegetation and nutrient of the peat in three forest areas in Northern Ireland. From this, it seems that the peatland in Northern Ireland can be divided into three broad categories on the basis of vegetation and total nutrient content of the peat. The differences between these categories are likely to be significant for tree growth. Within each category, the establishment of trees and their early growth seems likely to be determined by the severity of the competition between the natural vegetation and the trees. From this aspect, successful establishment appears to be inversely proportional to the vigour of species such as *Calluna vulgaris.*

Although there is considerable variation in peat nutrient content

between the vegetation types in each category, this may not be significant for early tree growth in view of the relatively large amounts of nutrient elements supplied as fertilizer.

In view of the close connection between the vegetation and the peat in the nutrient economy of the site, it would seem useful to regard the two as a unit and to relate tree growth to this unit, i.e. to site, rather than peat, nutrient content.

Once the vegetation has been suppressed, satisfactory initial tree growth can be expected on all vegetation types, but supplementary fertilization may be necessary to secure economic timber production on certain of the poorer, unflushed types. On the strongly flushed *Juncus* and *Schoenus* types the very high Iron content may lead to a deficiency of available Phosphorus.

Acknowledgments.

The author wishes to thank the Forestry Division, Ministry of Agriculture, Northern Ireland for granting him a Research Studentship which allowed the work reported in this paper to be carried out and to express his gratitude to Mr. R. E. Parker for his help and guidance throughout the course of study and, especially, in the compilation of this report.

References.

Anderson, M. L., 1961. *The Selection of Tree Species.* 2nd Ed. Oliver & Boyd, Edinburgh.

Asprey, G. F., 1947. The vegetation of the islands of Canna and Sanday, Inverness-shire. *J. Ecol.* **34** : 182-93.

Barry, T. A., 1954. Some considerations affecting the classification of the bogs in Ireland and their peats. Intl. Peat Symp. Dublin, 1954. (in *Irish Forestry,* **11** : 48-64).

Binns, W. O., 1959. The physical and chemical properties of deep peat in relation to afforestation. Ph.D. Thesis, Univ. of Aberdeen.

Bellamy, D. J., 1959. Occurrence of *Schoenus nigricans* on ombrogenous peats. *Nature,* Lond. **184** : 1590-1.

Fraser, G. K., 1933. Studies of certain Scottish moorlands in relation to tree growth. *Bull. For. Comm.,* Lond. **15.**

Goodman, G. T. & Perkins, D. F., 1959. Mineral uptake and retention in cotton-grass. *Nature,* Lond. **184** : 467-68.

Gorham, E., 1953. A note on the acidity and base status of raised and blanket bogs. *J. Ecol.* **41** : 153-56.

Gimmingham, C. H., 1949. Vegetation as an indicator of conditions on hill-land in Scotland. *Scottish Forestry,* **3** (3).

Leyton, L., 1954. *Growth and mineral nutrition of spruce and pine in heathland plantations.* Inst. Pap. For. Inst. Oxf. 31.

McEvoy, T., 1954. Afforestation of peat soils. Intl. Peat Symp., Dublin, 1954. (in *Irish Forestry,* **11** : 65-75).

Malmer, N., 1958. Notes on the relation between the chemical composition of mire plants and peat. *Bot. Notiser,* **111** : 274-88.

Newbould, P. J., 1960. The ecology of Cranesmoor. A New Forest valley bog. *J. Ecology,* **48** : 361-83.

Parkin, K. F., 1957. Afforestation of peatlands in Northern Ireland. *Irish Forestry,* **14** : 111-117.

Poore, M. E. D., 1955. The use of phytosociological methods in ecological investigations. *J. Ecol.,* **43**.

Walsh, T. & Barry, T. A., 1958. The chemical composition of some Irish peats. Proc. *Roy. Irish Acad.,* **59** (B) : 305-28.

Weatherwell, J., 1953. The checking of forest trees by heather. *Forestry,* **26** : 37-40.

Wright, T. W., 1959. Use of fertilizers in the afforestation of deep peat. *J. Sci. Fd. Agric.,* **10** : 645-50.

Some aspects of Peat as a Substrate for Tree Growth

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Introduction.

EXPERIMENTAL work on the afforestation of peat in Britain, up to about 1952, showed that phosphatic fertilization and some form of ground preparation was essential or beneficial to most species on all but *Molinia caerulea* peats, though pines might grow without P on some *Calluna vulgaris* peats (Zehetmayr, 1954). Little response to other nutrients was recorded, probably because the trees were all very young and there were adequate supplies in the peat at that stage. As a result, foresters have tended to assume that nutrients other than P would be deficient only in exceptional cases, provided that the severe check that spruces often suffer on *Calluna* ground (presumed to be due largely to competition for nitrogen) is excluded. More recent work has shown that, in addition to deficiency of N and P, potassium deficiency has now been found in peat-grown trees in Britain (Wright, 1959).

On the other hand in agriculture, calcium, manganese, copper, boron, and molybdenum, in addition to N, P, and K, may be necessary for the establishment and growth of crops on deep blanket bog, although the nutrients which are deficient will vary from case to case. It would, therefore, be reasonable to anticipate that, as early plantations come into the pole stage and more difficult types of peat are ploughed and planted, deficiencies of other nutrients might be detected in trees.

In its most infertile form peat is little more than a rooting medium for trees, and it would seem wise to delimit, as soon as possible, those nutrients which will eventually have to be added to maintain satisfactory growth. The problem is thus to decide on a suitable way of investigating the potential fertility of peat for all the essential nutrients; this paper describes one approach and the work from which it has developed.

Investigations at Inchnacardoch Forest.

An investigation by Illingworth-Longbottom (1954), at Inchnacardoch Forest, suggested that basic slag applied to peat could still be detected 23 years afterwards where trees had failed, but not where they had grown well; he also observed that the acetic soluble P content of the peat was highest in the surface layers.

This work was followed up at the Lon Mor experimental area in Inchnacardoch Forest (cf Macdonald, 1945), where the changes in peat due to tree growth were examined in two experiments, 19 P.26 and 47 P.28, growing Scots pine (*Pinus silvestris* L.) and lodgepole pine (*Pinus contorta* Loudon) respectively, which had both been partially treated with basic slag or ground mineral phosphate (G.M.P.). Some figures for tree growth in these two experiments (Edwards, 1962) suggest that increment has fallen off appreciably in the last few years. The investigations on the peat showed that a number of physical and chemical changes had taken place (Binns, 1959). As regards chemical changes, total potassium and inorganic phosphorus contents in the upper layers of the peat were lower under lodgepole pine than in unplanted ground, while organic phosphorus, total nitrogen, calcium and magnesium contents were not significantly different; a similar, though less marked, relationship was found under Scots pine. These results suggest that the P readily available to trees is largely in inorganic form and, in view of decreasing increment, are suggestive of incipient if not actual P and K deficiency: the results of a PK trial on the lodgepole pine show however that only K was limiting growth at that stage (Binns, 1961).

It would, therefore, seem that, as removal of nutrients by the trees over a period of 30 years can be detected by relatively simple analytical techniques, the chemical composition of peat in other areas may be used to estimate site fertility for trees; the usefulness of this approach can then be judged by comparison with tree growth and responses to fertilizers.

Experimental.

Deep Peat Sites Selected for Sampling.

In addition to the Lon Mor, eleven sites from Cumberland to Caithness (Fig. 1) have been selected, and the top foot of the peat sampled in two-inch layers; samples of the natural vegetation have also been taken, except at Mounces. Sampling has been in rides and outside experiments or, in some cases, within young experiments. Details of the sites are given in Table I.

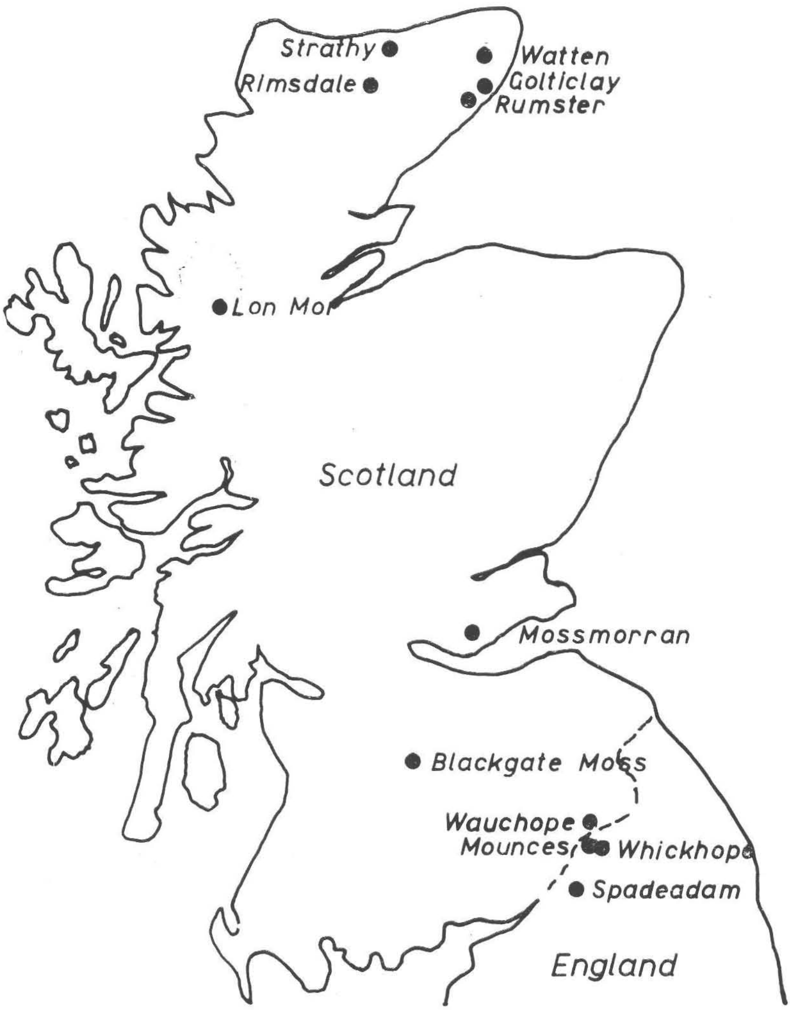

Fig. 1. Location of sites sampled.

TABLE I
Details of sites sampled

Site	Forest and use*	Type and depth of peat	Approx. area covered, acres	No. of profiles	Main plant species (excluding liverworts, and mosses other than *Sphagnum*)
Spadeadam, Cumberland.	Spadeadam, Experiments 1 and 2 P.56.	Raised bog, over 6 feet deep.	8	8	1. *Eriophorum vaginatum/Calluna*, some *Eriophorum angustifolium*, *Molinia* and *Sphagnum*. Now going to *Deschampsia flexuosa*. 2. *Trichophorum caespitosum/Calluna/Eriophorum/Sphagnum*, some *Erica tetralix* and *Narthecium ossifragum*. Now going to *Calluna*.
Whickhope, Northumberland	Kielder Forest, Compartments 158-160.	Flushed blanket bog, about 4 feet deep.	25	6	Pure *Molinia*.
Mounces, Northumberland	Kielder Forest, Experiment 73 P.54.	Blanket bog, $3\frac{1}{2}$ to 5 feet deep.	1	4	*Calluna/Eriophorum*, *Trichophorum* and *Sphagnum* frequent.
Wauchope, Roxburghshire	Experiments 4 P.53, 5 P.55, 6 P.55.	Raised bog over 6 feet deep (4 P.53), or $3\frac{1}{2}$ to 5 feet deep.	20	7	*Calluna/Trichophorum/Eriophorum*, some *Molinia* and *Erica*. *Deschampsia* in Expts. 5 and 6.
Blackgate Moss, Lanarkshire	Couthally Sect. Clydesdale Forest, Cpts. 1-10.	Raised bog, over 6 feet deep.	200	11	*Calluna/Eriophorum* with some *Juncus conglomeratus* and *Sphagnum*.
Mossmorran, Fifeshire	Blairadam Forest, Cullaloe No. 2, Cpts. 66-69.	Raised bog, over 6 feet deep.	150	9	*Calluna*, with *Eriophorum* and *Erica*.
Lon Mor, Inverness-shire	Inchnacardoch Forest, Experiments 19 P.26 and 47 P.28.	Basin and blanket bog, $1\frac{1}{2}$ to 4 feet deep.	2	16	*Calluna/Molinia/Erica*; frequent *Sphagnum*, some *Eriophorum*, *Narthecium* and *Myrica gale*.
Rumster, Caithness	Rumster Forest, Cpts. 4 and 5.	Flushed blanket or basin bog, over 6 feet deep.	20	6	*Calluna* with *Molinia*, *Sphagnum* and some *Deschampsia* and *Erica*.
Golticlay, Caithness	Rumster Forest, proposed acquisition.	Blanket bog, mostly over 6 feet deep.	over 1000†	10	*Calluna/Eriophorum/Trichophurum/Sphagnum* with *Eriophorum angustifolium*, *Narthecium*, *Erica*.
Watten, Caithness	D.O.A.S. farm block, with Forestry Commission Experiments.	Blanket bog, over 6 feet deep.	60†	6	*Calluna* with *Trichophurum*, *Sphagnum*, *Molinia* and some *Erica*.
Rimsdale, Sutherland	Pilot plot in Naver Forest.	Blanket bog, 2 to 6 feet deep.	60	9	*Calluna*, with *Trichophorum*, *Molinia*, *Sphagnum*, *Eriophorum*, and about 10 other species.
Strathy, Sutherland	Strathy Forest, experimental. sections I and II.	Blanket bog, $1\frac{1}{2}$ to 4 feet deep.	20	6	I. *Calluna/Trichophorum/Molinia* with *Erica tetralix* and *E. cinerea*. II. *Calluna/Molinia*, with *Erica tetralix*, *E. cinerea*. *Sphagnum*.

*All ground belongs to the Forestry Commission except Watten. †Part of the area on shallow peat has been omitted.

Of the six southern sites, four are very deep raised bogs, one, Mounces, is deep blanket bog, and one, Whickhope, a flushed *Molinia* peat. Of the six northern sites, two, Golticlay and Watten, are very deep blanket bog, three are deep blanket bog, and one, Rumster, is blanket or basin bog that has been extensively flushed. The terms "deep" and "very deep" are used here to differentiate between those sites where tree roots may reach the mineral soil in places, and those where they will probably never do so. At the time of acquisition all the sites except Whickhope and Mounces were considered poor, and either have been or will be given phosphate at time of planting; Sitka spruce [*Picea sitchensis* (Bong.) Carr.] would probably not now be planted pure on any of these ten sites, and its use in mixture with lodgepole pine is becoming less frequent. The sampling intensity varied in proportion to the area, being highest at the Lon Mor and lowest at Golticlay, and no attempt was made to get a constant intensity.

Although subjective estimates of the plant frequencies have been made at all sites except Mounces and Whickhope, the flora had apparently been altered by ploughing and application of phosphatic fertilizer in some cases, and by frequent burning and grazing in others, and it is therefore difficult to use the plant communities as indicators of site conditions. With draining, *Calluna* generally increases, and this has probably happened at most of the sites, except Golticlay, which is not yet drained or planted.

Analytical Methods.

(a) Peat Samples. All samples were oven-dried at 80° C., and, except for those from the Lon Mor (which were broken up and spread out to dry), were left during drying in the tins in which they were taken; this has probably resulted in loss of N. After drying and the determination of moisture content and dry weight per unit volume of wet peat, the samples were broken up and milled through a 2 mm. screen in a Christy-Norris Junior mill. Nitrogen was determined by the semi-micro Kjeldahl method. After ignition overnight at 470°-500° C., the ash was extracted with HCl and this extract was used for the following determinations: inorganic + organic P ($\approx$ total P except for peats with a high ash content) by the vanado-molybdate method (Hanson, 1950); total K, Ca and Na by the multichannel flame photometer (Ure, 1958) after removal of Al and P by complexing on an ion exchange resin in the citrate form (Riley, 1958; Binns, 1959); total Mg by the porous cup—spark method (Scott and Ure, 1958), and total Mn (six sites only) by a modified form of the tetrabase method (Nicholas and Fisher, 1950). Inorganic P was determined by the method of Saunders and Williams (1955) and organic P found by difference.

(b) Vegetation Samples. The methods used were the same as for the peat samples, except that only total P was determined, that P was

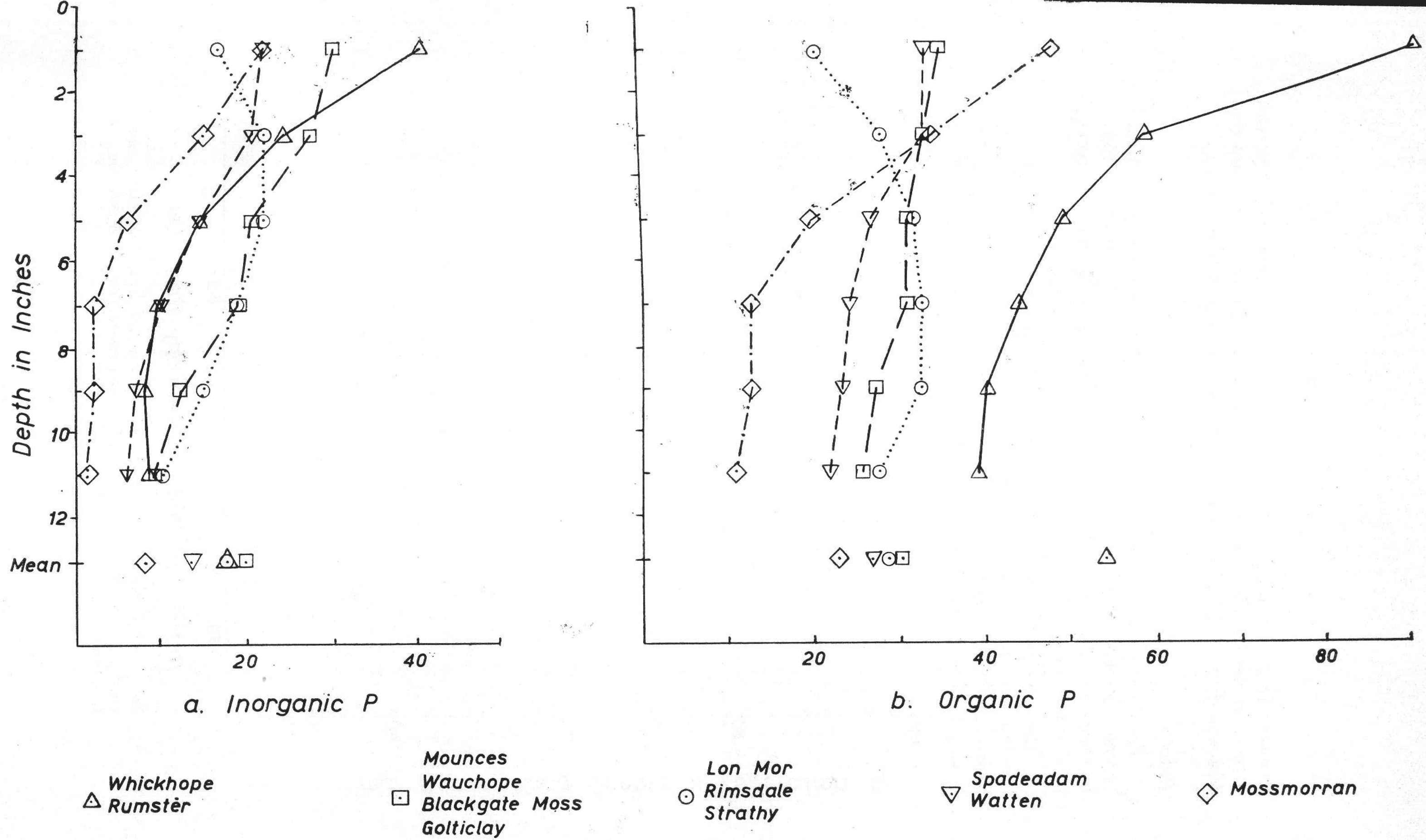

Fig. 2. Phosphorus content of peat (mg. P per 100g. oven dry peat).

removed from the solutions for flame photometry by ion exchange with a resin in the Cl form (Pinta and Bove, 1956; Binns, 1959), and that Mn was determined in the HCl extract by the periodate method.

Results.

Phosphorus. From the results in Figure 2 it is clear that the total P content decreases with depth at 9 out of the 12 sites, at three it increases and then decreases; the sites are grouped in order of average total P contents.

The sites in the first group have a high content of inorganic P in the top two inches, which then decreases rapidly; the second group shows moderate contents which fall fairly steadily, Blackgate Moss having a higher content than the others in this group, presumably due

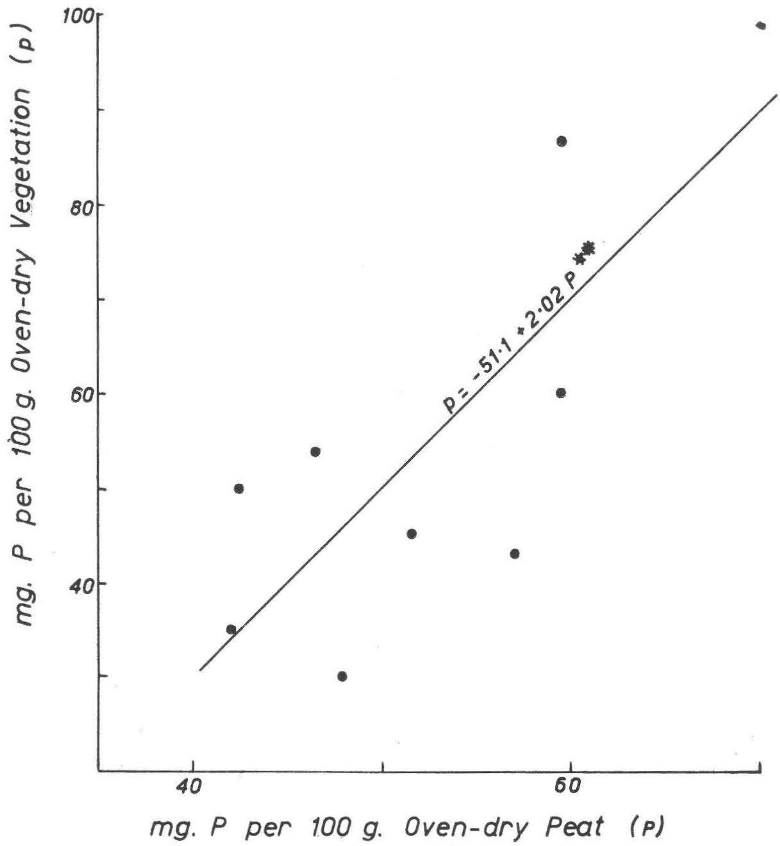

Fig. 3. Relationship between total phosphorus in 0-4 inch peat layer and in natural vegetation (9 sites, excluding Mounces, Whickthope, and Rumster).

to partial reclamation in the 1930's (Robertson, I. M., priv. comm.); the third group, the three northern deep blanket bogs, shows a slight rise followed by a fall; the fourth group shows still lower contents, which fall at about the same rate as the second group. The organic P contents follow the same trends as the inorganic P contents. However Mossmorran has a high content in the top two inches, and the first group maintains its superiority all the way down the profile, the reserves of slowly available P thus being substantially higher at the two sites in this group than at all the others.

The P content of the vegetation in general seems to be correlated with the inorganic and organic P content of the upper layers (though there were no vegetation samples from Mounces); eliminating the two flushed sites (Rumster and Whickhope) with high contents in the top layer, there is a fair correlation between the P in the 0-4″ layers and the total P in the vegetation (Figure 3). Though the regression is highly significant, the P content of the vegetation would only give a poor estimate of the content of the peat.

Potassium. For K contents the sites fall into four groups (Figure 4) but the arrangement is different from that for P contents. Three profiles at Golticlay have a very much higher K content than the rest, and are

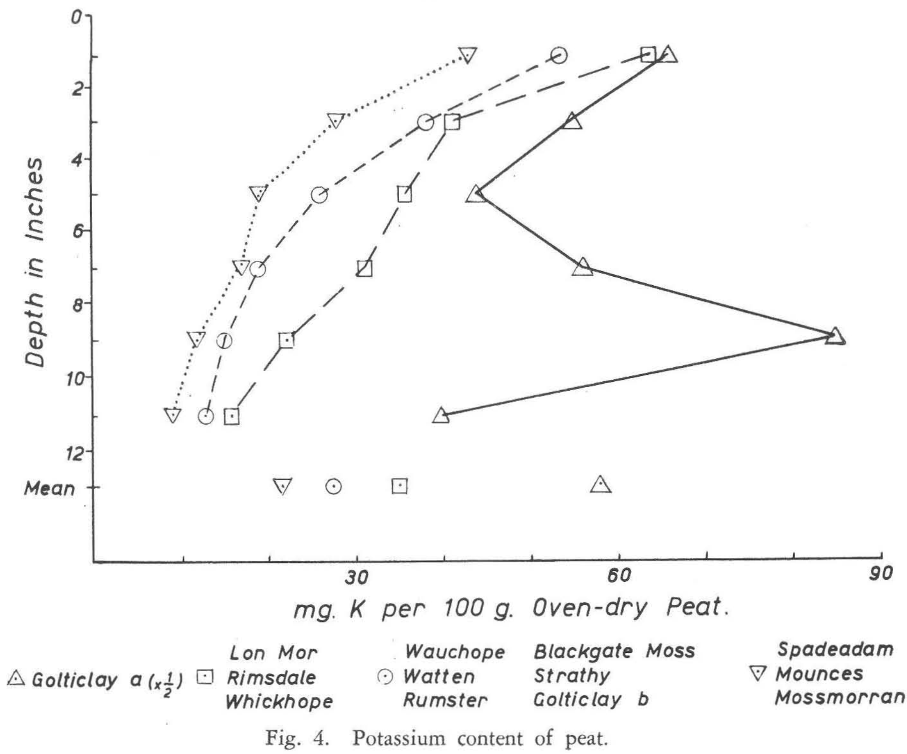

Fig. 4. Potassium content of peat.

shown separately; in all profiles other than these there is a rapid decrease in K content with depth. The Spadeadam samples represent two distinct sites (Table I), and the first has a higher K content in the peat and shows better tree growth than the second. The K content of the natural vegetation is two to five times that of the upper layers of the peat, but there seems to be no obvious correlation between the two.

Ash. The ash contents (Figure 5) fall into six groups, and if Figures 2 and 5 are compared it will be seen that, in general, ash and P contents have the same distribution at any one site, though there are large differences between sites; an exception is Whickhope, which has a high P content in the upper layers but only a moderate ash content.

Calcium, Magnesium and Manganese. Averaged values for all sites are shown in Table II. The Ca and Mg contents do not vary much down the profiles, and for most sites there is slightly more Ca in the vegetation than in the upper layers of the peat, while the Mg contents are about the same in the vegetation and the upper layers of the peat. Ca contents are higher at Blackgate Moss and lower at Wauchope and

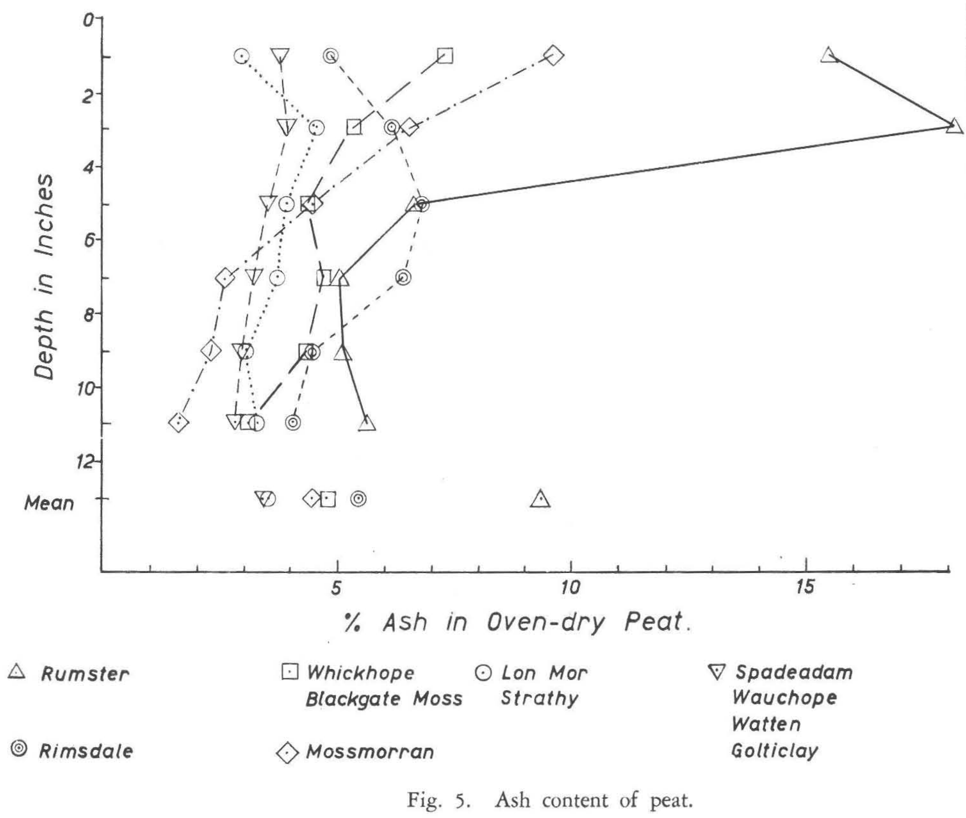

Fig. 5. Ash content of peat.

TABLE II

Amounts of Ca, Mg, and Mn in natural vegetation and peat, in mg./100g. dry matter, for the sites in Figure 1.

		Calcium		Magnesium		Manganese
		Blackgate Moss	All other sites	Watten and Strathy	All other sites	
Natural Vegetation*		265	200	125	90	27
Peat	0-2″	450	135	175	80	3.0†
	2-4″	405	130	150	80	1.8†
	4-6″	350	125	150	75	1.6†
	6-8″	310	135	160	75	1.4†
	8-10″	265	140	160	80	1.3†
	10-12″	220	145	160	80	1.2†
	Average	335	135	160	80	1.7†

* Values do not include Mounces.

† Values for Lon Mor, Watten, Strathy, Wauchope, Spadeadam, and Mounces only.

Mossmorran, and Mg contents lower at Mounces, Whickhope and Mossmorran, than at the other sites, but the Ca values at Blackgate Moss have presumably been affected by pre-war liming. Mn contents, where determined, show the same order of decrease with depth as K contents, and the content in the vegetation is about nine times that in the upper layers of the peat.

Nitrogen. The total N contents do not show much variation with depth, but there are considerable variations between sites. The average N content of the peat varies from 1.2 to 1.5% for the raised bogs, and from 1.6 to 2.4% for the other sites. At two of the four sites with average N contents of over 2% (Whickhope and Rumster) young Sitka spruce is, or until recently was, growing well, at another (Rimsdale) the experiments are still young, and at the Lon Mor the N values are probably not strictly comparable with the other sites because of the different method of drying the samples. At Mounces, where the N content of the peat averages 1.9%, the Sitka spruce have foliage N contents slightly over 1%, but are not in check. At Wauchope, however, where the average nitrogen content of the peat is 1.3%, the foliage nitrogen content of Sitka spruce has averaged between 1.0 and 1.5% over the last few years.

Thus, while high nitrogent contents in the peat may in some cases indicate a high nitrogen status, the converse may not be true, as most of the N in peat is in organic form, and largely unavailable: more important is the rate of mineralization, and although this is almost certainly related to the C/N ratio (e.g. Duchaufour and Mangenot, 1956) and therefore (in peat of low ash content) to the total N content itself, the method and intensity of ground preparation and the use of fertilizers seem to have an effect on this rate.

Nitrogen Mineralization.

The effect of ground preparation on nitrogen mineralization rates was seen in Experiment 4 P.53 at Wauchope, which was designed to test various ways of mixing several species of conifer with lodgepole pine. In this experiment alternate deep single mouldboard and shallow double mouldboard Cuthbertson ploughing were used, and in the second growing season trees on the deep ridges were growing up to 50% faster than trees on the shallow ridges; at first this was attributed to shelter. By 1957 however the trees were all well above the ridges, and as foliage N contents in the deep-ridge trees were higher than in the shallow-ridge trees in that autumn, samples of peat from the rooting zone (the "sandwich" layer) were taken at monthly intervals during 1958. Six pairs of samples were taken each month, three from among Sitka spruce and three from among lodgepole pine, each pair being on adjacent deep and shallow ridges. Seven adjacent sampling points along the ridges, midway between trees, were marked, and the pairs arranged in random order for monthly sampling. The ammonia- and nitrate-nitrogen contents were determined on the fresh samples, using the method of Bremner and Shaw (1955), and the moisture contents were also determined. The results are shown in Figure 6.

The values for NO_3-nitrogen were low and variable, being on average 1-2 mg. N/100g. dry peat. The NH_3-nitrogen content was significantly higher in the deep ridges in four out of the seven sets of samples, and the moisture content was higher in three sets of samples (the first set of samples for moisture determination was accidentally destroyed).

Foliage analysis and height measurements have been continued annually, and some of the results are shown in Figure 7. Each average is based on only three values, which gives a poor estimate of the variability, and statistical significance is not very meaningful. Differences between deep and shallow ridges for height increment and foliage N content have been decreasing year by year, while differences in foliage K content have been increasing, the deep-ridge trees containing *less*

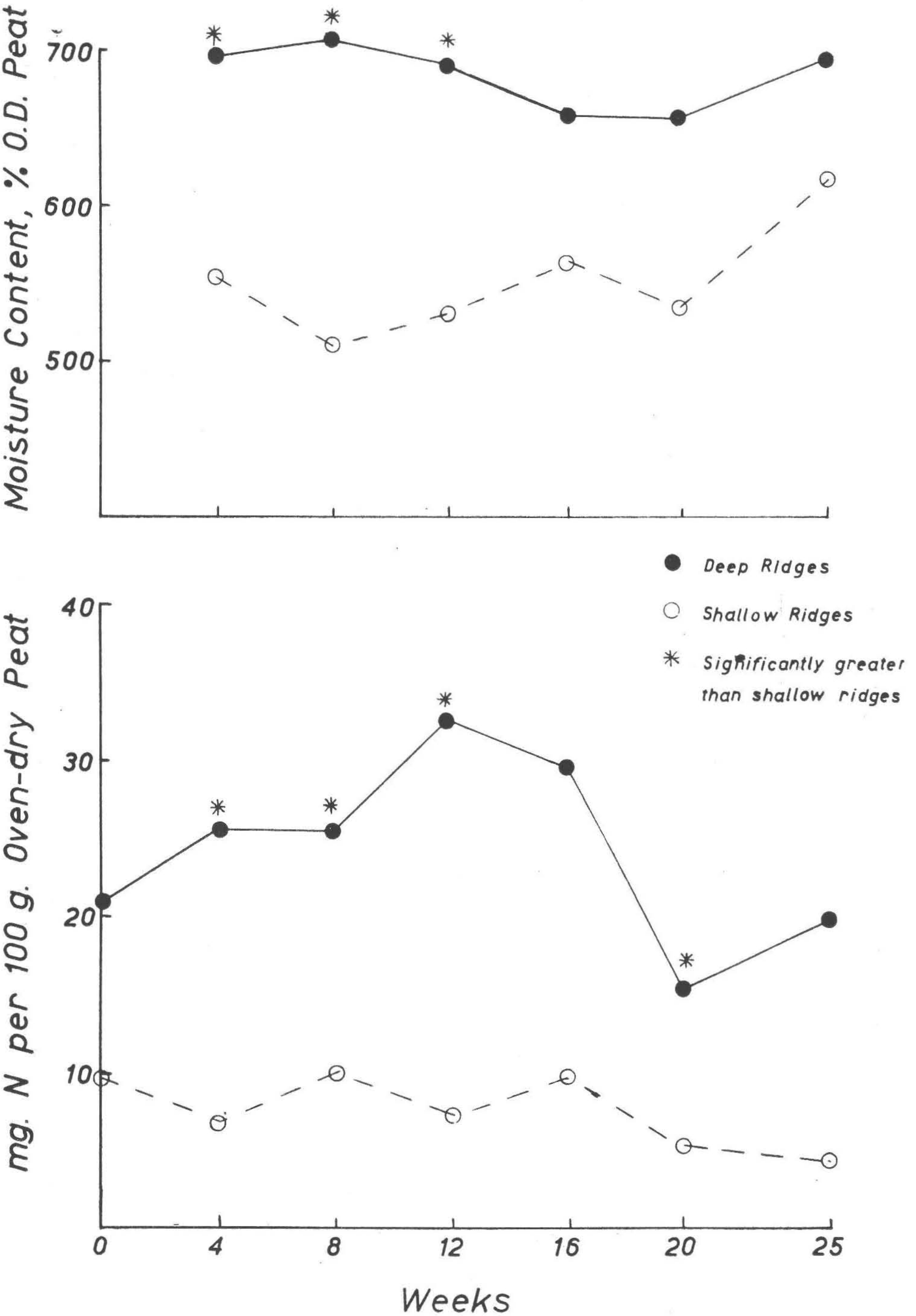

Fig. 6. Wauchope Experiment 4 P.53. Variation in moisture and ammonia-nitrogen content of peat between April 14th and October 6th, 1958.

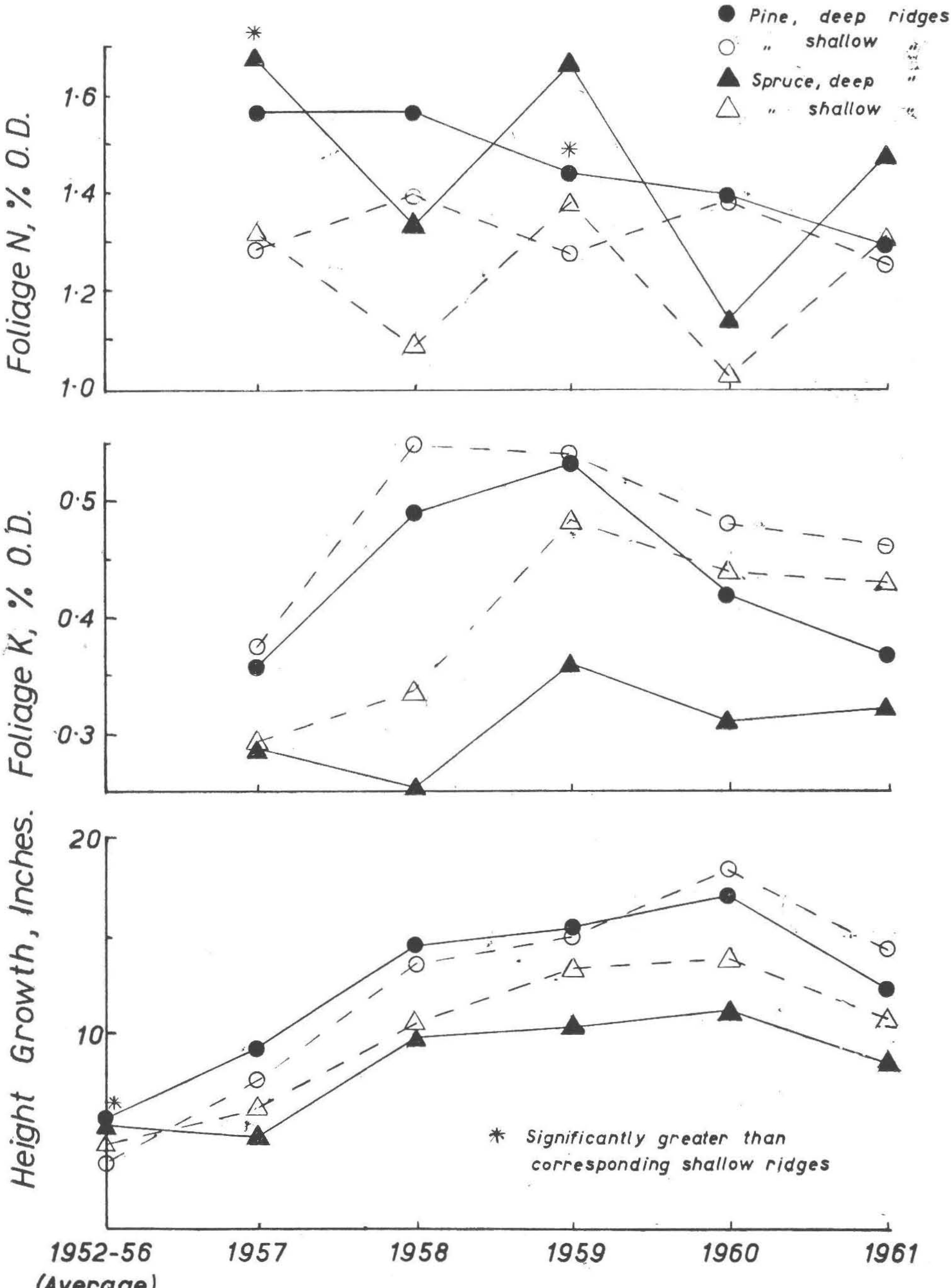

Fig. 7. Wauchope Experiment 4 P.53. Height growth and foliage nutrient content.

than the shallow-ridge trees. There is little doubt that all the trees are borderline for K deficiency, and that the Sika spruce on the deep ridges are definitely deficient. Figure 3 has already indicated that the peat at Wauchope contains less K than peat at the Lon Mor, so deficiency might be expected : the difference between deep and shallow ridge trees was, however, unexpected. The peat samples in 1958 were bulked and then analysed for nutrients as already described; the results show that the peat in the deep ridges contained significantly *more* inorganic P, total N, K and Mg than that in the shallow ridges, though all samples came from the same original peat layers (Binns, 1959). Leaching of nutrients down through the deep ridges possibly accounts for this, and may help to explain differences in growth and in N mineralization rates, but this would not account for lower K foliage values in the deep ridge trees. Although Gore and Allan (1956) and Kaila and Kivekäs (1956) have suggested that a large proportion of the K and Mg in peat is in exchangeable form, it seems that the total amounts of K and Mg present here are not directly related to uptake by the trees, and that temperature and moisture variation as well as the availability of nutrients may be affecting uptake; in 1957 the lodgepole pine on the deep ridges had much larger needles than the shallow ridge trees, but since 1958 for lodgepole pine, and 1959 for Sitka spruce, needle weights have been roughly the same on the two ridge types (needle weights for Sitka spruce were not determined before 1959).

An assessment for the whole experiment six years after planting showed Scots pine, lodgepole pine, and hybrid larch (*Larix eurolepis* Henry) to be significantly taller on deep ridges throughout the experiment and *Tsuga heterophylla* to be significantly taller in half the plots; Sitka spruce and *Picea omorika* show smaller differences between deep and shallow ridges, and these are significant in one or two plots (Edwards, unpublished).

This phenomenon of more rapid early growth on deep ridges has been reported from other Forestry Commission areas, and work at Glentrool, Kirkudbrightshire, now in progress, suggests that N mineralization there is more rapid in deep ridges than in shallow ridges, and that the difference is increased by adding P (Keay, J., unpublished). While the evidence is incomplete, the effect of P in mineralizing peat N under agricultural conditions has been known for some time (e.g. Kaila, 1958).

It is not clear whether this differential growth will be important as a long term effect: it might even be beneficial for lodgepole pine in reducing the incidence of wind-sway.

The Concentration Gradient in Peat.

One particular striking feature of the analytical results is the apparent accumulation of total K, Mn, and inorganic P in the surface layers of the peat, and the concentration of K and Mn by the vegetation vis-à-vis the amounts in the peat—which consist essentially of the dead plants of previous generations.

At the Lon Mor, where deeper samples have been taken, at 18 inches below the surface the inorganic P content falls to 2mg./100g. and the total K content to 5mg./100g. (Binns, 1959), and a similar decrease probably occurs at the other sites. Impeded drainage is a prerequisite for the formation of raised bog, and this is also true to some extent for blanket bog: though there may be lateral water movement, and fluctuations in the water table, there will usually be little leaching in a vertical direction. In some blanket bogs, nutrient-rich water may flow in from higher ground, but this is not possible in raised bogs.

The difference in P, K, and Mn content of the upper and lower peat layers has to be explained, and two theories have been advanced—either, that a recycling or "pumping" process by the vegetation maintains the nutrients at the surface (e.g. Kaila and Kivekäs, 1956; Binns, 1960), or that the nutrients are supplied by dust and rainfall (e.g. Mattson and Koutler-Andersson, 1955; Walsh and Barry, 1958). The recycling theory seems the more probable for the following reasons:

1. Although the nutrients supplied by rain are undoubtedly important for bog nutrition, rain water contains insufficient phosphate to account for the P gradient.

2. The Na/K ratio in rain water is of the order of 25/1 near the coast, and falls to 2/1 in some inland areas (Tamm, 1958) while the average Na/K ratio in the top foot of the peat at the 12 sites varies from 2/1 at Watten to 1/2 at Whickhope. Figure 8 shows the averages and the ranges for all sites. There is little change down the profiles for Na contents, and the change in ratio with depth is due almost entirely to the change in K content.

3. If leaching were responsible for the removal of P and K from the lower layers, one would expect replenishment by leaching from above; if there is no loss by leaching, the increase in concentration of the scarce nutrients at the surface can only be accounted for by recirculation of nutrients in the vegetation as the bog develops, which also explains loss of nutrients from the lower layers.

Mattson and Koulter-Andersson (1955) suggest that the higher concentration of nutrients and ash in the surface layers is due to increasing human activity during the historic period. However the main increase in K and inorganic P content at the Lon Mor occurs between 14 inches and the surface, while N increases between 24 and 10 inches, but is fairly constant in the top 10 inches (Binns, 1959). It may be that there are different causes for changes in P and K and for changes in N content, and the effect of human activity will of course vary greatly from place to place.

Apart from its fundamental interest, the practical importance of this

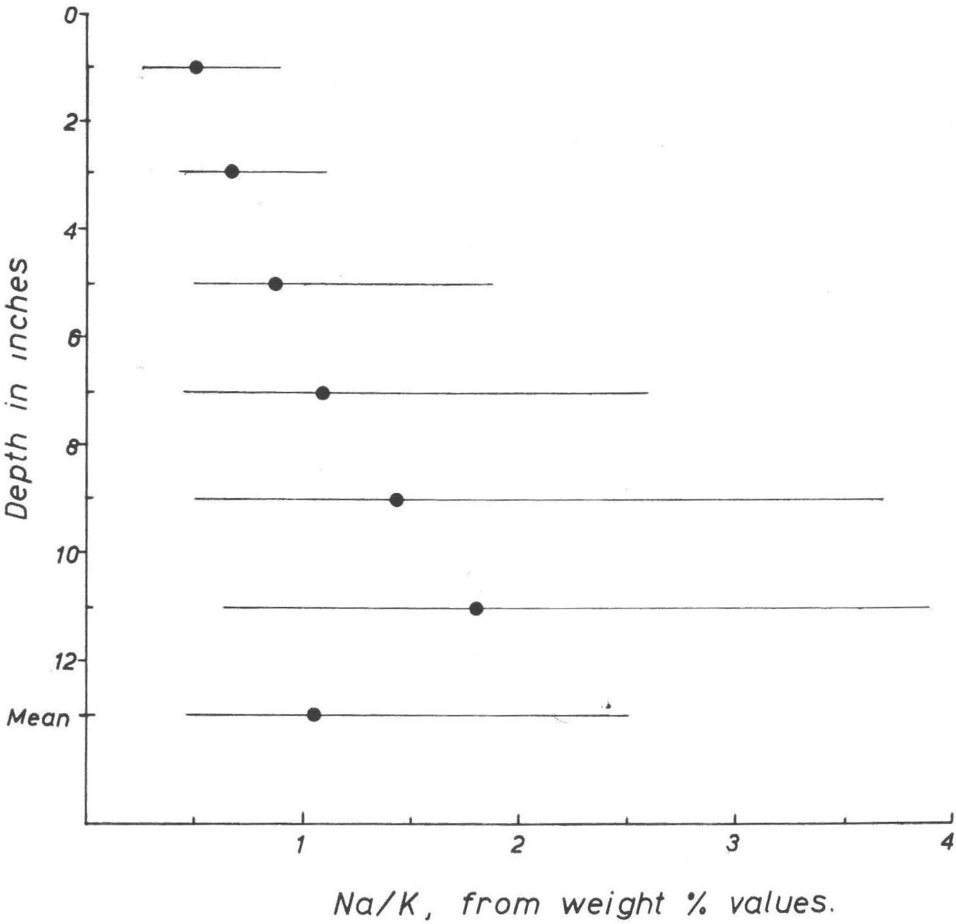

Fig. 8. Sodium-potassium ratios in peat; averaged values for all sites, and ranges.

phenomenon of a concentration gradient in peat is that while doubling the rooting depth may increase stability, it will only increase slightly the amounts of the scarce nutrients within reach of the trees.

Nutrient Requirements of a Whole Crop.

The data from the twelve sites studied may be used to calculate the amounts of nutrients in terms of lb. per acre, including the amounts in the vegetation, which can then be compared with the estimated demands of a tree crop. For the urgent short-term problem of growing the crop to maturity, the maximum immobilization of nutrients by a crop may be compared with the nutrients present in peat; for the long term problem of maintaining site fertility, the nutrients permanently removed in harvesting the tree crop may be calculated. While it is obvious that no tree can extract all the nutrients from peat, the total content of any nutrient may well, in the the present state of our knowldge, be a more useful measure of fertility than trying to determine the "available" fraction: not only is the latter difficult, but the peat is undergoing continual changes as a result of draining and tree growth, and the concept of availability is probably meaningless except for a single point in time.

Table III shows values for peat and natural vegetation at the sites studied, and the amounts immobilized by conifers, the latter calculated from data published by Rennie (1955), Meshechok (1957), and Wright and Will (1958). The weakness of both the comparison of Meshechok (1957) for Norwegian bogs and the present work is that since the data for the trees are not from peat grown trees, a large measure of luxury uptake may be involved. Although only the nutrients in the top foot of the peat are included in the table, the concentration gradient for scarce nutrients is such that for practical purposes the amounts in the top foot can be used as a basis for calculating the amounts per acre for these nutrients.

A direct comparison suggests that in relation to tree growth peat contains sufficient N, reasonable amounts of Ca and Mg, and apparently enough P, but is deficient in K. Though peat contains large reserves of

TABLE III

Nutrients in natural vegetation and the top foot (30 cm.) of peat at the sites studied, and immobilization by conifers, in lb./acre (x 1.12=Kg./ha.).

	N	P	K	Ca	Mg	Mn
Ground vegetation	130	7	22	30	10	3.7
Peat	5285	149	84	450	280	4.9
Total	5415	156	106	480	290	8.6
Immobilization by conifers	200-550†	20-80‡	120-300‡	180-500‡	30-90†	20-60*

* Data from Meshechok (1957).
† Data from Meshechok, and Wright and Will (1958).
‡ Data from Meshechok, and Wright, and Rennie (1955).

N, the rate at which it is mineralized will control its availability to trees, and it is possible that N may be lost with increased soil biological activity following drainage and afforestation. In peat, as in other soils, only a small part of the soil P needed to produce satisfactory growth is actually taken up by plants, and the comparison can only be used to show the probable drain of P over a rotation. Conifers tend to accumulate Ca in the heartwood, and the amounts lost to the site may be proportionately large, but this loss may be made up in practice as Ca is applied in all commonly used P fertilizers.

Figures for Mn are given for only six of the sites, and as plants may take up trace elements in much greater amounts than is needed for adequate growth, the comparison in Table III may be misleading. However older lodgepole pine at the Lon Mor, manured with G.M.P., show foliage Mn contents of under 1mg./100g., which is the approximate level recorded for Mn deficient spruce in Sweden (Ingestad, 1958); lodgepole pine manured with basic slag shows much higher foliage Mn contents.

Considered over a whole rotation, the amounts taken up by trees are not large, and Madgwick and Ovington (1959) have shown that the amounts of K, Ca, and Mg in trees in Kent, permanently lost to the site, are made up by the amounts in the rainfall, and Ebeling (1959), for example, shows that in South Sweden 1-3 lb. N per acre per annum may be expected in the rainfall : only P, of the major nutrients, shows a large deficit. Tamm (1958) has pointed out the importance of the nutrients in rainfall in bog economy.

Discussion.

Only two of the twelve sites, Whickhope and Mounces, were originally considered capable of growing a tree crop without added P. At Whickhope, with high peat N and P, and Rumster, with high peat N, P, and ash, Sitka spruce has made a good start, although a routine dressing of G.M.P. was given at Rumster. Growth disturbances at Rumster now reported may be due to competition for N by *Calluna*, or to K deficiency; the peat K contents at both sites are lower than at the Lon Mor, where older trees have already shown K deficiency.

The peat at Mounces contains more P on the average than at any site except Whickhope and Rumster, but in the experiment on the site (Kielder 73 P.54) Sitka spruce and lodgepole pine have both shown a small but significant response to G.M.P. (Edwards, 1959) though the trees have not failed in its absence; foliage P levels in the controls were by 1960 barely adequate at 100-120mg./100g. At Wauchope, in Experiment 5 P.55, Sitka spruce has not responded to G.M.P. (Edwards, *loc. cit.*) and growth is quite good, though variable; foliage P content of the controls in 1960 was adequate at about 150mg./100g. The P levels in the peat are higher for this experiment than for the rest of Wauchope, and inorganic P levels are slightly higher than at Mounces.

At the Lon Mor lodgepole pine grew for 11 years without added P, while at Rimsdale the same species was dying without it 3 years after planting. However the lodgepole pine site at the Lon Mor is richer in P than the Scots pine site there (Binns, 1959), and is also richer than Rimsdale, particularly for organic P, although these areas are grouped together in figure 2.

While it seems that the P available to trees is mainly within the inorganic fraction, an examination of the results suggests that the organic fraction also contributes to site fertility for P. Table IV shows

TABLE IV

Total P content of 0-6″ peat layer in mg./100g. dry weight, compared with responses to P.

Site, and Experiment or Compartment Number	P content	Response to phosphate
RIMSDALE, Naver Experiment 3 P.58	45	Lodgepole pine failing at 3 years without P, growing well with P.
LON MOR, Inchnacardoch Expt. 19 P.26	46	Scots pine slow early growth, eventual severe check without P, good response to P added in 1928.
LON MOR, Inchnacardoch Expt. 47 P.28	59	Lodgepole pine survived for 11 years without P, good response to P added in 1939. Some unmanured controls still surviving and growing (but probable root interaction).
MOUNCES, Kielder Expt. 73 P.54	71	Sitka spruce and lodgepole pine respond to P in the early years, pine more than spruce.
WAUCHOPE, Expt. 5 P.55	76	Sitka spruce has shown no early response to P, and growth is slightly better than at Mounces, though variable.
WHICKHOPE, Compartment 159	90	Sitka spruce growing well in youth without P.

how values for peat P may be tentatively related to response to P at those sites where there are controls. While the evidence is thus incomplete (and interpretation at some sites is complicated by K deficiency), it does suggest that the total P content in the top six inches of the peat may be used to indicate those areas where additional P is unnecessary, and those where application may safely be delayed for some years after planting if desired.

There have been colour and growth responses to added K at the Lon Mor (Binns, 1961); low foliage K levels of 0.3-0.5% have been found at Wauchope, Watten and Strathy, and very low levels of 0.2-0.4% at Mossmorran and Mounces, where there have also been marked colour responses to recently applied K. Thus the results of foliage analyses and fertilizer trials, when compared with figure 4, suggest that the time at which K deficiency first occurs is well correlated with the total K content of the top foot of the peat; if this proves to be generally true, peat analysis should be useful for forecasting K requirements.

The ash content of the peat is used elsewhere as an estimate of peat quality class for forestry (e.g. Vomperskij, 1958), but unless ash and P contents are well correlated (or unless other nutrients are correlated with ash content), the evidence suggests that ash content by itself is not likely to be an important parameter. For example, Mossmorran has a high ash content in the surface layers (due possibly to industrial pollution) but appears to be the most infertile of the sites studied, and Rimsdale has a high average ash content but appears to be rather deficient in P.

High peat N contents may indicate ground where Sitka spruce will grow well in youth, but the future of this species is problematical on all but the better, *Molinia,* peats.

The nutrient content of the natural vegetation gives only an approximate indication of site fertility for P, and virtually none for N and K, which is disappointing; there may however be several reasons for this. Thus, previous land use followed by fencing and ploughing has usually resulted in unstable communities. In addition, the mixture of species on each site has been alalysed, not individual species, and sampling has not been done at the same time of year for all sites, which have probably affected the results considerably. Moreover, work in Canada on forest plant communities by Gagnon *et al.* (1958) has suggested that the levels of cations in plant tissues are apparently governed, not by the available amounts in the humus layer, but by the inherent capacity of the species; useful differences between sites will therefore only appear when there is a clear deficiency of any nutrient, and species with higher requirements have been unable to compete on all these infertile sites.

It is clear that a detailed examination of tree foliage and tree growth at the sites studied is needed, together with further fertilizer trials, and it will also be necessary to see if the trace element contents of the peat, the trees, and the natural vegetation are in any way related, and if there are any responses to trace elements; preliminary studies on these problems are now in progress.

The phenomenon of more rapid early growth on deep compared with shallow plough ridges, though striking in the early years, seems to become less marked later on, but it is still not clear how important it will eventually be. It seems probable that ploughing regimes in the future are more likely to be designed on the basis of their effect on drainage intensity, crop stability, and extraction techniques, rather than their effect on early growth rate, provided the last reaches an acceptable minimum.

While peat analysis looks promising for estimating site fertility for P and K, and perhaps for N, foliage analysis is well established as a means of detecting major nutrient deficiencies in trees (e.g. Leyton, 1958), and may be better and easier than peat analysis. Analysis of newly acquired and unplanted peat may however help to prevent the planting of unsuitable species, as well as forecast probable nutrient deficiencies.

Foliage analysis for trace elements is another matter : though foliage levels for deficiencies of some nutrients have been reported, e.g. for Cu (Benzian, 1956), Mn (Ingestad, 1958), and Zn (Kessel, 1943), little is known of the best time of year and place in the crown to sample the foliage, and both of these may differ for major and minor nutrients. The trace element content of Scottish peats varies considerably, showing zones of accumulation in some cases (Mitchell, 1954), and the total amounts may be a poor guide to the availability of elements which are strongly bound by organic matter, e.g. Cu (Mitchell *et al.*, 1957). Nevertheless, in peats with a low ash content the relative amounts of the micronutrients in different areas may be a useful guide to the likelihood of deficiencies, and in conjunction with foliage analysis may simplify diagnosis and field trials considerably.

The calculation of nutrient turnover in peatland forests, by analysis of whole trees, natural vegetation, peat, rain water, and drainage water, would provide a better understanding of bog economy, and the effects which afforestation may have on this. Important as such a study would be from the long term aspect, it would probably not provide information quickly enough, or for sufficiently varied conditions, to answer the urgent questions concerning fertilizer requirements for trees on peat : this can probably be done more easily and rapidly by a comparison of the chemical composition of peat and by foliage analysis, followed by fertilizer trials. Studies of forest nutrient balance, though generally incomplete, suggest that if the working capital of deficient nutrients is increased sufficiently, only small additions may be necessary thereafter under good management.

Acknowledgements.

Forestry Commission staff who have assisted at some point in the investigations are too many to name individually, but thanks are due particularly to Mr. G. S. Forbes, who did the monthly sampling at Wauchope. Drs. T. W. Wright and J. Keay kindly collected the samples from Mounces and Whickhope respectively. Thanks are also due to Dr. R. L. Mitchell, who arranged for the spectrochemical analyses, and to Dr. R. C. Mackenzie and Mr. R. A. Robertson for helpful criticism of the manuscript.

Summary.

Investigations at 12 deep peat sites in Scotland and N. England, have suggested that the needs of conifers for additional P and K may be estimated from the total P and K contents of the upper layers of the peat; concentration of these two nutrients in the surface layers, attributed to recycling by the natural vegetation, indicates that although deep rooting may improve stability it will probably not benefit trees much nutritionally. Mineralization of nitrogen, more rapid under deep than under shallow plough ridges, appears to be responsible for faster growth of young pine and larch on deep ridges. The deficiency of potassium at the sites studied is confirmed by a comparison of the maximum amounts of nutrients immobilized by conifers with the amounts present in the peat.

References.

Benzian, B., 1956. Copper deficiency in Sitka spruce seedlings. *Nature* **178,** 864-5.

Binns, W. O., 1959. The physical and chemical properties of deep peat in relation to afforestation. Ph.D. Thesis, University of Aberdeen.

——— 1960. Scottish soils in relation to afforestation. *J. Inst. Biol.* **7,** 18-20.

——— 1961. Forest soils research in Scotland. *Rep. For. Res.,* Lond. **1960,** 93-4.

Bremner, J. M., and Shaw, K., 1955. Determination of ammonia and nitrate in soils. *J. Agric. Sci.* **46,** 320-8.

Duchaufour, Ph., and Mangenot, F., 1956. Recherches sur l'évolution expérimentale de certains humus. *Ann. Agron* **A7,** 159-81.

Ebeling, F., 1959. Bonitering av Skogsmark—trolleri med tabeller eller tillämpad biologi? *Skogen* **46,** 472-5.

Edwards, M. V., 1959. Use of triple superphosphate for forest manuring. *Rep. For. Res.,* Lond. **1958,** 117-30.

——— 1962. The progress of peatland afforestation in Great Britain. *Irish Forestry* **19,** 102-109.

Gagnon, D., Lafond, A., Amiot, P., 1958. Mineral nutrient content of some forest plant leaves and of the humus layer as related to site quality. *Can. J. Bot.* **36,** 209-20.

Gore, A. J. P., and Allen, S. E., 1956. Measurement of exchangeable and total cation content for H^+, Na^+, K^+, Mg^{++}, Ca^{++} and iron, in high level blanket peat. *Oikos* **7,** 48-55.

Hanson, W. C., 1950. The photo electric determination of phosphorus using the phospho-vanado-molybdate complex. *J. Sci. Fd Agric.* **1,** 172-3.

Illingworth-Longbottom, K., 1954. A study of ground vegetation types and tree growth on a typical area of moorland in the north-west Highlands of Scotland. Unpubl. Thesis, University of Aberdeen.

Ingestad, T., 1958. Studies on manganese deficiency in a forest stand. *Medd. SkogsforsknInst.* Stockh. **48,** (4).

Kaila, A., 1958. Effect of superphosphate on the mobilization of nitrogen in a peat soil. *Maataloust. Aikakausk.,* **30,** 114-24.

Kaila, A., and Kivekäs, J., 1956. Distribution of extractable calcium, magnesium, potassium, and sodium in various depths of some virgin peat soils. *Ibid.* **28,** 237-47.

Kessel, S. L., 1943. The nutrition of the forest crop. *Australian Forestry* **8,** 5-21.

Leyton, L., 1958. The mineral requirements of forest plants. *Encyclopedia of plant physiology* IV, 1026.

Macdonald, J. A. B., 1945. The Lon Mor : twenty years' research into wasteland peat afforestation in Scotland. *Forestry* **19,** 67-73.

Madgwick, H. A. I., and Ovington, J. D., 1959. The chemical composition of precipitation in adjacent forest and open plots. *Forestry* **32,** 14-22.

Mattson, S., and Koutler-Anderson, E., 1955. Geochemistry of a raised bog. *Kungl. Lantbruks. Ann.* **21,** 321-66; **22,** 219-24.

Meshechok, B., 1957. Om myrgjodsling for skogproduksjon. *Tidsskr. Skogbruk* **64,** 119-48.

Mitchell, R. L., 1954. Trace elements in Scottish peats. Pap. Int. Peat Symposium, Dublin, Section B.3., pp.9.

——— Reith, J. W. S., and Johnston, I. M., 1957. Trace element uptake in relation to soil content. *J. Sci. Fd Agric.* **8,** Suppl. Issue 551-9.

Nicholas, D. J. D., and Fisher, D. J., 1950. A note on the use of tetramethyldiamino-diphenylmethane for determining small amounts of manganese in plants. *Long Ashton Ann. Rep.* **1950,** 115-20.

Pinta, M., and Bove, C., 1956. Application of flame photometry to the analysis of plant material (in French). *Mikrochim. Acta* **12,** 1788-817.

Rennie, P. J., 1955. The uptake of nutrients by mature forest growth. *Plant and Soil* **7,** 49-95.

Riley, J. P., 1958. Analysis of silicate rocks. *Analyt. Chim. Acta* **19,** 413-28.

Saunders, W. M. H., and Williams, E. G., 1955. Observations on the determination of total organic phosphorus in soils. *J. Soil Sci.* **6,** 254-67.

Scott, R. O., and Ure, A. M., 1958. The determination of magnesium in solution by direct photometry. *Analyst* **83,** 561-70.

Tamm, C. O., 1958. The content of plant nutrients in precipitation, dust and air. *Encyclopedia of plant physiology* IV, 233-42.

Ure, A. M., 1958. Spectrochemical applications of electronics in soil research. *Brit. Commun. Electronics* **5,** 846-9.

Vomperskij, S. E., 1958. Methods of assessing wet peatland in surveys with a view to forest site improvement. *Lesn. Hoz.* **11,** 76-7 (in Russian). *For. Abs.* 1960, **21,** 1346.

Walsh, T., and Barry, T. A., 1958. The chemical composition of some Irish peats. *Proc. roy. Irish Acad.* **59B,** 305-28.

Wright, T. W., 1959. Use of fertilizers in the afforestation of deep peat. *J. Sci. Fd Agric.* **10,** 645-50.

——— and Will, G. M., 1958. The nutrient content of Scots and Corsican pines growing on sand dunes. *Forestry* **31,** 13-25.

Zehetmayr, J. W. L., 1954. Experiments in tree planting on peat. *Bull. For. Comm.,* Lond. **22.**

The Effects of Fertiliser Treatments on the Growth and Composition of Sitka spruce

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This paper presents the results of some experimental work carried out jointly by members of the Chemical Research and the Forestry Divisions of the Ministry of Agriculture, Northern Ireland, with the Botany Department of the Queen's University, Belfast. Full details of the work will be found elsewhere. (McConaghy, *et al* 1962, and in preparation).

Summary

THE problem of check has caused concern for some ten years and the Forestry Division of the Ministry of Agriculture, Northern Ireland, first began investigating the matter in 1953. The results described in this paper relate to experiments which began in 1956.

A practical but expensive method of bringing trees out of check has been in operation for some time and has consisted of deepening drains and placing excavated peat round checked plants. Within four years of such treatment the average height of trees is more than double that of trees on untreated areas and annual growth rate is very significantly increased.

The effectiveness of such treatments is undoubtedly due to a combination of several factors, including better drainage, suppression of heather competition by peat litter and extra nutrients supplied by excavated peat.

Checked trees are always stunted and invariably show pale yellow colours, usually indicative of low needle nitrogen contents.

A pilot experiment laid down in 1956 included the use of various forms of nitrogenous materials, with and without phosphate; other nutrients included calcium as lime and gypsum, potassium, iron and copper. The best results were obtained with bone meal though later applications of hoof and horn meals also gave promising results in the year of application.

In 1957 two experiments were laid down when Sitka spruce seedlings were being transplanted in the peat. A further experiment, started in 1959 involved the aerial application of a compound fertiliser to established trees.

I. *Effects of placement of nitrogen and phosphate.*

In the first of the 1957 experiments a variety of nitrogenous materials was applied with a standard amount of basic slag. In two of the four blocks of treatments the fertilisers including basic slag were placed in and around the planting holes, and in the other two blocks the fertilisers including basic slag were broadcast under the turf ribbons. The results have shown that with the exception of rich garden soil the nitrogen containing materials had little positive effect when placed in and around the planting holes, but bone meal containing both nitrogen and phosphate had a significant positive effect, and many other organic nitrogenous materials had a slight positive effect when broadcast under the turf ribbon. Treatments were much more effective when broadcast under the turf ribbon—apart from urea and ammonium nitrate which significantly depressed tree growth. Comparisons of the results by the two methods of fertiliser application are given in Table I.

Table I.

Mean tree heights and mean leader lengths (1960), four years after treatment.

Fertiliser position	Mean tree height (ins.)	Mean leader length (ins.)
Placed in and around planting hole	21.3	3.8
Broadcast under ribbon	24.4	5.5
Mean difference	3.1**	1.7**

** Differences significant at 1% level.

Analysis of tree needles in 1960 showed that both nitrogen and phosphate contents tended to be low and that all growth improvements were associated with increases in nitrogen contents and to some extent in phosphate contents of needles.

The effects of bone meal at different rates are summarised in Table II.

Table II.

Response to bone meal

Rate of application oz./tree	Fertiliser in and around hole		Fertiliser broadcast under ribbon	
	% N. in D.M.	% P. in D.M.	% N. in D.M.	% P. in D.M.
1	0.68	0.11	0.85	0.10
2	0.70	0.11	0.83	0.09
3	0.93	0.12	1.03	0.16

II. *The effects of lime and of different phosphates.*

This experiment consisted of 48 rows each of 50 trees in two blocks, one of which was limed with 50 cwt. ground limestone/acre before planting in Spring 1957. Phosphates were applied (with and without added nitrogen) as basic slag at 1 and 2 oz. per tree and as superphosphate, ground rock phosphate and bone meal, supplying phosphate equivalent to 2 oz. basic slag per tree. Tree measurements and needle samples were taken in April, 1961.

Results.

In the absence of phosphate trees made practically no growth and nitrogen alone had a deleterious effect. Lime in the absence of phosphate resulted in better tree growth by 1961, though lime had its usual effect of decreasing the availability of ground rock phosphate even under the very acid conditions of this site where the pH of the limed soil is still below 4.5. Trees on the limed block have improved with time and by 1960 were greener and healthier in appearance than on the no lime block. The main effects of treatments are summarised in Tables III and IV.

Table III.

Effect of applied N and of lime on tree growth and leader length

Treatment 1957	Mean tree height (1960) ins.		Mean leader length (1960) ins.	
	No Lime	Lime	No Lime	Lime
Nil	14.2	16.7	1.5	3.2
N only	11.4**	17.4	0.9	3.9
P only	22.9**	22.4**	4.5**	4.7*
N + P	23.0*	20.3**	5.0**	4.6*
G.R.P. only	23.3**	20.9**	5.3**	3.2
G.R.P. + N	22.4**	18.8	4.5**	3.5

* Significant at 5% level; ** Significant at 1% level.

Table IV.

Effects of treatments on nitrogen and phosphate contents of needles after three years: Sitka spruce

	Average percentage in dry matter of needles			
	Nitrogen (as N)		Phosphate (as P)	
Treatments	No Lime	Limed	No Lime	Limed
No phosphate	1.22	1.33	0.07	0.09
Basic slag. Rate 1	0.87	1.24	0.09	0.09
Basic slag. Rate 2	0.70	1.02	0.13	0.11
Superphosphate	1.09	1.06	0.12	0.10
Ground rock phosphate	1.11	1.14	0.11	0.08
Bone meal	0.80	1.08	0.11	0.10
Average	0.98	1.14	0.11	0.10

Needle samples from trees which had received no phosphate had very low phosphate contents but fairly high nitrogen contents. Lime, in the absence of phosphate, slightly increased the phosphate contents of needles presumably through its effect on peat decomposition. It also increased the nitrogenous contents of needles of trees which had received phosphate, though it tended to reduce height growth over the first three years. Lime, as expected, also had a significant effect on the calcium contents of needles. Added nitrogen had no effect either on tree growth or on nitrogen contents of needles.

III. *Effects of manuring on the growth of established trees.*

In established forests the growth of trees may often be limited by low nutrient supplies. In 1959 a compound fertilizer (containing 6% N, 10% P_2O_5 and 8% K_2O) was applied from the air to Sitka spruce trees on a mountain peat soil in County Londonderry. Two plantations of trees were selected—nine and nineteen years old—in each of which there were areas where growth was poor. Within two years of treatment there was a significant increase in growth rate of trees which had previously been making unsatisfactory progress. Mature trees, nineteen years old, making apparently normal growth, showed no increase in growth rate as a result of treatment but the nine years old trees apparently making normal growth, showed a significant increase in growth rate as a result of the fertiliser. Results are summarised in Table V.

The general conclusions from these experiments may be summarised as follows :—

(1) that added nitrogen has only small and transient effects on growth of Sitka spruce growing on deep peat, or it may be toxic in some seasons at high levels;

(2) that phosphate is the most important factor limiting growth in early years;

(3) higher levels of phosphate than are normally supplied may be worthwhile and the position of placement of phosphate, relative to young tree roots, must be carefully considered.

Table V.

Effects of manuring on growth of established trees (Sitka spruce)

Age of trees (years)	Growth	Av. growth (ins.) June 1959	Treatment : NPK compound June 1959	Av. increase in growth (ins.) June 1959-61
	Good	15.08	None	0.79
19		14.32	Treated	0.74
	Poor	5.36	None	1.10
		6.40	Treated	1.94**
	Good	7.73	None	1.35
		6.55	Treated	1.90*
	Poor	4.62	None	0.98
		4.33	Treated	1.48**

References.

McConaghy, S., McAllister, J. S. V., Parkin, K. F., and Parker, R. E., 1962. The growth of Sitka spruce on deep peat in Northern Ireland. (i) The effect of fertilizers and other treatments on the growth of young trees. *Res. Exp. Rec. Min. Agric.*, N.I., 10, Part 2. In the press.

——— *et al* (ii) The effects of fertilizers and other treatment on composition of needles. *Res. Exp. Rec. Min. Agric.*, N.I., 11, Part 1. In preparation.

Factors Limiting Tree Growth on Peat Soils

An Investigation into the nutrient status of two peatland plantations

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A good deal has been said and written already about the potentialities and the limitations of both soil analyses and foliage analyses in the diagnosis of nutrient deficiencies of forest stands. (e.g. Binns, 1962; Duchaufour, 1958; Leyton, 1958b; Tamm, 1956; Viro, 1961; and Wright, 1959). It is not my object here to add to this discussion but to give an account of the investigation of two peatland planations by means of a method which included the determination of the nutrient content of both soil and foliage samples.

Objects.

Among the plantations established on peat soils in Northern Ireland between the late nineteen-twenties and the early ninteen-fifties there are many in which tree growth, either in whole or in part, has been unsatisfactory. Some of the younger stands which were planted on very poor land just before the introduction of ploughing are more or less uniformly retarded and may be regarded as 'in check'. The older stands were generally planted on rather better land and have been more successful. Within them the areas of retarded growth occur only as patches within compartments, the growth of which has otherwise been satisfactory. Such stands have already been briefly described (Parker 1957, and 1962). In these older stands the trees show a very wide range of growth rate. In terms of present tree height there is often a ten-fold difference between the largest and the smallest trees. These large differences may be regarded as resulting from parallel differences in soil fertility and despite the complication of competing vegetation it was considered probable that these fertility differences could be interpreted simply in terms of nutrient supply. It would appear that on sites in this condition the locally unsatisfactory tree growth results from one or more nutrient deficiencies which have arisen directly as a result of site differences present at the time of planting; in other words, that the trees are acting as simple indicators of site fertility. In some of the peatland plantations where growth for several decades has been generally satisfactory there is now evidence of a fall in growth rate, particularly in those parts where growth in the past has been best. It was thought that this fall might be due to a significant reduction in site fertility brought about by the trees themselves: that on sites in this condition the larger trees are now reacting to their own past depletion of their rooting zone in respect of one or more nutrients.

The first and main object of this investigation was to test the hypothesis that the trees growing on these peat soils are subject to one or more nutrient deficiencies and to identify the deficient element or elements. The second object was to test the hypothesis that there are significant differences between the nutrient relationships of the two kinds of site described above; in particular that the fall in growth rate of the larger trees is indicative of the onset of further nutrient deficiency resulting from impoverishment of the site by the trees themselves.

Sites.

Two sites were selected for investigation; one, which will be referred to as Site 4/60, was thought to be typical of the first condition defined above; the other, which will be referred to as Site 5/60, was thought to be typical of the second condition. Both are located within Springwell Forest, which lies about 6 miles from Coleraine, astride the Coleraine-Limavady Road, in Co. Derry.

Site 4/60—Site 4/60 carries a crop of Sitka spruce which was planted in 1939. The site is flat and peat-covered to depths ranging from 9 inches to 4 feet 6 inches. In the course of the investigation a number of indistinct steps were found in the peat surface. These suggest that the site has at one time been subjected to some peat cutting. The area of the single patch which shows markedly poor growth, i.e. on which the trees have not yet closed canopy, is about 2,000 square yards. The smallest trees stand amongst tall *Calluna* which despite its age is still dense and accompanied only by a little *Molinia* and a fragmentary ground layer of mosses. Beneath the trees which are just closing canopy the *Calluna* is being killed out, the *Molinia* is more conspicuous, and mounds of *Sphagnum* are accumulating. The smallest trees which have been brashed have beneath them a thick spongy carpet composed of several Hypnaceous mosses and scattered mounds of *Sphagnum*. Under the rather larger trees the moss carpet thins out and there is no *Sphagnum,* and under the largest trees the mosses are sparse or absent altogether. Tree heights at the time of sampling ranged from 105 to 1,248 cms. (3 ft. 6 ins. to 41 ft.).

Site 5/60—The plantation selected as Site 5/60 had already been under observation for several years and two permanent belt transects had been established within it to facilitate the study of vegetation changes. It carries a crop of Sitka spruce which was planted in 1933. The site has an overall slight slope to the E.S.E. but the gradient is not uniform. Peat depth ranges from 9 inches to about 5 feet. Two small patches on which the tree canopy is not yet closed, with a total area of about 120 square yards, were included in the area sampled. The vegetation on the site varies with tree size much as that on Site 4/60 but differs in that the moss carpet extends further beneath the larger trees. There is good evidence that this extension has taken place recently in response to increased light intensity resulting from heavy needle cast.

Methods.

Following the recommendations of C. O. Tamm who found the nutrient content of Norway spruce needles to fluctuate least in late autumn and winter (Tamm 1955), sampling was carried out during the last few days of November and the first few days of December, 1960. The procedure used was the same on both sites. Trees were selected to cover as evenly as possible the whole height range present. 40 trees were selected on Site 4/60 and 21 trees on Site 5/60. In those parts of the stands where the canopy was closed only dominant or co-dominant trees were considered eligible for selection, and trees seen to have double or broken leading shoots were excluded.* For each tree the following measurements were made and samples taken :—

1. The peat depth was measured with a probe at several points within the crown spread of the tree and a mean value, to the nearest three inches, recorded.
2. A brief description of the vegetation beneath the larger trees or in the immediate vicinity of the smaller ones was recorded.
3. Two cylindical samples, each about 250 mls. volume were taken of peat beneath the tree. These samples were taken from immediately beneath the soil surface and did not include needle litter or living vegetation.
4. The tree was marked at breast height (4 ft. 3 ins. from the soil surface) and then felled, care being taken that the leading shoot and the uppermost lateral branches were neither damaged nor soiled.
5. The total length of the felled stem was measured and the height of the stump surface above the ground added to obtain total tree height.
6. The length of the leading shoot was measured and the shoot was then carefully removed in a labelled polythene bag.
(The needles from the leading shoot were to be analysed for plant nutrients and the results used in the diagnosis of nutrient deficiencies, following the recommendations of Leyton and Armson (1955).
7. The uppermost lateral shoots were treated similarly.
(The needles from the uppermost laterals were also collected in case they should also be required for analysis.)
8. The distances between adjacent branch whorls were then measured for as far back from the uppermost whorl as they could be reliably recognized.
9. From those stems capable of providing one a section about 2 inches long was taken at breast height. For the smallest trees a similar section was taken from the butt. (Cover photograph).

The shoots taken were oven-dried at 100° C. the next day and the needles removed. An enlarged record of the size and shape of a random sample of the needles from each leading shoot was made by placing them on a glass plate in the film carrier of a photographic enlarger and printing their enlarged shadows (at about × 3 linear) on bromide paper. The girths of the stem sections were measured. All needle samples were then ground to pass a 1 mm. sieve in a 'Casella' grain mill. The peat samples were stored at about 1° C. for a few days. One

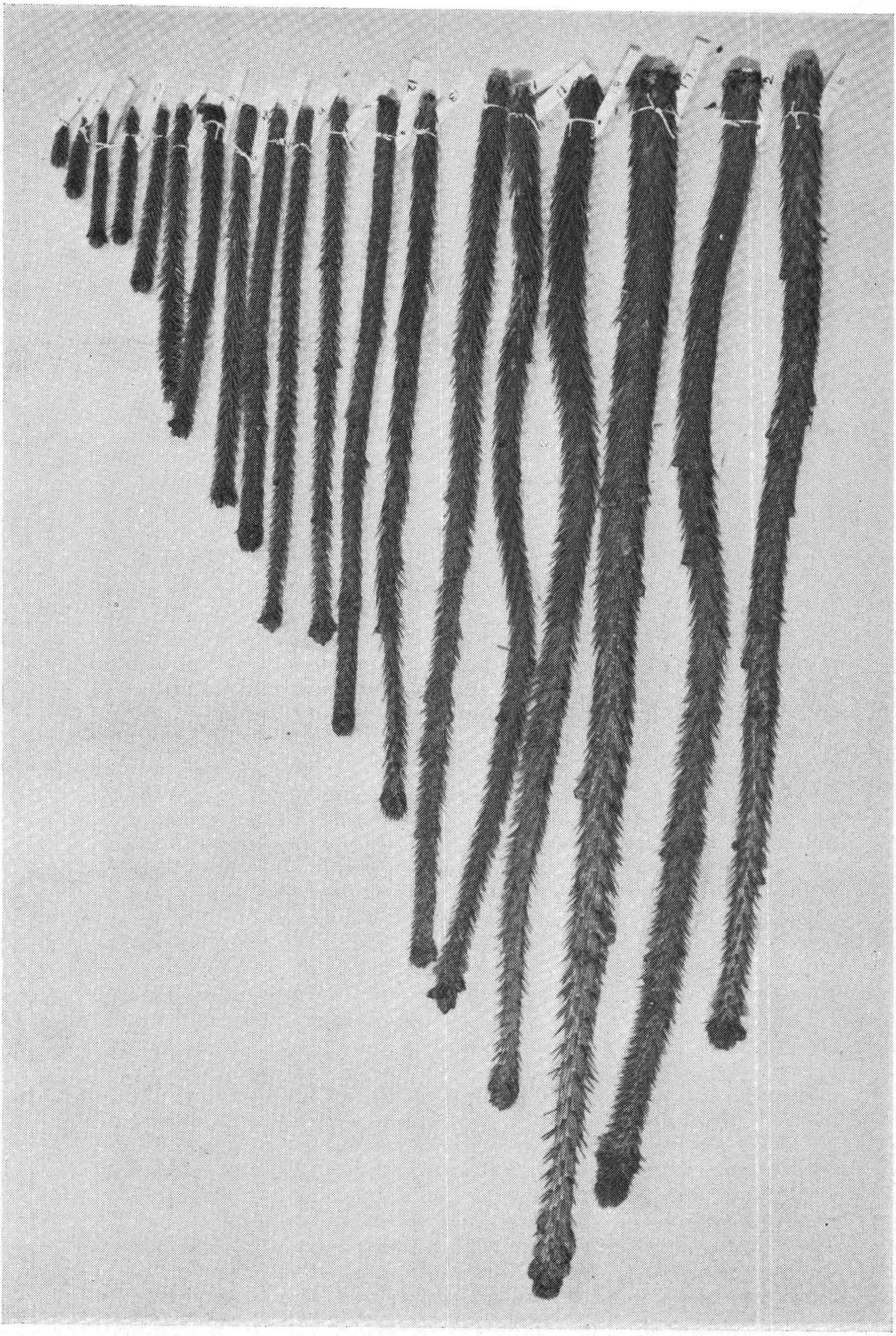
* The twenty-first tree on Site 5/60 was intended to replace one which on felling proved to have a double leading shoot, but as samples taken from all trees were later analysed the data for the 21 trees have been included in the results.

of each pair was then used for the determination of pH; a spear-type glass electrode and reference electrode were inserted into the peat as collected and the value read dirctly from the scale of a 'Pye General Purpose' pH meter. The other was oven-dried at 100° C. in a forced draught oven and milled to pass a 1 mm. sieve. The leading-shoot needle samples were analysed for their total content of nitrogen, phosphorus, potassium, calcium, magnesium, sodium and managanese. After the results of the needle analyses had been examined the peat samples were analysed for their total content of N, P, K, and Ca. N was determined by the semi-micro Kjeldahl method. The remaining elements were determined using a solution prepared by mixed-acid digestion. P was determined by the molybdenum-blue method using stannous chloride as the reducing agent. Both Na and K were determined by means of an 'EEL' flame photometer. Ca was determined by compleximetric titration with EDTA using murexide as the indicator; Mg by the titan-yellow method; and the Mn by the periodate method. During the summer of 1961 further observations were made on the relationship between tree size and vegetation type on Site 4/60.

Results.

Tree height was taken as a measure of overall tree growth and the relationships between this quantity and the other recorded variables were examined. On Site 4/60 the relationship between tree height and length of current leading shoot was strikingly linear (Plate 1).

The equation for the regression line of height on length of leading shoot (in cms.) is $Y=12.66\ X + 93.8$, with a correlation coefficient (r) of .94. This relationship is consistent with the hypothesis that the planted trees have responded and are still responding consistently to differences in site fertility within the area sampled. On Site 5/60 the corresponding relationship is less regular (Plate 2) but there is an obvious tendency for the height increments of the tallest trees to fall below those of the trees of intermediate size. The history of the height growth of each tree sampled was reconstructed for as far into the past as the measurements between branch whorls would allow. This was to 1948 for Site 4/60 and to 1945 for Site 5/60. The seven largest trees on Site 5/60 began to show a fall in height-growth rate in 1953. A comparison of height-growth increments in more recent years is complicated in that all but the most stunted trees on both sites showed a marked fall in increment for the years 1957 and 1958. Since 1958 however only this group of large trees on Site 5/60 has failed to show a recovery, and the mean height increment for this group in 1960 was less than that of the 7 next tallest trees on the same site. This evidence is consistent with the hypothesis that the environmental conditions of the larger trees on Site 5/60 have markedly deteriorated in recent years. There is a significant negative correlation between tree height and peat depth on Site 4/60 (r=.754, *P* better than .001) but inspection of the actual dot diagram shows that the relationship owes more to the absence



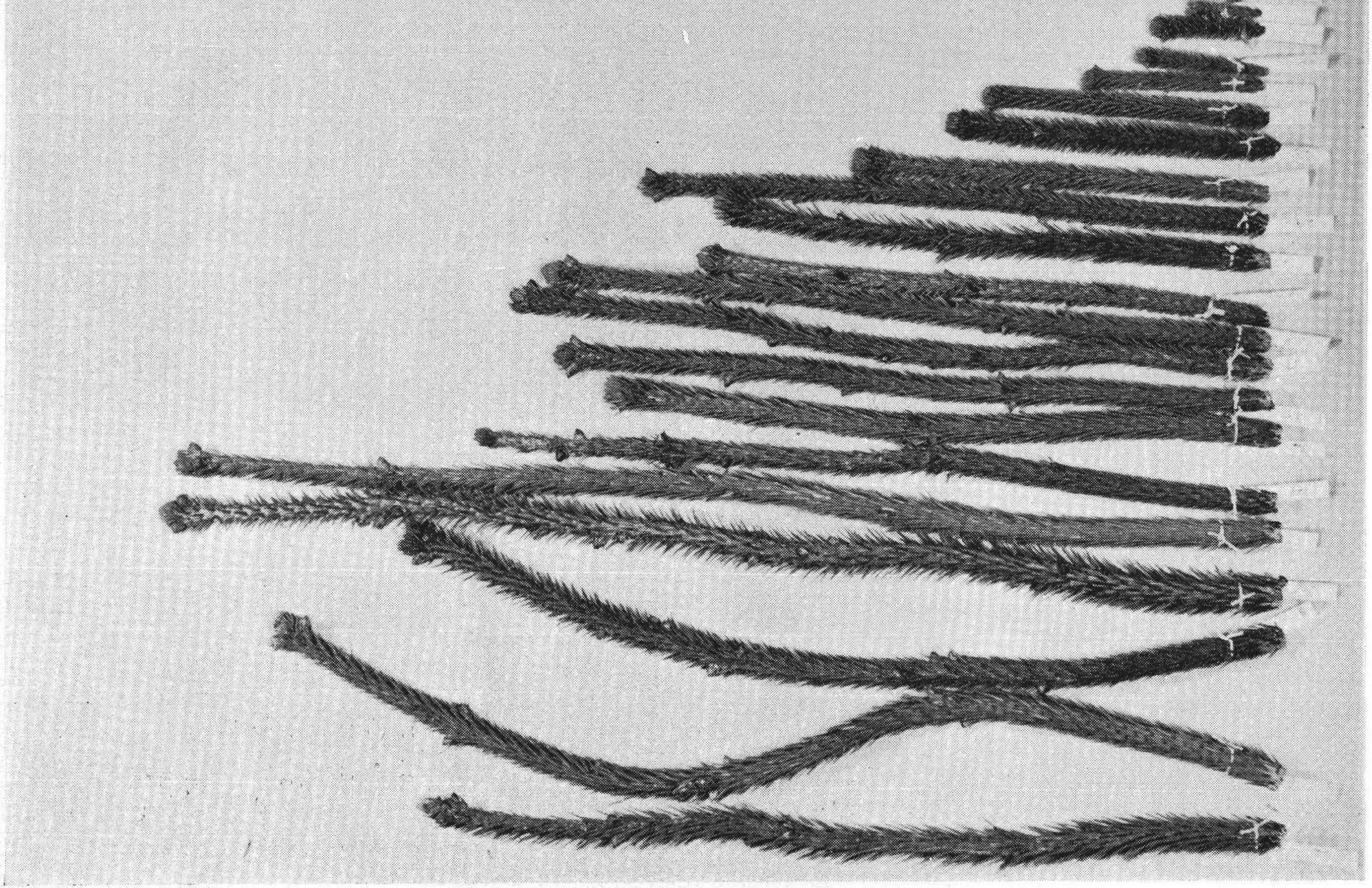


Plate 1. Leading shoots from the two groups of 20 sample trees taken on Springwell 4/60, the shoots arranged in each group in order of tree height; smallest tree towards the top of page.

of small trees from the shallow peat than to the absence of tall trees from the deeper peat, e.g. whereas there are no trees under 400 cms. (13 ft. 6 ins.) on peat of under 3 ft. 6 ins. deep there are 5 trees of over 900 cms. (30 ft.) on peat of over 2 ft. 6 ins. deep. Data for the 21 trees on Site 5/60 indicate no simple relationship between peat depth and tree height. Trees under 400 cms. occur on peats both 9 ins. and 5 ft. deep but the tallest trees are confined to peats between 2 ft. 3 ins. and 4 ft. 6 ins. deep.

Vegetation.

The vegetation accompanying the trees on Site 4/60 was examined in detail and classified into six 'types' to allow the relationship between vegetation and tree height to be examined. The six types were defined as follows:

Type 'F'—Tall *Calluna vulgaris* (c 4 ft.) forming a more or less complete canopy, accompanied by frequent but small tussocks of *Molinia caerulea,* and occasional small tussocks of *Eriophorum vaginatum.* Beneath the weaker parts of the *Calluna* canopy, occasional mounds of *Sphagnum* (*S. rubellum* and *S. plumulosum*) and an incomplete ground layer consisting of the pleurocarpous mosses listed under Type 'D'.

Type 'E'—*Calluna* still present but tall and weak or already dead. *Molinia* more conspicuous and mounds of *Sphagnum* species larger and more frequent.

Type 'D'—*Calluna* absent. Almost complete bryophyte cover consisting of a thick spongy carpet of several pleurocarpous mosses, the most abundant species being *Hypnum cupressiforme, Rhytidiadelphus loreus, Plagiothecium undulatum, Hylocomium splendens,* and *Pleurozium schreberi,* with cushions of *Dicranum scoparium,* and occasional hummocks or more numerous small patches of several *Sphagnum* species. (*S. palustre, S. recurvum* and *S. rubellum*). Small tussocks of Molinia locally frequent.

Type 'C'—Similar to Type 'D' but *Sphagnum* species absent and other mosses less luxuriant.

Type 'B'—Forest floor bare except for a few thin wefts of pleurocarpous mosses, the most abundant species being *Hypnum cupressiforme, Thuidium tamariscinum,* and *Eurhynchium praelongum.*

Type 'A'—Vegetation absent.

Nine plots fifteen feet square were selected within the area sampled as bearing vegetation of the types described above; two plots each of types C, D, and E; and one plot each of types A, B, and F. The heights of the 70 trees present on these plots were measured, and also the B.H. girths of all but the smallest. The data for these 70 trees were combined with those for the 40 trees taken as samples. A close relationship between tree size and vegetation type was found to exist, the six

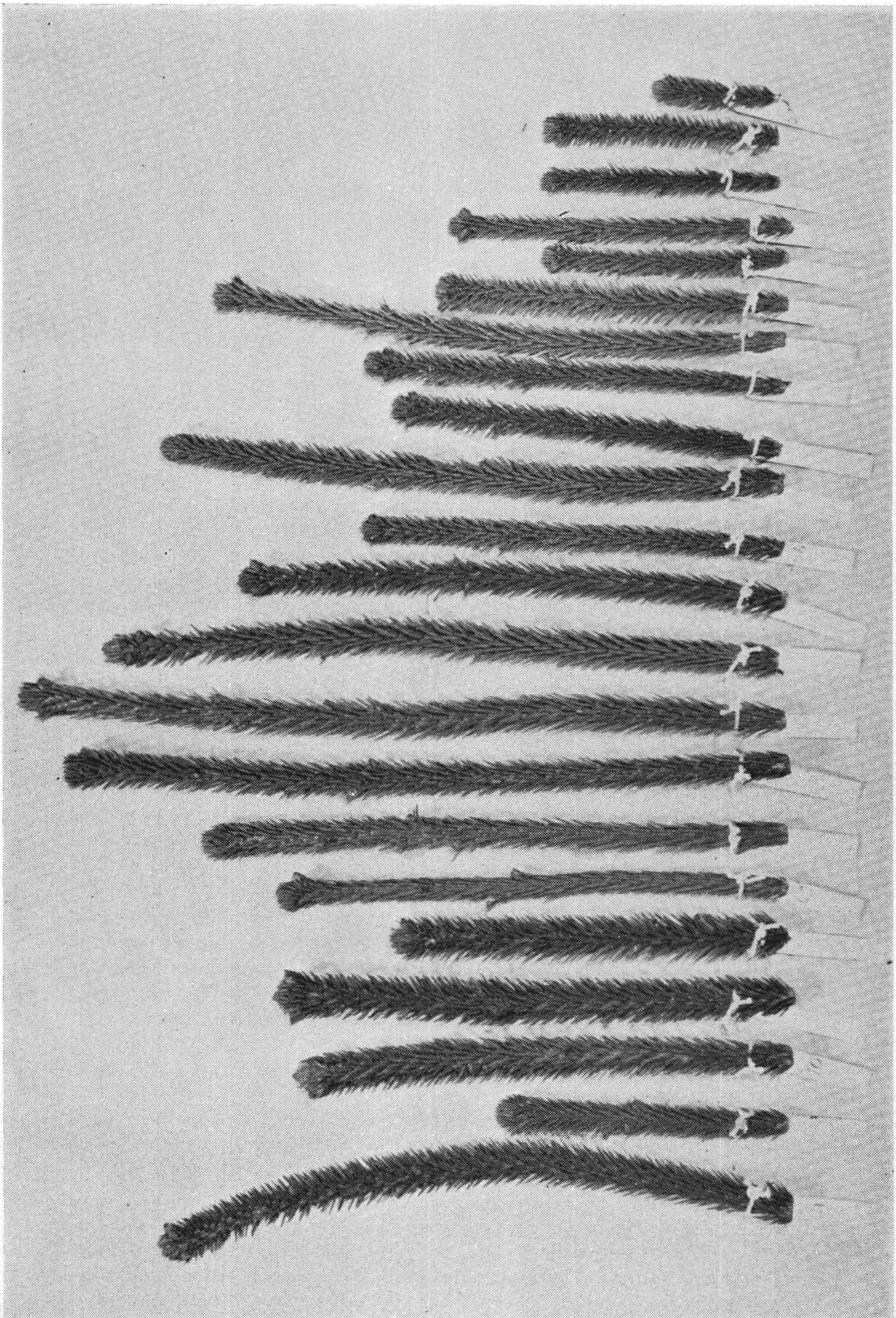


PLATE 2. Leading shoots from the 20 sample trees taken on Springwell 5/60 arranged in order of tree height; smallest tree towards top of page.

types from 'F' to 'A' indicating progressively higher fertility levels. A summary of the data is given in Table I.

Table I.

Vegetation type	Mean Height (cms.)	Mean Girth (cms.)
'F'	182	—
'E'	370	20
'D'	569	30
'C'	715	35
'B'	903	41
'A'	1,153	52

Foliage analysis.

The relationships between tree heights and nutrient contents of the needles taken from the leading shoots were examined for both sites. Dot diagrams were prepared for the individual elements, and for those cases in which recti-linear relationships were suspected the regression of tree height (in metres) upon foliage nutrient content (as percentage dry weight) was calculated. For those in which a significant linear component was found the correlation coefficient was also calculated. (Figs. 1-4).

Nitrogen—There are strong positive relationships between tree height and total needle N on both sites. For Site 4/60 $r = .869$ and for Site 5/60 $r = .797$ with P better than .001 on both. This fact considered alone suggests a deficiency of this element over the whole, or at least the greater part, of the range represented (Leyton 1957a). If this were so the actual levels of N in the foliage would be expected to be sub-optimal. Leyton has suggested, on the basis of work with Sitka spruce on heathland sites in England (Leyton 1954 and 1958a, etc.), that the optimum value for this species lies between 1.5 and 1.6%. This suggestion appears to rest on the results of two experiments. In one the higher N levels were obtained by 'scalping' the surrounding heath vegetation, a type of disturbance which in some instances had an inimical effect on the trees' water relations. In the other supra-optimal concentrations of N in the foliage were not definitely established. This estimate may therefore be low. Recent work by Ingesstadt (1959) indicates that the optimum for Norway spruce is at about 2.0%, and that of Tamm (1956) that it is rather higher than this. In the present investigation all but the three highest values for Site 4/60 were less than 1.6% so the case for the existence of N deficiency on both sites is well established.

Phosphorus—There are also strong positive relationships between needle P and tree height on both sites. For Site 4/60 $r = .701$ and for Site g/60 $r = .680$ with P better than .001 for both. Considered alone this would suggest that growth on both sites was limited not only by N but also by P supply. Leyton has suggested that the optimum level of P for Sitka spruce is 0.14% (1957) but as Ingestadt (1959) observes, this value was obtained as a result of an experiment in which supra-optimal concentrations were not definitely established, and it may therefore be too low. Wright (1959) has reported growth responses of Sitka spruce with heavy application of G.M.P. up to a foliar P content of .0165% in one experiment (Glentrool 9 P.52) and .0212% in another (Watten 2 P.51) but these responses might have been due to increased availability of N, as the N levels are only 1.45% and 1.52% respectively. Ingestadt (1959), on the results of water-culture work with Norway spruce seedlings has suggested a value of 0.2% as the

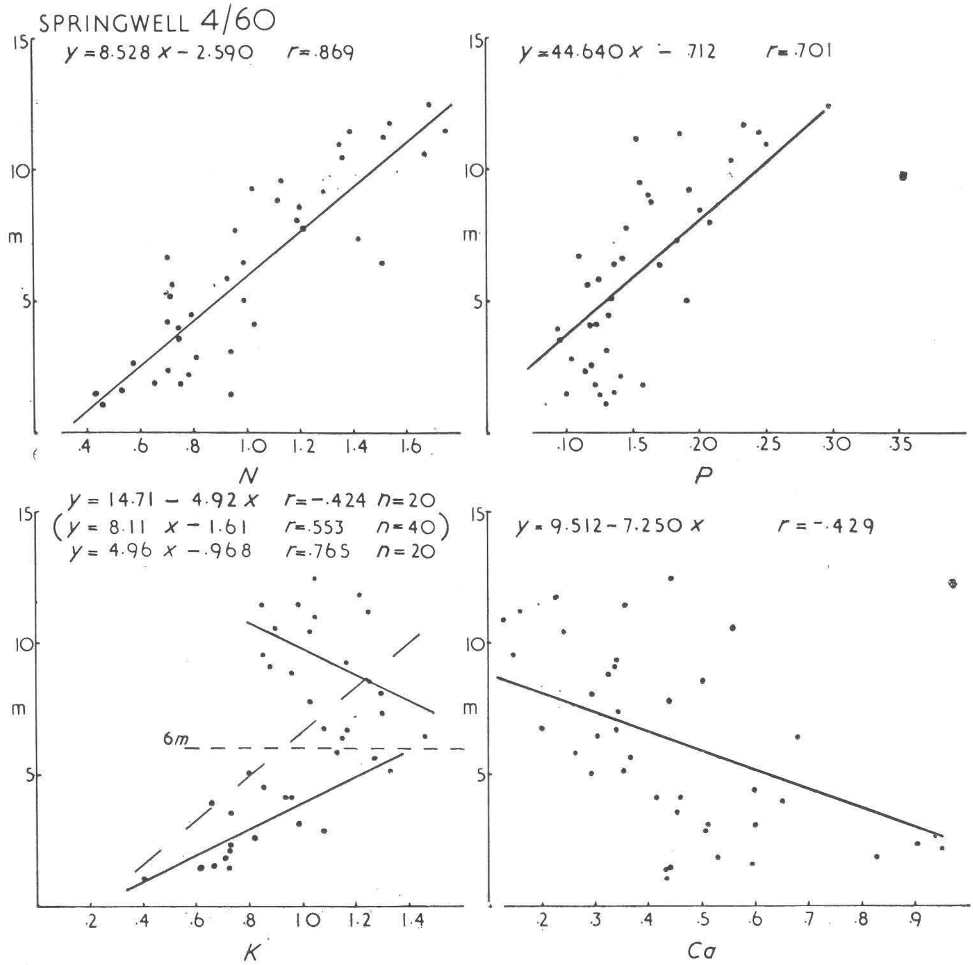


Fig. 1. Springwell 4/60: Relotionships between tree heights (in metres) and the N, P, K and Ca contents (as % dry wt.) of needles from leading shoots.

optimum for P. In the present investigation the mean value for Site 4/60 was 0.158% and for Site 5/60 it was 0.125%, with maximum values of more than 0.3% and 0.2% respectively, so the height range over which P is limiting current growth on these sites remains problematical. It is of some interest to note that the smallest trees on Site 4/60, e.g. those below 300 cms. (10 ft.) tall, and almost confined to vegetation type 'F', have rather higher P levels than would be expected from the nature of the overall relationship between tree height and P for the site. This may well be an indication of the peristence of the effect of the P given at the time of planting in trees the growth of which has been greatly retarded by some other deficiency or other deficiencies.

Potassium—Although there is a significant linear component in the

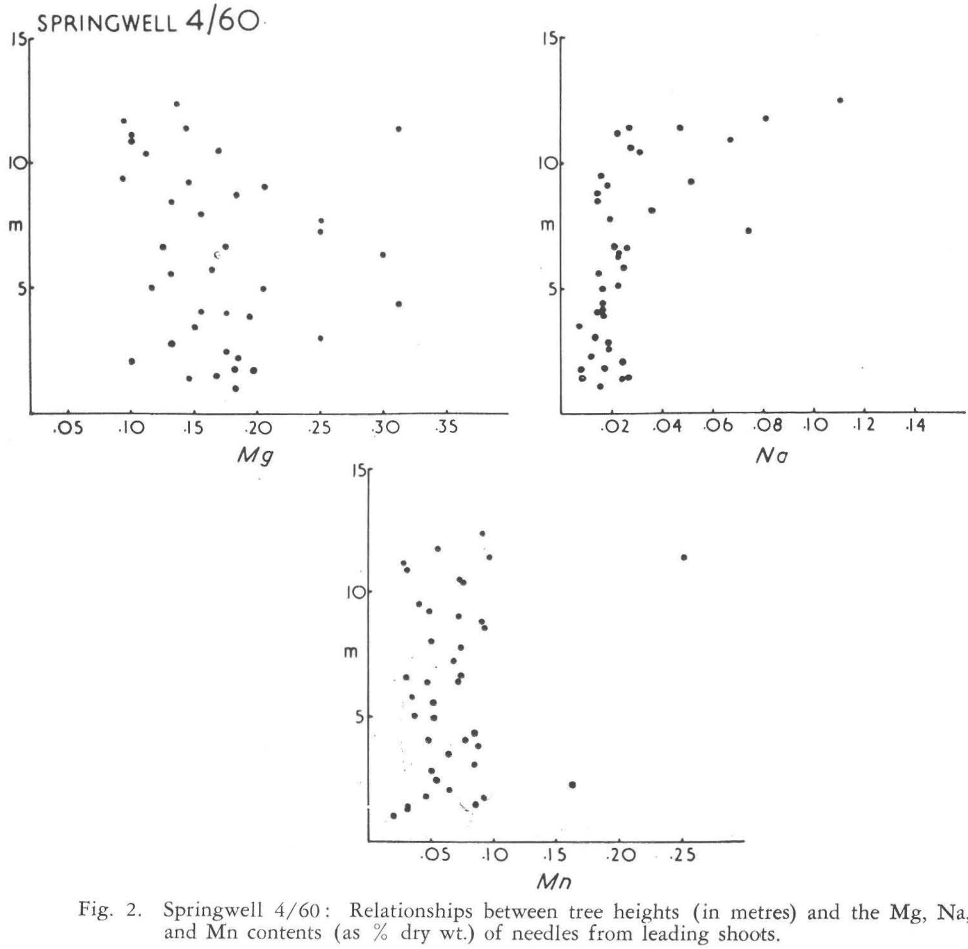


Fig. 2. Springwell 4/60: Relationships between tree heights (in metres) and the Mg, Na, and Mn contents (as % dry wt.) of needles from leading shoots.

relationship between needle K and tree height, considered on the data as a whole (r = .553 with *P* better than .001), it is clear that the relationship between these two variables is different in the two halves of the tree height range. If the taller 20 trees, i.e. above 600 cms. (20 ft.) are considered alone the relationship is negative, with r = —.424 and *P* approximately .05, but if the 20 smaller trees are considered alone the relationship is more strongly linear and positive, with r = .785 and *P* better than .001. Few estimates for optimum K content of Sitka spruce needles have been made. Leyton (1957) has suggested an optimum value of 1.5 for the N/K ratio. For the optimum

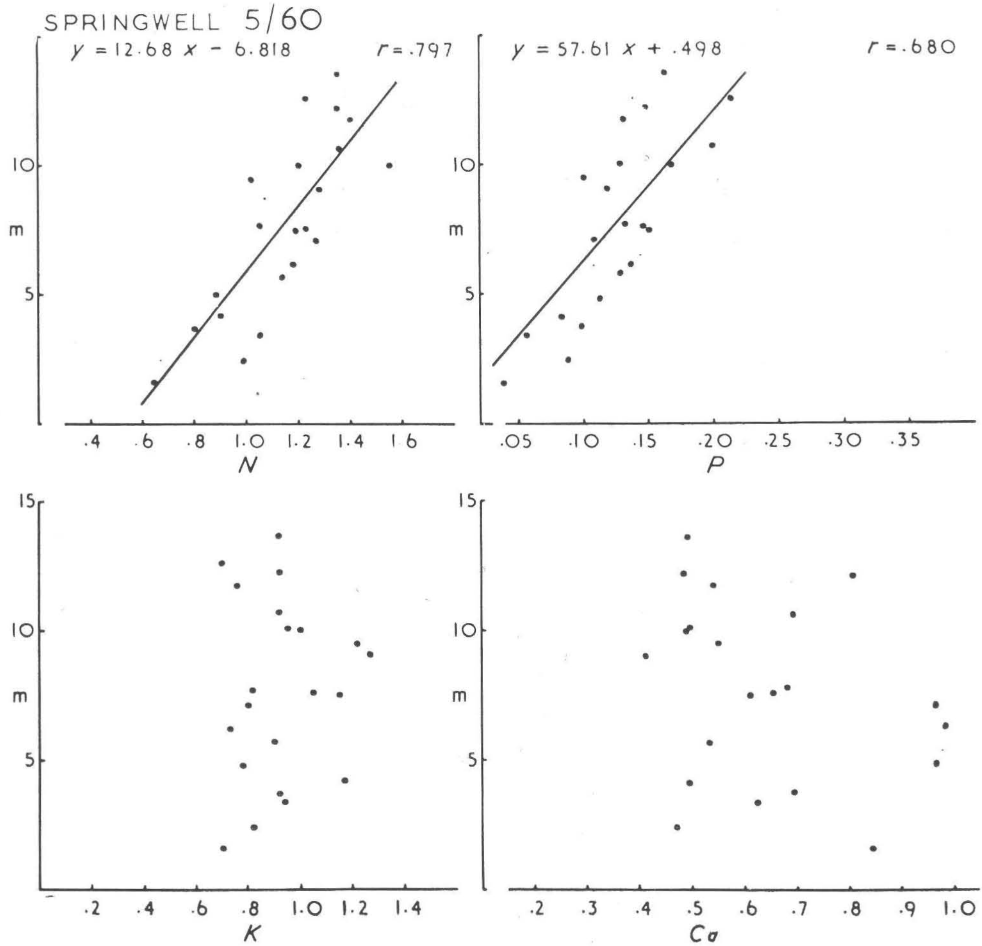


Fig. 3. Springwell 5/60: Relationships between tree heights (in metres) and the N, P. K, and Ca contents (as % dry wt.) of needles from leading shoots.

of 1.5% N indicated by the same experiment this means a K optimum of 1.0%. Ingestadt (1959) suggests a value for Norway spruce of 0.9%. The strongly linear positive relationship between K% and tree height over the lower half of the height range and the occurrence within this range of K contents less than 1.0% only in trees of less than 500 cms. (16 ft. 6 ins.) tall strongly suggests that K is limiting growth on this site for the trees which have not yet closed canopy and thus eliminated the bog vegetation beneath them. This is a condition which might have been anticipated from our knowledge of the distribution of K in the vegetation and peat of unplanted sites (Parker 1962). Those methods of diagnosing nutrient deficiencies which rely on demonstrating linear relationships between the nutrient level and growth assume relative constancy of soil fertility, at least between the time of

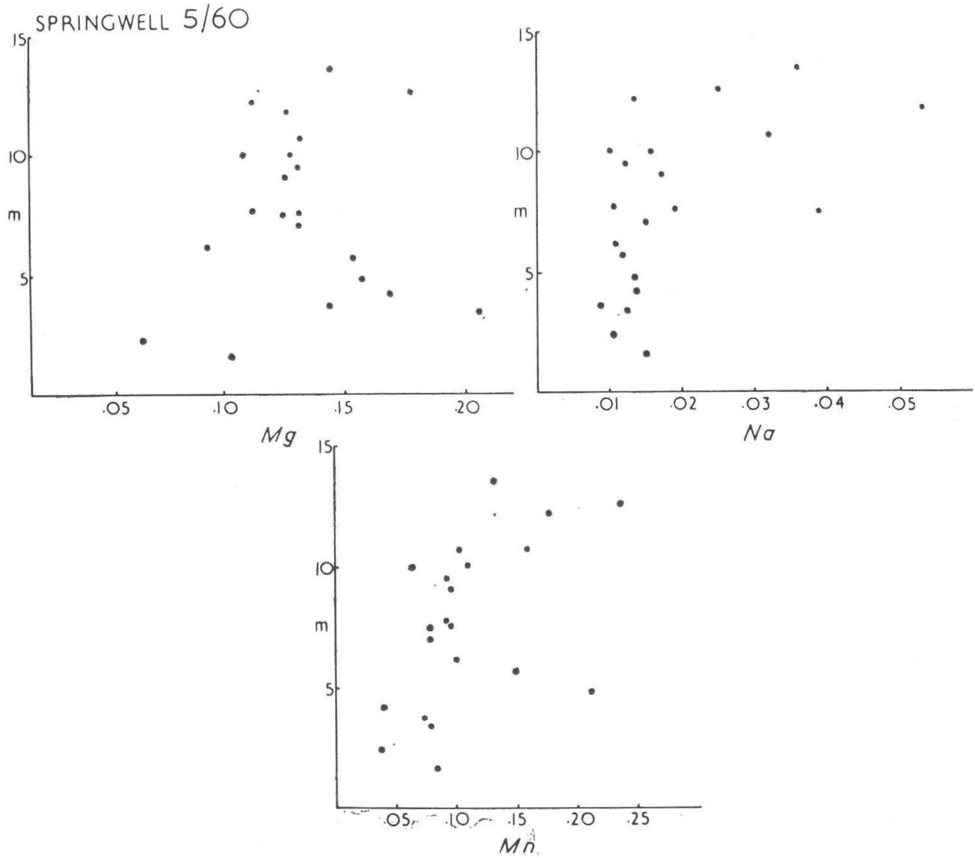


Fig. 4. Springwell 5/60: Relationships between tree heights (in metres) and the Mg, Na, and Mn contents (as dry wt.) of needles from leading shoots.

planting and of sampling. For peatland planations of more than a few years old this is not justified. The negative relationship shown here by the larger trees and the relatively low levels of K (0.8% and less) in the foliage of a few of the largest trees, are surely due to the failure of the faster-growing trees to obtain adequate supplies of K after exhausting those concentrated in the living bog vegetation and surface peat (Binns 1962). Further and stronger evidence of the depletion of peat nutrients will be presented later in this paper. The values for K content on Site 5/60 give no significant indication of the existence of a similar situation on that site.

Calcium—On site 4/60 there is a significant negative relationship between tree height and needle Ca content, with $r = .429$ and P about .01. This, considered alone might suggest that the concentrations of Ca are supra-optimal throughout and that the growth of the smaller trees in particular is retarded by high Ca levels. The significance of different Ca levels in Norway spruce needles has recently been discussed by Ingestadt (1959). There is no well-defined optimum for this quantity but it would appear that maximum growth of the spruce is possible with foliage values of below 0.1% Ca. In the present investigation even the lowest values are greater than 0.1% so Ca deficiency appears unlikely even for the largest trees. Again, there is no well-defined upper level beyond which Ca is clearly toxic so it is not possible to say on the basis of existing evidence whether the Ca levels approaching 1.0%, recorded for some of the smallest trees, are the cause of their slow growth or the result of it. The Ca values recorded for site 5/60 range from just above 0.4% to almost 1.0% and although apparently supra-optimal their distribution with tree height does not suggest a negative relationship.

Magnesium—The results for Site 4/60 suggest the existence of a negative relationship between foliage Mg and tree height but the probability level of the correlation coefficient does not reach 0.1 Ingestadt (1959) suggests that the optimum concentration of Mg for spruce foliage is about 1.0%. Since all the values recorded for Site 4/60 and all but one on Site 5/60 lie above 0.9% a deficiency of this element seems unlikely. In addition to the trees grown in culture solutions with the highest concentration of Mg used (45 p.p.m.), Ingestadt found Mg levels in the foliage exceeding 0.2% only for trees supplied with the two lowest concentrations of K. It seems possible then that the supra-normal levels of Mg found here (approaching 2% and above) are the result of K deficiency. This suggestion is consistent with the fact that there is no relationship between tree height and Mg% for site 5/60.

Sodium and Manganese—The values for the Na content of the needles taken from both sites mostly lie below 0.3% but those for a few of the taller trees on each site are several times greater. Binns reports similar results (Binns 1959) and suggests that the much higher figures result from the presence of atmospheric NaCl interecepted by the tops of the taller trees. Since the two sites described here lie only about seven miles from the sea this explanation may also apply here. Most of the Mn values for the two sites lie between 0.02% and 0.10% with no relationship between concentration and tree height. A small number of trees have values greatly exceeding 0.10% but the distribution of these values does not suggest their cause.

When more than one element shows a simple linear regression between its concentration in the plant and plant growth it is not safe to assume that the different elements which show his kind of relationship are acting independently. For example, it would not be safe, on the evidence of simple regression alone, to conclude that tree growth on Site 4/60 was limited simultaneously by deficiencies of N, P, and K and by excess of Ca and Mg. It is possible, and indeed probable, that the variation in one element is the result of variation in one or more of the others rather than a separate cause in itself. Leyton, who obtained significant positive correlations between growth of young Japanese larch and percentages of N, P, K, and Ca in the foliage (Leyton 1956) submitted his results to multiple regression analysis and wrote ". . . . . from the analysis of the multiple regression of height on these nutrient factors, it was found that only N, and to a lesser extent K, made significant contributions to the regression and that the apparent relation of growth to P and Ca arose out of significant internal relations between these and the significant nutrient factors." (Leyton 1957a p 40). Leyton was later able to obtain confirmation for his conclusions by means of fertilizer trials (Leyton 1957b). In the face of this a conclusion that P is limiting growth on the sites described here, in the absence of the results of multiple regression analysis, would be suspect. The negative correlations between Ca and Mg contents of the foliage and tree height might be accounted for in terms of simple dilution or as resulting from the deficiency of K, but the positive correlation between the values for N and for P (4/60 $r = .785$ and 5/60 $r = .735$) is quite another matter. No direct evidence of an internal process which would account for this relationship in spruce has been brought forward. Ingestadt (1960) has shown a 50% increase in P accompanying a 300% increase in N with Scots pine but Norway spruce (Ingestadt 1959) showed no sign of this effect. Van Goor (1953) has found evidence of a marked antagonism between N and P with Japanese larch seedlings. Leyton's own results (1957b) with Japanese larch show that with this species fertilization with N reduces the P uptake and in discussing this he allows of the possibility that the interaction takes place outside the tree. The results of Tamm (1956) with Norway spruce and our own with Sitka spruce (Parker 1962) show this same effect. The linear relationship between tree height and the P content of the foliage of the leading shoot is real enough and should be susceptible to a casual explanation. In the absence of independent experimental evidence that increased availability of N, resulting in increased N content of the foliage, by some internal mechanism also raises the P content, the most likely explanation of the results reported here would seem to be that the prime cause of the parallel variation lies outside the trees. Thus, the positive correlation between the concentrations of these two elements in the foliage of the trees on these peatland sites would seem to be due to the variation in an external factor which affects similarly the availability of N and P. The most likely factor is surely the rate of organic matter decomposition in the peat soils.

Peat Analysis.

The results presented so far have been relevant to the first object of this investigation. They have confirmed the existence of N deficiency and indicated also the existence of deficiencies in both P and K, but they have failed to show any marked differences between the sites which would account for the falling growth rate of the larger trees on Site 5/60. Evidence for this comes from an examination of the relationship between tree height and the present nutrient content of the peat in which they are rooted. (Figs. 5 & 6).

Nitrogen—For site 4/60 there is a strong positive relationship between peat N and tree height (Omitting the data for the two trees on 9 ins. peat, the peat samples for which were found to contain a high % of insoluble mineral material, r = .75 with *P* better than .001). The values for the smaller trees lie at about 2% N and for the larger trees at about 2.5% N. The values for Site 5/60 show greater variation overall, there is some indication of a negative relationship but this does not reach significance. These results show however that the smallest trees on Site 5/60 are growing on peat with a very similar N content to that beneath the smallest trees on the other site, but that most of the larger trees are growing on peat with an N content considerably less than this.

Phosphorous—For Site 4/60 there is a strong positive relationship between peat P and tree height (r = .75 with *P* better than .001). The values for the smaller trees lie at about 0.075% P and for the largest they rise to twice this value. The distribution of values for Site 5/60 suggests a negative relationship but the significance level is again not reached. The peat beneath the smallest trees on both sites shows similar concentrations of P but the P contents of the peats taken from beneath the taller trees on the two sites differ widely.

Potassium—As for N and P the relationship between the K content of the peat and tree height on Site 4/60 is positive and significant (omitting the data for the two trees also omitted from the N calculations r = .37 with *P* about .02). The K values for Site 5/60 vary little about their mean of 0.030% and show no relationship with height. Many of the smaller trees on Site 4/60 are growing on peat with about this K content but the mean value of K for the site is 0.044%.

Calcium—The relationship of the peat Ca with tree height on Site

4/60, like that of the foliage Ca, is negative (r = —.56 with *P* better than .001). On Site 5/60 there is no regular relationship between these

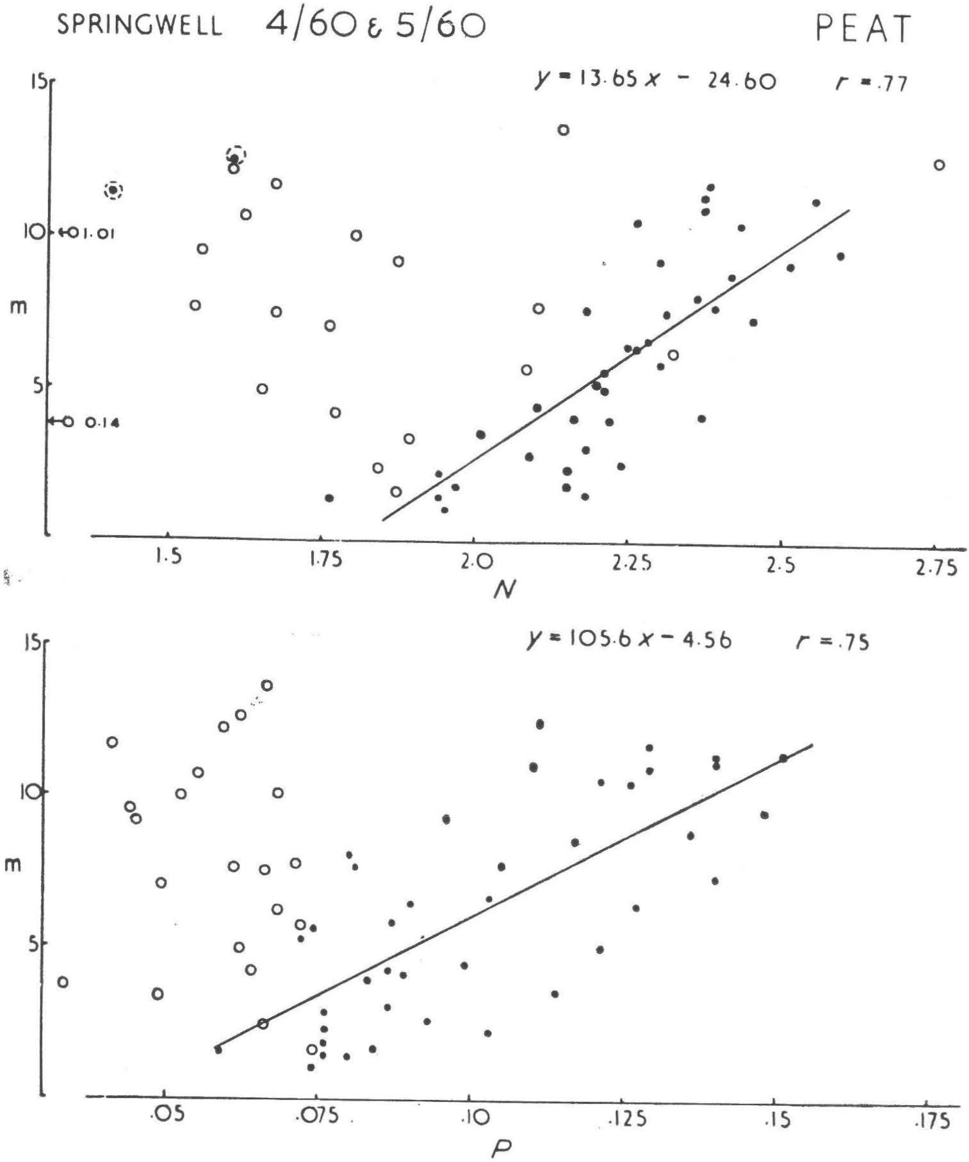


Fig. 5. Springwell 4/60 and 5/60: Relationships between tree heights (in metres) and the N and P contents of the peat on which they are growing. (Points 4/60, Circles 5/60). Points ringed by broken line not included in calculations.

quantities although the absolute values for peat Ca are generally much higher.

The positive relationships shown to exist for Site 4/60, between the tree heights and the amounts of N, P, and K in the peat on which they are growing, show that the original pattern of soil fertility on

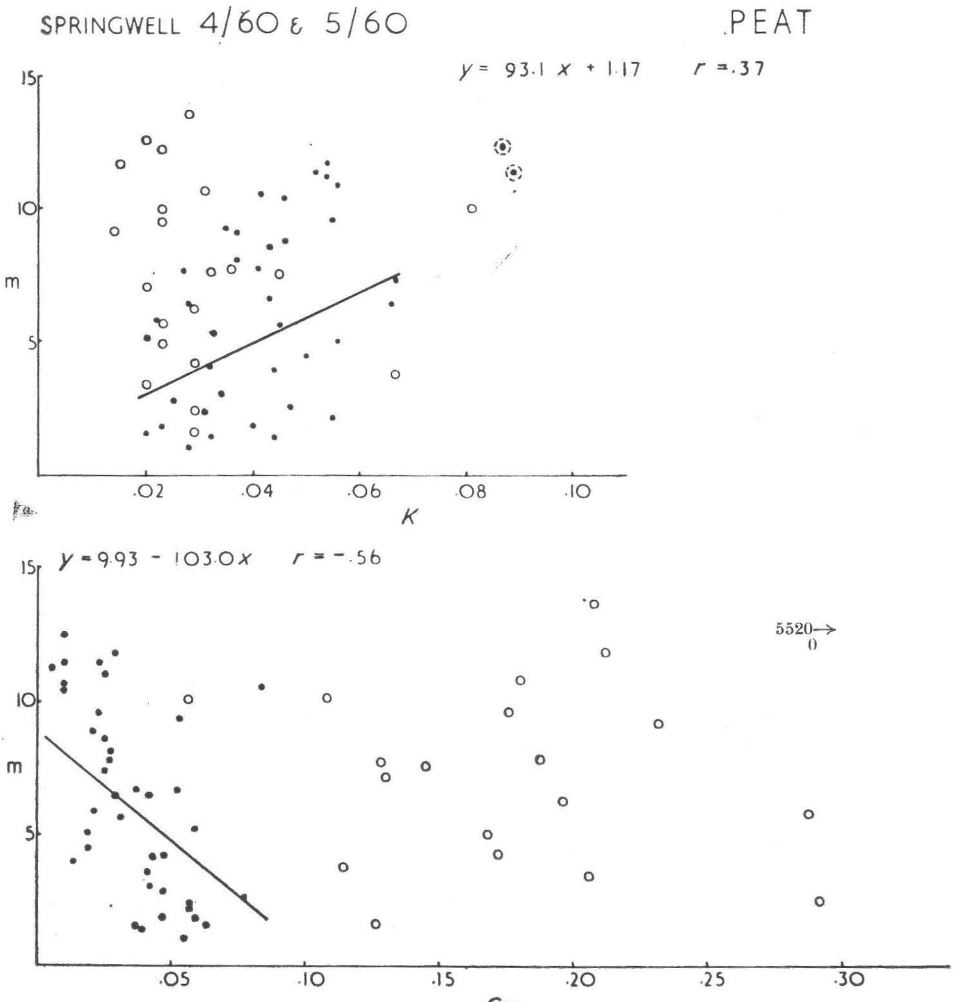


Fig. 6. Springwell 4/60 and 5/60: Relationships between tree heights (in metres) and the K and Ca contents of the peat on which they are growing. Points ringed by broken line not included in calculations.

the site has not been markerly affected by tree growth. Those parts of the site which before planting were richest in N, P, and K have grown the largest trees and are still richest in these elements. The situation on Site 5/60 is quite different. The positive relationship which must formerly have existed between tree growth rate and the nutrient (N, P, and K) content of the underlying peat has gone and there are now indications even of a negative relationship. The largest trees here, although currently bearing foliage relatively rich in these nutrients, are growing on peat containing as little of these elements as the least fertile parts of the other site, or less of them. This must surely be an indication of the extent to which the peat beneath the trees has been depleted. The other marked difference between the two sites is in the Ca content of their peats. Although the values for Site 5/60 are much greater than those for the other site the importance of this difference in relation to the fertility of the site and to its change with time is far from clear.

Discussion.

The analysis of the needles from the leading shoots of the trees on these two sites provided a good deal of information concerning the present nutrient status of the trees and in particular provided the basis for the diagnosis of several nutrient deficiencies affecting growth. But it failed to reveal the major differences between the two sites in terms of nutrient content of the peat beneath the larger trees. These only came to light when the nutrient content of the peat itself was examined. There are three hypotheses which would account for this. It is possible that despite the low nutrient levels indicated by our analysis for Site 5/60 the trees are not affected by nutrient deficiency. Either nutrient supply is maintained at these levels or our technique, by excluding the needle litter and the actual surface peat, has failed to reflect the effective nutrient level of the soil. The third possibility is that although nutrient uptake is now inadequate to maintain past growth rates this deficiency is not significantly reflected in the nutrient content of the current foliage. In view of the fall in growth rate of these trees the third hypothesis seems the most likely, especially since the elements likely to be deficient are all known to be mobile within the tree. This hypothesis is consistent too with the history of heavy needle cast.

Two points of practical importance emerge. It is clear that foliage analysis alone should not be relied upon for the diagnosis of nutrient deficiencies in stands with a falling growth rate, and even if the growth rate is not falling foliage analysis cannot be expected to indicate incipient deficiencies resulting from the depletion of the soil by tree growth. It would appear that although more laborious the combined approach by means of both foliage and soil analyses is capable of providing a clearer understanding of the nutrient relations of the stand and of indicating more reliably the soil amendments required.

Forest soil development has apparently proceeded differently on the two sites investigated and we might examine the available data for the cause of this difference. The plantation on Site 5/60 is 6 years older than that on Site 4/60 and it might be that the difference in development is more apparent than real, i.e. that the stands are following very similar courses of development but that Site 5/60 has developed further. There is some evidence to support this in the fall in growth rate of the few largest trees on Site 4/60 (Plate 1), and for one nutrient element at least in the negative relationship between the height and foliage K content of the larger trees, and the low level of significance of the relationship between tree height and peat K on this site. These sites also differ greatly in the Ca content of their peats and it is possible that the higher Ca content of the peat of Site 5/60 has been one of the factors determining the rate of microbial activity and of peat decomposition on this site. (There is also a small but highly significant difference in mean peat pH between the two sites; Site 4/60 pH 3.20 and Site 5/60 pH 3.59 with $t = 5.5$ and P better than .001).

Prolonged microbial action on fibrous organic matter with a wide C/N ratio normally results in the formation of a more amorphous residue with lower C/N and C/P ratios. It is of interest to note that prolonged microbial activity combined with the absorptive action of the roots of the larger trees on Site 5/60 has resulted, after a period of about 30 years, in the formation of a highly colloidal residue which contains percentages of N, P, and K (per unit dry weight) no higher than the material from which it was formed, and probably less.

Acknowledgments.

The very numerous chemical analysis in this investigation were carried out by Mr. I. T. Hamilton and I gratefully acknowledge his invaluable assistance. The sampling and field measurement was done by a team which included several of my colleagues and several members of the staff of the N.I. Forestry Division; thanks are due to those who took part. Thanks are also due to Mr. W. J. Bryan, the forester at Springwell Forest, who first drew my attention to the sites investigated, and to the Chief Forest Officer for N.I. (Mr. K. F. Parkin) who gave permission for the sample trees to be felled. This investigation forms part of the work carried out by staff and students of the Botany Department, Q.U.B. which has been supported financially by the Forestry Division of the N.I. Ministry of Agriculture.

Summary.

The application of the technique of foliage analysis to two representative peatland plantations in Northern Ireland has permitted the firm diagnosis of N deficiencies and the less firm diagnosis of deficiencies in P and K. It is suggested that the correlation between the N and P contents of the tree foliage and between these and tree height, over the whole tree height range, arises because the availability of these two elements is determined by the rate of microbial decomposition of

organic matter in the peat soil, and that the rate of this decomposition is the main factor limiting tree growth on these sites. The results for K are cconsistent with the hypothesis that at the time of planting a high proportion of the site K is contained within the living bog vegetation. The analysis of the peat soils has indicated the marked depletion of peat nutrients (N, P, and K) by tree growth associated with a current fall in growth rate of the larger trees on one site. The peat on this site has a much higher Ca content; the possible significance of this is discussed.

References.

Binns, W. O., 1959. Ph.D. Thesis, University of Aberdeen.

——— 1962. Some Aspects of Peat as a Substrate for Tree Growth. *Irish Forestry,* **19,** No. 1, 32-55.

Duchaufour, Ph., 1958. L'Utilisation des Engrais en Forêt. *Rev. Forestière Française,* **10,** No. 6.

Ingestadt, T., 1959. Studies in the Nutrition of Forest Tree Seedlings II. Mineral Nutrition of Spruce. *Phys. Plant,* **12,** 568-93.

——— 1960. Studies in the Nutrition of Forest Tree Seedlings III. Mineral Nutrition of Pine. *Phys. Plant,* **13.**

Leyton, L., 1956. The Relationship between the Growth and Mineral Composition of the Foliage of Japanese Larch. *Plant and Soil,* **7,** No. 2, 167-177.

——— 1957a. The Mineral Nutrient Requirements of Forest Trees. *Ohio Jour. Sci.,* **57,** No. 6, 238-345.

——— 1957b. The Relationship between the Growth and Mineral Composition of the Foliage of Japanese Larch II. Evidence from Manurial Trials. *Plant and Soil,* IX, No. 1, 31-48.

——— 1958a. *The Relationship between the Growth and Mineral Nutrition of Conifers, in the Physiology of Forest Trees,* (Thimann, K. V., Ed.) Ronald Press.

——— 1958b. The Mineral Requirements of Forest Plants in *Encyclopedia of Plant Physiology* (Ruhland, W., Ed.) IV, 1026-39.

——— and Armson, K. A., 1955. Mineral Composition of the Foliage in relation to the Growth of Scots Pine. *Forest Sci.,* **1,** No. 3, 210-218.

Parker, R. E., 1957. Some Problems arising in the Afforestation of Peat-land in Northern Ireland. *Irish Forestry,* **14,** No. 2, 118-121.

——— 1962. The Problems of Peatland Forestry. *Irish Forestry,* **19,** No. 1, 4-14.

Tamm, C. O., 1955. Studies in Forest Nutrition I. Seasonal variation in the Nutrient Content of Conifer Needles. *Medd. Skogsforskn. Inst. Stockh.* **45,** No. 5.

——— 1956. Studies in Forest Nutrition III. The Effects of Supply of Plant Nutrients to a Forest Stand on a Poor Site. *Medd. Skogsforskn. Inst. Stockh.* **46,** No. 3.

Van Goor, C. P., 1953. The Influence of Nitrogen on the Growth of Japanese larch (*Larix leptolepis*). *Plant and Soil,* **5,** 29-35.

Viro, P. J., 1961. Evaluation of Site Fertility. *Unasylva,* **15,** No. 2.

Wright, T. W., 1959. Use of Fertilizers in the Afforestation of Deep Peat. *J. Sci. Food Agric.,* No. 12, 645-650.

The establishment of Alder on Peatland and its possible role in Afforestation

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THE only experimental plantings of alder on acid peat which I have come across have been on the Forestry Commission experimental forest at Inchnacardoch, near Fort Augustus in the Great Glen of Scotland. This is a fairly extensive area of blanket peat mostly over one metre in depth and lying around 150-300 metres above sea level. The alders were planted about 30 years ago, the species used being *A. glutinosa, A. incana, A. viridis* and *A. oregona.* None of these was a great success; all failed without the application of a few ounces of basic slag, and when I saw them in 1953 the best trees, *A. incana,* were those which had been given a top dressing of ditch cleanings from the A1 horizon in addition to slag; these had reached a height of four metres. The best *A. glutinosa* was only 1-2 metres high with sparse foliage and extensive die-back and the two other species had failed completely even where slag had been applied.

At the present day I think I am right in saying that alder, mostly incana and Oregon alder, is used for amenity purposes in small flushed areas along roadsides, where it forms thickets a few metres tall.

Between 1949 and 1952 I had gone into the ecology of *A. glutinosa* in some detail and it seemed to me that one should be able to do better than this. I therefore included alder in a programme for investigating the possibilities of establishing native trees by direct sowing on shallow blanket peat at Beinn Eighe in Ross-shire. The results of the alder trials have been published in the Journal of Ecology as Part VII of a series on the ecology of the species (McVean, 1959).

It was immediately apparent that nothing happened if one simply scattered alder seeds over the ground. In wet areas a crop of small chlorotic seedlings was certainly obtained in the first year but these generally failed to survive the winter. If sowing was followed by an application of ground rock phosphate at about 2 oz. per square yard seedlings still failed to appear on the drier peat with a vegetation of *Calluna, Erica, Trichophorum, Molinia* and lichens but a good crop of seedlings was obtained in damper areas dominated by *Molinia, Trichophorum, Myrica, Sphagnum* and other mosses and from this crop a small number of seedlings began active growth, turned dark green in colour and reached about 6 cm. in height by the end of the growing season. These actively growing seedlings were invariably well nodulated while the seedlings that remained small and chlorotic were usually without nodules.

In the spot sowing that was carried out in subsequent years, therefore, the sowing mixture contained an inoculum of crushed alder nodules in addition to ground rock phosphate. Results were extremely satisfactory and at least 90% of the sown spots gave groups of actively growing seedlings in the first season. Spots that had been inoculated without the addition of phosphate gave small green seedlings which were nodulated but failed to develop satisfactorily.

The earlier experiments on this ground were unfenced so that it was not long before the young alders reached a size at which they attracted browsing red deer during winter and early spring. Significant measurements of plant size do not extend beyond five years for this reason. Height measurements can, however, be given as follows :

Year 1	....	5-10 cm.
2	....	40 cm.
3	....	80 cm.
4	....	110 cm.
5	....	175 cm.

In other words these alders are making something very close to their maximum growth rate in virtually waterlogged peat with a pH of less than 4.0. There is as yet no sign of die-back although leaf curl fungi are abundant on the leading shoots as they often are on quick growing alder shoots. The plants have good surface root development among the mosses and *Molinia* leaf bases and these roots are abundantly nodulated. The best growth is obtained where water free from peat acids emerges from the underlying drift or bedrock and irrigates the slope. Plant indicators of this state of affairs are *Schoenus nigricans* and the moss *Breutelia chrysocoma.* Growth is nevertheless quite satisfactory in the absence of irrigation.

The original components of the vegetation also benefit from the added phosphate and show this by an increased growth rate and greener colour. Phosphoric acid will produce the same reaction but not lime, thus indicating that phosphorus rather than calcium is the active ingredient of the rock phosphate.

The final size of the alders remains to be seen and we wait with considerable interest to see if the plants by themselves will bring about any drying of the site. Sowing is being carried out at Beinn Eighe on a sufficiently large scale for this effect to be noticed if it exists.

Bond and his collaborators in Glasgow have established that appreciable quantities of nitrogen are fixed in the root nodules of *A. glutinosa* and that this takes place under field conditions as well as in the laboratory (Ferguson and Bond 1953, Bond 1956). Crocker and Major have shown that increase in total nitrogen in soils developed on glacial moraine in Alaska is probably largely due to colonisation of the moraine by a scrub of *A. crispa* and that when the alder is replaced by *Picea sitchensis* and *Tsuga* forest at 60-70 years there is a fall in the rate of nitrogen accumulation and even a loss of nitrogen from the forest floor (Crocker and Major 1955).

Unlike alder, birch is not generally considered to be a phosphate demanding species. I was therefore slightly surprised to find that naturally occurring birch seedlings and small stunted saplings within the area of the above trials had begun active growth unlike the birches on the neighbouring untreated peatland. Experiments are now being carried out to determine if this is a response to phosphate under very wet soil conditions or if it is associated with the nitrogen fixing activity of the alders.

The alder sowings have so far been carried out without any ground treatment such as ploughing and draining and, in fact, establishment is definitely better on the wetter sites. This preference of the alder for wet or waterlogged ground is purely an establishment phenomenon and after the first season growth is not hindered and may be considerably improved by better drainage. Here then is a way in which nitrogen fixation by the alder might be utilised in peatland afforestation just as the broom is often used as nurse species in heathland plantations. It should not be difficult to arrange for the direct sowing of alder on suitably wet blanket peat one or two years in advance of the usual deep ploughing. The alders will survive ploughing sufficiently well to form a significant element in the resulting forest and this intermixture may prove to have a beneficial effect on the growth rate and productivity of the conifers.

References.

McVean, D. N., 1959. Ecology of *Alnus glutinosa* (L.) Gaertn. VII. Establishment of alder by direct seeding of shallow blanket bog. *J. Ecol.* **47:** 3, 615-618.

Ferguson, T. P., and Bond, G., 1953. Observations on the formation and function of the root nodules of *Alnus glutinosa* (L.) Gaertn. *Ann. Bot. N.S. XVII:* **65,** 175-188.

Bond, G., 1956. Evidence for the fixation of nitrogen by root nodules of alder (*Alnus*) under field conditions. *New Phyt.* **55:** 2, 147-153.

Crocker, R. L., and Major, J., 1955. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. *J. Ecol.* **43:** 2, 427-448.

The Progress of Peatland Afforestation in Northern Ireland

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IN this paper it is proposed to outline the progress made in peat afforestation to date in Northern Ireland. Current methods will be described and a description of future trends given.

The present ultimate target of the Ministry is to have approximately 150,000 acres in production by the year 2,000 A.D. The present reserve of plantable forest land is around 40,000 acres of which approximately 35,000 acres are on peat. Current policy is to plant about one-eighth of this reserve annually and the present planting programme is approximately 5,000 acres. It is estimated that, of this figure, 4,000 acres are on peat. Future planting programmes will depend on the rate of acquisition of land and will vary proportionately with it. To date an area of 58,700 acres has been planted, 25,000 of which is on deep peat.

It was not until 1949 that large scale attempts at afforesting deep peat were made. It is true that some small peat areas were planted prior to this date but most were on shallow peat. 1949 is, therefore, regarded as the beginning of the mechanized deep peat afforestation era in Northern Ireland.

Mechanization.

The economics of afforesting deep peat hinge largely on the machinery used and it is interesting to consider the pattern of machinery development in Northern Ireland.

In 1949 when 12 acres were experimentally ploughed at Ballypatrick Forest at 20 ft. spacing, a Fordson tractor with Rotaped conversion and a Turnall plough were used. Later in 1949 and in 1950 a Single-furrow Cuthbertson MK. I plough was used. Many will recall this unit with its characteristic rectangular transporter portal. 1951 saw a change to a Fowler Mark V unit with the same Cuthbertson plough. In 1952 a Beggs plough was purchased and used with the

Fowler. David Brown D.30 and D.50 Trackmaster Crawler tractors were used from 1953 with the Single-furrow Cuthbertson plough. The Beggs unit was also used during this period.

A Cuthbertson Water Buffalo was purchased in 1953 and with it Cuthbertson Single (Type F) and Double furrow (Type P) ploughs. This tractor was successful but found expensive to maintain. Its initial cost was high and the optimum drawbar pull of around 15,000 pounds was considered in excess of that required. The Water Buffalo has now given way to Fordson County Crawler wide gauge, swamp model tractors. These units first appeared in 1955 and modified versions are now in universal use. Present models have 30 inch wide extended length tracks, front mounted winches and ground anchor equipment. They still retain the 2.5 lb./in. ground pressure of the Buffalo but have a draw-bar pull of 10,000 pounds. The cost of the unit is approximately half that of the Buffalo. Cuthbertson ploughs, types P. and F. with minor modifications, are still in use.

Plantation Layout, Drainage and Ploughing.

In the early days of mechanized peat ploughing the ploughing was regarded more as an alternative to the old turfing method than a drainage method. Both aspects are now considered together. Formerly the practice was to produce a minimum number of plough scores which could be cut and spread as turves. Current practice now eliminates the cutting and spreading by providing turf ribbons every 5 or 6 feet. The change occurred because of economic comparison of the two methods.

Little heed was paid in the earlier years to forest planning and it was only around 1953 that a standard method of layout was developed. Great strees is laid on careful planation layout and much time has been spent on its development. The following layout system has been used for several years but will be replaced in 1962 by a method which will be described later.

Prior to ploughing, a combined drainage, road and extraction route plan was prepared and based on several basic principles :—

1. The economic extraction of forest produce.
2. Access to fire hazard areas.
3. The elimination of the necessity for cutting out, immediately prior to thinning, extraction paths which expose stand edges, and reduce the wind stability of the forest crop.

In addition the following principles were adhered to :—

(a) Drains were situated with full regard to effect and economy.

(b) Minor extraction routes were made easily negotiable—having a minimum length serving a maximum area.

(c) The forest was divided into management units or compartments averaging 25 acres within the limits of 15 and 40 acres.

This plan was then transferred from the map to the site. Road lines were laid out first, then followed a system of rides which with the roads formed the compartment boundaries. Within each compartment further extraction routes called racks were laid out. These together with the rides were left unplanted. Rides were approximately 35 feet wide and racks 15 feet. Racks were normally situated at intervals of 5 chains thus leaving a maximum extraction distance of around 160 feet from stump to rack edge. When all roads and ride positions had been carefully marked on the ground with survey posts, they were defined permanently with deep plough furrows (Cuthbertson F type). These furrows together with ,'cut-off" drains formed the basis of the main drainage system. "Cut-off" drains were constructed along the upper boundaries of the areas to be planted and so situated trapped all inflowing water.

Additional drains at 30 ft. spacing were then ploughed across the slope at right angles to the racking system. These emptied into the main drainage network.

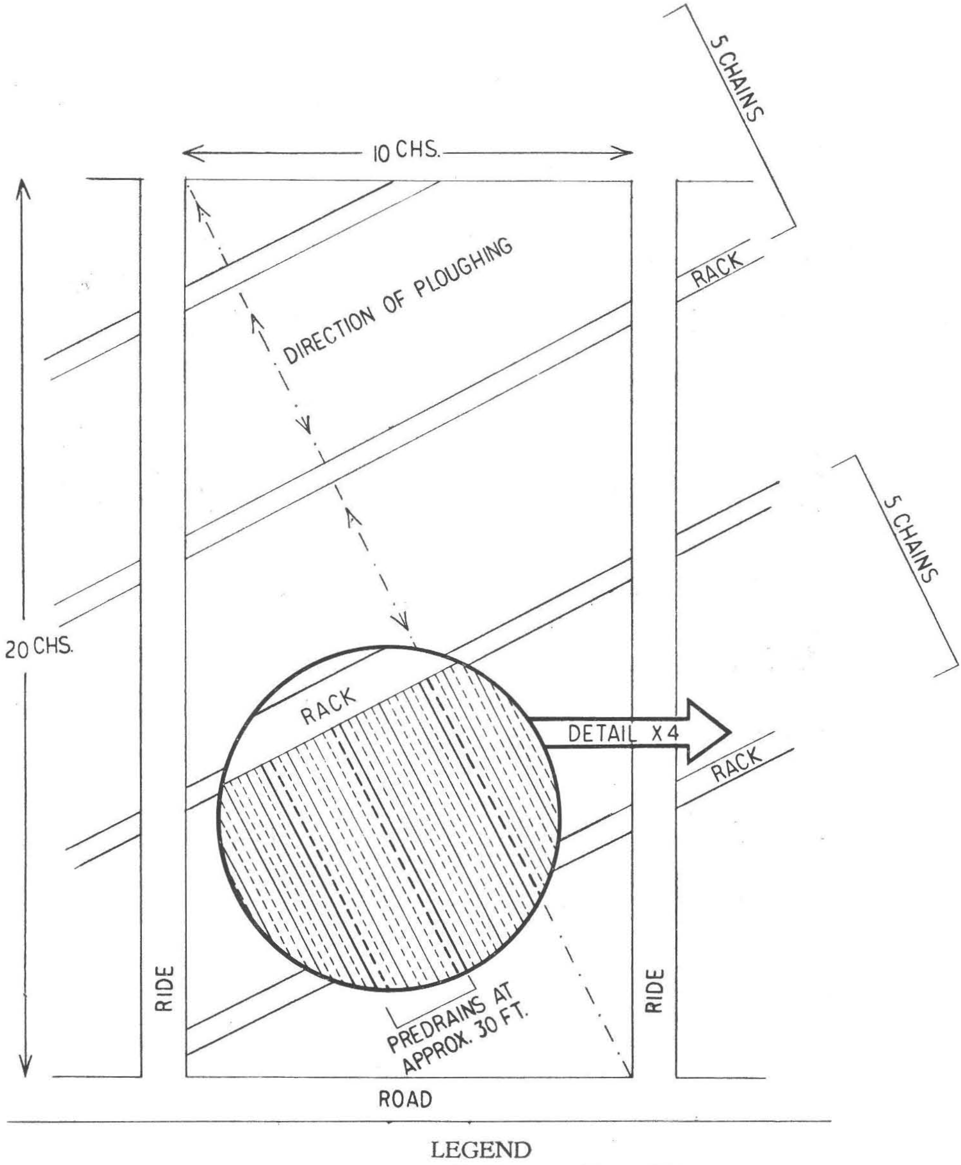
The ploughing described above was termed pre-draining because it preceded the later close pre-planting ploughing. The period which elapsed between pre-draining and planting depended on the wetness of the area. In relatively dry areas it preceded it by only a few weeks and in wet areas by as much as 5 years.

The main purpose of pre-draining was to remove surface water and consolidate the peat surface. This enabled the narrower tracked tractors to be used for the close ploughing. Pre-draining was carried out using Cuthbertson F type ploughs which produced a 30 in. furrow. Some of the drains, after an initial drying out period, were further deepened by hand to 36 inches and in very wet areas considerably widened to prevent closing due to peat flow. Pre-planting ploughing was carried out at 10 ft. spacing using Cuthbertson double furrow ploughs (Type P). The result was a peat planting ribbon every 5 feet. This ploughing was carried out at right angles to the racks which enabled eventual extraction to take place along the tree rows on to the racks and eliminated crossing the irregular surface caused by ploughing. The shallow double furrow drains were deepened by hand where necessary and connected to the main drainage system. This layout system is illustrated in Figure 1.

The main factors responsible for the change in layout and drainage practice were:

(1) The benefits of pre-draining were considered limited and once efficient wide gauge, extended length, tractors capable of negotiating water-logged peat were available, it was found that these could plough satisfactorily at close spacing. The main benefit of pre-draining in the past was simply the removal of surface water.

(2) The eventual difficulty of extraction from stump to rack, entailing an estimated maximum haul of around 160 feet.



LEGEND

(thick solid line)	Cuthbertson Type "F" Ribbon
(thick dashed line)	,, ,, ,, Furrow
(thin dashed line)	,, ,, "P" Ribbon
(thin solid line)	,, ,, ,, Furrow

Fig. 1.

The method currently in use differs from the previous method in the following ways :—

(1) There is no intense pre-draining. Pre-draining consists purely of the clearing of existing watercourses and the tapping of flushes and pools.

(2) Deep ploughing is done at approximately 16 feet spacing using an 18 inch single furrow plough. Between each pair of single furrow drains a double furrow P type Cuthbertson plough is used maximum depth. The present Cuthbertson P type ploughs plough only to a depth of about 12 inches and the development of an 18 inch P type implement is being considered. Ideally the aim is to provide a rooting depth of at least 18 inches for a rotation. The water table must, therefore, be lowered to this level by drainage, evaporation and transpiration. This could best be achieved by using an F type plough every 6 feet, but until this plough can be modified to produce a 9 inch, instead of an 18 inch planting ribbon, the present combination of P and F type ploughs will continue. F type peat ribbon will be "stepped" to produce a satisfactory depth for planting. The machinery section of the Forestry Division of the Ministry is at present working on such a modification.

(3) Every 13 rows one double furrow run will be omitted to form a rack. The distance between racks will, therefore, be about 24 yards giving an approximate maximum stump-to-rack haul of 36 feet. The rack width will be between 16 and 18 feet. In actual practice the rack will be left by omitting one double furrow plough run every 13 rows. This obviously greatly reduces the stump-to-rack haul compared with that of the previous system. It will be seen that in this case the irregular surface produced by ploughing will have to be traversed at thinning to load a machine on the rack but it is thought that this will not present a serious problem over the short distance. This system of ploughing layout is illustrated in Figure 2. The direction of ploughing is not very important from the tree growing or drainage point of view but since the racks are to be parallel to the plough scores it is important that the ploughing should take the shortest line to a road or ride which gives a negotiable rack.

(4) Greater use will be made of natural barriers to extraction, such as streams and main drains, as compartment boundaries. As explained below racks will be left along such barriers. These will provide sufficient area for future extraction and rides will be unnecessary in these circumstances.

In order to standardize drainage terminology and to clarify instruction, three distinct types of drain will be recognized.

(1) *Main drains*—these will be existing watercourses such as rivers and streams.

(2) *Leader drains*—these will be main watercourses formed by mechanical or hand drainage and will include (a) "cut off

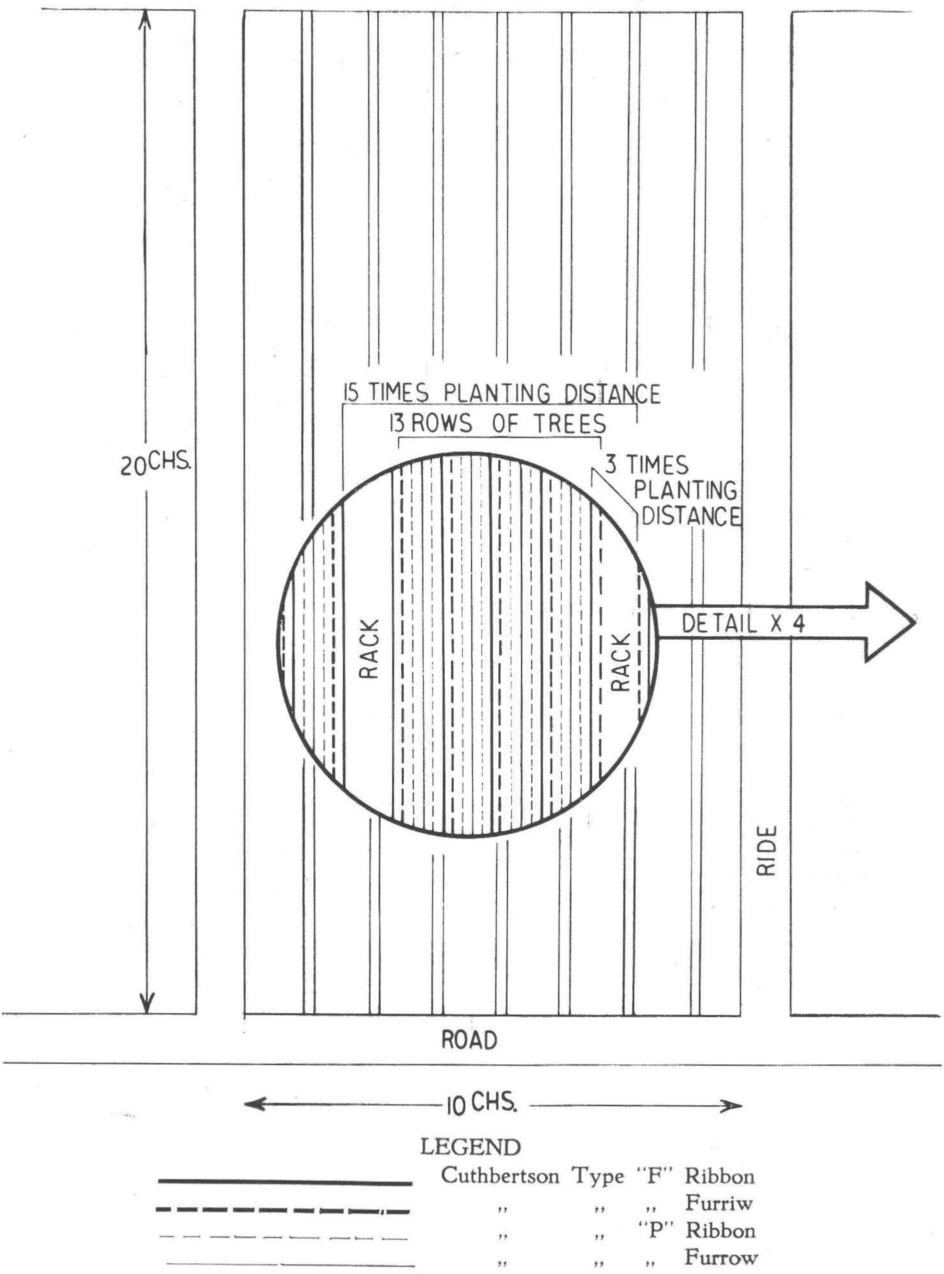

15 TIMES PLANTING DISTANCE
13 ROWS OF TREES
3 TIMES PLANTING DISTANCE
20 CHS.
RACK
RACK
DETAIL X 4
RIDE
ROAD
10 CHS.
LEGEND
Cuthbertson Type "F" Ribbon
" " " Furriw
" " "P" Ribbon
" " " Furrow

Fig. 2.

drains" which trap inflowing water to planting areas and (b) drains which top flushes and pools. Occasionally a leader drain with a particularly high flow may be classified as a main drain. Where practicable these drains will be opened after ploughing for planting has been completed.

(3) *Plough drains*—these will be the F type and P type plough furrows—which may be deepened where necessary to ensure a flow.

It is being assumed that maintenance of many main and most leader drains will be done mechanically and with this in mind racks approximately 7½ feet wide will be left on each side of the drains to facilitate the future use of machinery. Experience in the past has illustrated forcibly that erosion of main and secondary drains can be a serious problem especially where the drains have been ploughed or deepened on to the underlying soil layer. This fact will be carefully considered when siting such drains and definite optimum gradients will be calculated for each soil and peat type.

Coupled with this problem is one of drain "closure" on slopes where the extreme "fluidity" of the peat may, within less than twelve months, render a normal F type drain ineffective. On such areas the tendency is now to excavate the uphill slope to as much as 45°.

Both these problems are still under observation in the field but there is a definite trend towards wider drain bottoms and more gradual side slopes to counteract the trouble.

Possible adverse wind effects following intensive use of the 18 inch plough have been considered. In a departmental report produced following recent field investigations Jack and Forbes (1961) described the rooting habits of Sitka spruce and contorta pine in similar conditions. They do not agree that roots will not cross these drains; and on the contrary they found in all cases investigated that there was strong root development across the drain bottoms. These roots were, however, confined to the litter layer and also to developing *Sphagnum* layers. In some cases the roots had commenced to ascend the opposite drain side. It is probable that with the continuing lowering of the water table, due to evaporation and transpiration, the roots will penetrate deeper and provide increased anchorage. Jack and Forbes in most of the cases investigated discovered roots extending to distances approximately twice the height of the trees excavated—up to the "closing canopy stage".

Roads.

Until recently a road intensity of up to 8 miles per square mile (planted) was planned and most of this was often constructed at the pre-establishment stage.

In future the intensity of metalled roads will be low—approximately 2 miles per square mile (planted). Supplementary road alignments will, however, be left at the 8 mile per square mile intensity in case future technical developments should demand the additional metalled surface.

Fire Breaks.

Where the potential fire risk is high on extensive peat areas which are to be afforested, the forest will be broken into blocks of approximately 250 acres by fire breaks. These fire breaks will consist of a 50 ft. wide cultivated area without vegetation in the centre, with, where possible, 50 ft. wide strips of hardwood trees or fire-resisting vegetation on each side. Fire breaks will follow road alignments and rides where possible. Birch and alder species are at present used experimentally and are being fertilized to ensure early establishment.

Planting Methods.

Practice to date in the majority of forests has favoured the 4 inch semi-circular spade with only local preference for notch planting. Evidence, however, appears to be accumulating in favour of notching but no immediate changes in practice are envisaged. In earlier years planting was carried out at a 5 ft. × 5 ft. spacing but this has now changed to 6 ft. × 6 ft.

Several years ago the practice of planting up to the sides of main drains was prohibited. No planting is now allowed within 5 feet of these drains. This prevents the cutting of many roots during maintenance operations and results in a more wind firm tree crop.

Species.

For many years the main species used was Sitka spruce with fluctuating proportions of contorta pine. Until 1955 considerable areas were planted using mixtures of these two species but the results of this proved so unhappy that the practice was abandoned. Invariably the Sitka spruce fell behind the pine and the ultimate result was an almost pure pine crop which contained many openings. The danger of these openings has been well described by Parker (1957). Divisional policy now prohibits the use of contorta pine except on shallow peat over rocky ground and Sitka spruce is being planted almost exclusively. This choice of species is in direct contrast to that in use on similar sites in the Republic of Ireland. It is justified on the following grounds :—

(1) There is no evidence in Northern Ireland, apart from initial heather check, that contorta pine will grow better than Sitka spruce on deep peat.

(2) There are preliminary indications that re-invasion by *Sphagnum* at the pole stage may be much more difficult to control with a light-demanding pine crop. (Parker 1957).

(3) Market trends suggest that it will be difficult to sell contorta pine in Northern Ireland whereas there is a ready market for spruce.

(4) The potential timber production of a high quality contorta pine crop is considerably less than a Sitka spruce crop.

Fertilization.

Phosphatic fertilizer has been in constant use in various forms for the past 12 years. Basic slag has been most widely used with some local preference for ground rock phosphate and Semsol. Slag is now, however, in use on all forests. Experiments until recently have not provided any conclusive evidence which conflicts greatly with practice.

Fertilizer application has, according to local preference, been "in the hole" or "around the plant". There are, however, indications that greater success can be obtained by (a) applying the fertilizer under the ribbon or (b) spreading it broadcast over the area but only a few small areas have been treated in these ways. Referring again to the investigation of Jack and Forbes (1961), these workers, during their rooting studies, discovered a large solidified portion of basic slag still intact after 6 years. This slag lump was penetrated by a few active roots. Analysis showed a phosphate content of 18%. This discovery is no recommendation for the "in the hole" method. Both the under ribbon and the broadcast methods will be used during the coming year. A recently acquired Bombardier Muskeg tractor will be used for the broadcasting.

Growth Check.

The problem of growth check is well known throughout the British Isles and much experimental work has been done which includes several experiments in Northern Ireland. Present belief is that this early check is induced by the presence of *Calluna.* Many remedies have been and are being tried to prevent the check.

The most efficient, although by no means the most economic, method in use is the hand spreading around plants of material dug from drains. The remedy here appears to lie in the physical suppression of the heather.

In 1958 aerial application of a concentrated NPK compound fertilizer was tried on an experimental basis and following its success it is proposed to treat similarly a 300 acre area with the same fertilizer. It is estimated that on a large scale the cost of aerial treatment per acre will be many times cheaper than that of any other known method.

At this stage it may be pertinent to consider the growth response to the various methods and types of ploughing tried to date. It is now apparent that planting done in the early years when ploughing was carried out at wide spacing and the ribbons cut and spread, is producing poor crops. Development is also poor on deep peat areas ploughed by Beggs plough only. In both cases the poor response may be attributed to inadequate drainage. Methods subsequently used which provide better drainage are more successful and it is difficult to detect any significant difference in the rate of establishment.

This paper has stressed forest policy and practice on deep peat areas. Something, however, should be said of the progress made in the development of the Division's research programme. Several bodies are now co-operating on forestry research in Northern Ireland. These include the Botany and Geography Departments of Queen's University, Belfast, and the Chemical Research Division of the Ministry of Agriculture. The Forestry Division acts as a co-ordinating agency for these bodies and is also conducting many investigations on its own. Apart from a few research projects the greater part of the combined research programme is devoted to problems of afforestation on deep peat. The Ministry constantly changing policy and practice as a result of research developments.

References.

Jack, Dr. W. H. and W. H. B. Forbes, 1961. *Investigations in drainage and tree rooting at Ballypatrick Forest.* Forestry Division, Ministry of Agriculture, Northern Ireland; unpublished report.

Parker, R. E., 1957. Some problems arising in the afforestation of peatland in Northern Ireland. *Irish Forestry,* **14.** No. 2.

The Progress of Peatland Afforestation in the Republic of Ireland

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THE area of bogland in Ireland has been very approximately estimated at 1½ million acres, of which less than one-third consists of midland raised bog, and the remainder of blanket bog (Miller, 1957). A small proportion of this blanket bog occurs at high elevations in the east, mainly in Wicklow, but its main development is towards the west coast, where it occurs right down to sea level. It is intended here to deal with the afforestation of the western blanket bogs because it is on these bogs that the most extensive plantings have been made and there that the greatest potentiality seems to lie, and because midland bogs have formed only a small proportion of our peatland plantings in the past, and are unlikely to increase in importance in the future. This is because in the case of the larger raised bogs exploitation for fuel has priority over afforestation, and in the smaller ones acquisition would be complicated by extensive turbary requirements and rights, turbary being scarce in many areas.

In time large areas of cutover bog will become available for use either for forestry or agriculture. Should the decision be in favour of afforestation the problems presented will be totally different from those presented by the afforestation of virgin blanket bog.

The first government attempt at peatland afforestation, at Knockboy in West Galway, was begun in 1890 with the purchase of almost 1,000 acres, situated on an exposed peninsula with the sea about 2 miles away to North, West and South. The site has been fully described and the work carried out reported by Schlich (1908).

It seems quite likely that, were it not for the fires which have swept Knockboy on several occasions, many of the trees might have survived in a moribund condition but in fact only a few patches, about 15 acres in all, now bear a tree cover. These areas are relatively sheltered and well drained, often with an admixture of mineral matter in the peat, and consist mainly of mountain pine scrub. These small areas are atypical and too unlike the whole to give any indication of the potentiality of the surviving species with present day techniques. The only extensive surviving block is one of about 8 acres situated in a low lying part of the area. This block contains many species apparently distributed in a haphazard fashion. The dominant species at present is *Pinus radiata* which has reached a height of 50 ft. in places, closely followed by *Cupressus macrocarpa* and *Pinus pinaster*. After these come Sitka spruce and *Thuja plicata.* Sitka spruce appears to have grown well in the early years but annual leader growth is now only a few inches. Only one of the species mentioned above, *Pinus pinaster,* appears in the list of species originally planted. When these others were introduced is not exactly known except that it was later than 1900 when the area was disposed of by the Government, although ring counts suggest that it was not much later. Over most of the area not a sign of a tree remains, and even with present techniques the chances of establishing a satisfactory crop on the hill would be assessed as slight. It is an indication of the rashness of the original attempt that only now is a mere seventy acres of relatively less exposed ground in the area under consideration for acquisition by the Forestry Division.

The Knockboy fiasco has had an important place in the history of peatland afforestation in Ireland due to its usefulness as evidence against the possibility of expansion in that direction. It might also be taken, incidentally, as an example showing the danger of selecting the extreme of any problem as a subject for research. One possible advantage, however, is that the very completeness of the failure may have deterred further large scale efforts until techniques had been advanced to such a stage as to give reasonable hope of success.

Following Knockboy, peatland afforestation as a separate issue was not again considered until the late 1940's although during the decades preceding this many areas with a shallow peat cover or smaller areas of deep peat were acquired and planted as part of the normal afforestation programme. The general practice in these areas was to use the Belgian turfing or mounding system introduced to Ireland by M. L. Anderson about 1930, possibly as early as 1928. Drains were 20 ft. to 30 ft. apart giving four to six rows of mounds spread out between them. The inverted mounds, into which the trees were planted, were usually 16 inches square and 6 to 9 inches deep. No fertilizers were used at this time.

But all during this period the vast areas of blanket bog were present as a nagging thought in the minds of foresters, and in the absence of a forest research organization in Ireland the progress of the Forestry Commission experiments on peat afforestation were closely followed. The methods evolved were first studied intensively in Scottish and border forests during the 1947 Commonwealth Forestry Conference and the impressions gained there were reinforced during a study tour in Wales organized by the Society of Irish Foresters in 1949. This was followed by a tour of Scottish peatland forests by officers of the Department in 1950 which led to the purchase in 1951 of 22 tractor and plough units, and this started the large scale peatland afforestation programme which is still proceeding. The progress since that time can be seen from the following figures showing the acreage of peatland planted in the years 1951 to 1960 in the west of Ireland;* peatland in this instance being defined as land bearing a cover of one foot or more of peat:

Year	*Total bare land planted* acs.	*Total peat planted in West* acs.	*Peat as % of total bare land*
1950-51	6,171	590	10
1951-52	11,825	2,290	19
1952-53	9,924	3,070	31
1953-54	10,201	2,880	28
1954-55	11,866	3,110	26
1955-56	13,035	3,910	30
1956-57	15,142	4,460	29
1957-58	17,999	5,340	30
1958-59	20,573	6,460	31
1959-60	23,020	7,160	31
1960-61	24,252	7,690	32
Totals	164,008	46,960	29

As to the types of peatland at present being acquired for afforestation there are no hard and fast definitions and rules, except that there

* Co. Donegal, the province of Connaught, Co. Limerick, Co. Tipperary west of line Roscrea-Tipperary, Co. Kerry, and Co. Cork west of Bandon-Macroom.

must be a reasonable prospect of establishing a tree crop. The usual limiting factors taken into consideration now are exposure and ploughability of site. To date it has been assumed that infertility is a factor which can be artificially adjusted if not controlled, so that in general the types of land excluded are rocky slopes where mechanical cultivation is very difficult or impossible, very exposed ridge tops or upper south and west facing slopes, and expansive flats, pool studded or not, where ploughing is particularly difficult and costly due to softness of the ground, or where drainage cannot be made effective due to lack of slope or lack of suitable outfall. It is thought also that the more extensive flats may be of value as fuel producing areas. This leaves as the modal type of peatland acquired the gentle slopes or undulating areas with a moderate to deep cover of peat and without extensive rock outcrop or free water. Land is only inspected with a view to purchase following an offer by the owner, and a rather small proportion of the land inspected is eventually purchased, the remainder being rejected as unsuitable for one of the reasons already given. Even allowing for this it is remarkable that no less than 70% of the total area at present on offer to the Forestry Division is in the west and it may be assumed that peatland forms a very high proportion of this.

As already indicated, in the acquisition of peatland for forestry only areas which are wholly or almost wholly susceptible to ploughing are considered. Any necessary pre-drainage is attended to first, by opening up natural watercourses, or in the case of very soft ground, ploughing at wide intervals with the Cuthbertson "F" or single mouldboard plough. Ploughing for planting is generally done with the Cuthbertson "P" or double mouldboard plough with drains spaced at 10 to 12 ft. giving ribbons for planting 5 or 6 ft. apart. In some areas it has now become standard practice to use the "F" plough exclusively resulting in deeper drains spaced at 5 or 6 ft. and a larger peat ribbon in which to plant. It is thought that this may reduce later drain deepening operations which, being done by hand, can be very costly. According to the configuration of the ground further drains may be necessary after the general ploughing has been carried out and these are usually put in with the "F" plough running across the previous furrows.

In an attempt to find a solution to the foreseeable difficulty in extraction of produce over the uneven ground resulting from present ploughing techniques and also the instability following the uneven root development induced by planting on ribbons, an experiment on rotovation was laid down at Glenamoy (N.W. Mayo) in 1959. After three years' growth the technique shows little promise. Drainage has been poor and the only species showing any promise now are Sitka spruce and contorta pine; even these are inferior to neighbouring plantations of the same age established after orthodox ploughing methods. Possibly a more promising implement in this line is the tunnel plough developed at the Peatland Research Station of the Agricultural Institute, Glenamoy

(Anon. 1960) but this has only just been tried in afforestation experiments and no results are available.

Although only two species, Sitka spruce and contorta pine, are in general use in peatland planting, the selection of species remains one of the most confused and unsettled issues in the whole field. A common practice seems to be to vary the selection from 100% Sitka on the best types to 100% contorta on the worst, the proportions of Sitka and contorta respectively decreasing and increasing as the quality of the site drops. No general definitions of site quality have been adopted although a scheme has been suggested for the North West (Condon, 1960), but from observations it seems that pure Sitka is confined to peats carrying a vegetation of pure or dominant *Molinia,* or on *Juncus* flushes, while the proportion of contorta rises directly with the proportion of heather present and its dominance.

It is difficult to find any rational basis for this approach. If it can be established that an admixture of contorta can, by suppressing heather, benefit the spruce it is unlikely that the optimal proportion of contorta in the crop will vary very much with site vegetation.

More simply it is often suggested that the mixture is a safe bet, since if one species fails a crop of the other will remain. Since the contorta is unlikely to fail on ground where Sitka will grow, this means that we are deliberately running the risk of having a widely spaced crop of contorta on our hands, and, of all species, contorta is unlikely to form an economically attractive crop under these conditions. Contorta has also been suggested as a stabilizing influence in Sitka. While its ability to produce deep going roots under very wet or waterlogged conditions can be observed in mineral soils this has not yet been extensively demonstrated on peats, and in any case the increased rooting depth is quite possibly counterbalanced by its heavier and denser crown.

In the past contorta pine has been the species used most extensively on peats but with varying degrees of success. Almost all of this variation, however, seems to be safely ascribable to provenance which is a very important factor in this species. When contorta began to be used in quantity in Ireland in the 1920's the coastal form was picked as the most likely to succeed, and this decision has been amply justified on the poor mineral soils and shallow peats of the old red sandstone areas. Where an inland form has been used, usually from inland British Columbia, prospects of producing a closed stand are poor (Mooney, 1957). While none of these older stands are located on the deep climatic peats which are being considered here it seems reasonable to avoid the use of the inland form and in fact no seed from truly inland regions has been purchased since 1948. But still the problem was not solved. Quantities of seed were purchased during the early fifties whose origin was given as Lulu Island, off the coast of British Columbia, and without known exception these have proved to be slow growing and light foliaged, unable to suppress vegetation.

Lulu Island contorta seed, being from young stands, or stands stunted by disease, is cheap to collect (Roche, 1961), and it is quite likely that if its purchase had continued it would have had an effect on peatland afforesation nearly as bad as that of Knockboy.

In recent years there has been an increasing tendency to favour Sitka spruce on peats. While this species has in many cases shown considerable early promise there are cases among the earlier plantings, now up to 10 years old where its present condition does not promise a future as good as its past. As yet, and with present establishment techniques, there are no grounds for optimism with this species on deep peats in general.

Many other species have been tried in various places, usually in a small way, in recent years. Three species which have shown considerable early promise are *Pinus radiata, Pinus pinaster* and *Abies nobilis.* Radiata has been planted in many areas in the west, and although initial failures have been high, early growth has been very good. In the northwest, in particular at Glenamoy, in addition to the initial deaths, further deaths have occurred during the subsequent winters, but these are ascribed to severe climatic conditions. Pinaster is in a rather similar position as far as its early survival is concerned, but again the survivors show considerable vigour. That this early growth can be kept up for sixty years or more is shown by the results at Knockboy, mentioned already. The promise of *Abies nobilis* is along rather different lines from the other two. Although early growth is very slow, survival is usually close to 100% and the individual plants look completely healthy, well balanced and sturdy. Many other species have been tried in one way or another, but as yet none has given any indication that it may supplant any of the species already mentioned.

Routine manuring of newly planted trees on peat came into effect in the early fifties following the introduction of ploughing techniques and the beginning of the large scale expansion of peatland afforestation. Basic slag was used in the first years followed by a change to ground North African phosphate which is now standard. Dressings of 1 to 1½ ozs. per plant are given to contorta pine and 2 to 3 ozs. to Sitka spruce and other species. Areas left unmanured for observation have shown clearly the need for phosphate applications but the optimum rate of application is, of course, not yet known nor is it known whether repeated applications will be necessary. Work on these questions is being carried out by the Research Section of the Forestry Division, and also on the necessity for applications of fertilizers other than phosphates, but there are as yet no positive indications in this field.

A common practice after two or three years growth of the crop, is to deepen by hand every second or third plough furrow to a depth of 2 ft. or more, the sods so obtained being used to mulch the young trees. This seems to produce an improvement in growth, particularly of Sitka spruce, in the years immediately following the operation but there are indications that the improvement may be of a quite temporary nature. The effect of increased drainage is a question which still seems completely open. It is thought that the amount of drainage provided by ploughing is essential—planting on individual sods turned up without a continuous drain have not been successful, but whether this amount of drainage is sufficient, or whether increased drainage will be beneficial, or harmful or have no effect at all is a question on which there are many different personal opinions, but where there seems to be little or no evidence to support a firm conclusion.

We can now consider the results apparent from our decade of peatland afforestation as manifested in the actual growth of the trees. Contorta pine, as the most important species has given no cause for doubt as to its future, where a good provenance has been used. The only exception to this is where it has been planted in conditions of extreme exposure where many trees have shown a tendency to heel over in the early years, and then grow upright, but not always straight. Such crops will have very little commercial value, even for pulp where straight lengths are required, but considered purely as pioneer crops they may be doing a valuable job in preparing the site for a more wind resistant species such as Sitka spruce. It may be doubted, however, whether this job could not be done more quickly, efficiently and economically by artificial methods. How this might be done will be considered later.

Where Sitka spruce is concerned we cannot be nearly so confident. Most of our Sitka on peat seems to be living a life only bordering on healthy. Most of it is still putting on height growth but possibly only under the influence of the initial impetus given by ploughing and phospate. In fact one rarely sees on deep peat a crop of Sitka spruce with that fully healthy glaucus appearance one gets on ideal Sitka sites on mineral soil. If he would only admit it the Irish forester's attitude to Sitka spruce on peat is much like that of Dr. Johnson to performing dogs—he is surprised not so much that it grows well, but that it keeps growing at all.

With present techniques of ground preparation and manuring the prospects of success in our peatland afforestation programme seems good, but it is not certain that we have reached the ultimate in such techniques. A very striking example of what can be achieved by intensive ground preparation is to be seen at Cloosh Valley, in South Connemara. A large area acquired here by the Forestry Division about 1950 contained some acres of deep peat which had been reclaimed about 1941. This, and adjoining unreclaimed ground was ploughed by Cuthbertson "P" plough and planted with Sitka spruce in 1952. The then standard dressing of 3 ozs. of basic slag per plant was applied. Both the reclaimed and the unreclaimed areas were treated exactly alike. The present position is this. On the unreclaimed area the trees are an average of 2.6 ft. high and in a state of almost complete check. The few remaining needles are chlorotic and many of the new shoots die back every year. On the reclaimed area, by contrast, the trees average 6.7 ft. in height, or over 2½ times the height of the others with current leaders of up to 30 inches and averaging about 18 on the good trees. Colour is very good, though not perfect, and over much of the area canopy has almost closed. The exact method of reclamation used here is not easily available from records but the method sems to have been as follows: Main drains 4 to 5 feet deep were first opened wherever necessary. Subsidiary drains 2½ ft. deep were then opened at intervals of one chain. These were left open for a time and then covered over leaving a channel at the bottom. The bog surface was then dug to a depth of 8 to 10 inches, left to weather for a while and then dug again. After this an application of 2 tons of burnt lime and 12 tons of local granite gravel per acre was given, although up to 20 tons of gravel may have been used in the later reclamation on the area with which we are now concerned. The ground was then rolled and treated with 2 cwts. sulphate of ammonia, 5 cwts. potash and 6 cwts. of ground mineral phosphate per acre. Either a grass clover mixture or a crop of potatoes was then sown.

A method such as this may sound completely out of the question as far as Forestry is concerned, but on this particular area it is abundantly clear that it has meant the difference between success and failure. It must also be remembered that this reclamation was intended for agricultural purposes and a less intensive and less expensive method might give equally good results in forestry.

At this stage brief reference may be made to the start which has been made in the experimental afforestation of cutover midland bog. In 1954 an area of 9½ acres was leased in Co. Offaly and planted the following Spring using 17 species. After seven seasons' growth the indications are that depending on the depth and type of peat remaining after cutting over, and the degree to which it is then mixed with the underlying mineral soil, it will be possible to grow valuable crops of pine, spruce or Douglas fir on these cutover bogs.

An account of the progress of peatland afforestation in the Republic of Ireland would not be complete without reference to its social impact. In its most simple and obvious form this is shown in the change in direct employment level in the counties where peatland afforestation is concentrated. Thus in the four counties Kerry, Galway, Mayo and Donegal, forestry employment between the years 1952 and 1960 increased by 69% whereas in the other counties the increase was only 27%. This difference is perhaps exaggerated by the fact that natural expansion of direct employment in the older established forest areas is somewhat reduced by the limitation of direct labour work on thinning and some other operations. Another and more important effect, although one which is less susceptible to assessment, is the effect on the inhabitants of the western counties when they see that large areas which formerly might as well not have existed except for the occasional grazing beast, are being put to gainful use. In the report of a one-man F.A.O. mission to Ireland in 1950 a separate social afforestation programme in the west of Ireland was proposed (F.A.O., 1951). This was to have as its main purpose the stabilising of employment by means of a capital investment which would pay its own operating costs, rather than unproductive investments such as road-building. In this programme, the planting of peatlands mainly, was envisaged. Although this was not adopted as a separate programme it is clear that the aims set out in the report are being achieved by normal development of afforestation following improved knowledge and experience.

Acknowledgement.

Grateful acknowledgement is due to the many members of the Forestry Division staff who provided much of the information contained in this paper, and for much helpful discussion and criticism.

References.

Anon., 1960. Annual Study Tour *Irish Forestry*, **17**, No. 2, 62.

Condon, Liam, 1961. The Progress of Deep Peat Afforestation in the North West. *Irish Forestry*, **18**, No. 1, 3-18.

F.A.O., 1951. *Report on Forestry Mission to Ireland.* The Stationery Office, Dublin.

Miller, H. M. S., 1957. Peat. *A View of Ireland.* British Association for the Advancement of Science, Local Executive Committee, Dublin.

Mooney, O. V., 1957. *Pinus contorta* in Irish Forestry. *Irish Forestry*, **14**, No. 2.

Roche, Laurence, 1961. The Lulu Island Provenance of *Pinus contorta. Irish Forestry*, **18**, No. 2.

Schlich, W., 1908. Report on the Knockboy Planation. *Departmental Committee on Irish Forestry. Minutes of Evidence, Appendices and Index.* H.M.S.O., Dublin, 328-331.

The Progress of Peatland Afforestation in Britain

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A high proportion of new afforestation in Britain is carried out on peatland. Any attempt to specify a figure immediately raises the question as to what is meant by 'peat'. It is very difficult to find any precise definition in spite of the detailed information about peat, on the one hand from ecologists and on the other from engineers. Recently the Soil Survey of Britain, in conformation with international usage, has described peat as an organic soil if over twelve inches deep, and peats below that depth as either peaty podsols or peaty gleys. This makes a convenient definition for foresters. Peat under a foot in depth is usually covered with heather (*Calluna*) or grasses (for instance *Molinia*) and with modern methods of ground preparation these peaty podsols or gleys are not usually a problem in establishing trees.

The twelve-inch limit is not necessarily a hard and fast one, but it is the most convenient depth at which to draw the line on the average. It is considered better than any definition based on the rooting depth of trees, as this can be varied by treatment.

The fen peats exceed a foot in depth, but they are usually in the hands of the agriculturists and are rarely a forest problem. Blanket, valley or raised bogs are all classified by foresters as the poor peats, 'poor' in the sense that they are too infertile to support vigorous *Molinia coerulea* and bear instead the Eriophoretum, Trichophoretum (Scirpetum) or Sphagnetum communities. In the Trichophoretum the scale of poverty is apparently related to the lack of vigour, or even in the last extremity the complete absence, of *Molinia.*

Early History.

Older writers on the afforestation of peat, e.g. Steele (1826) in Scotland, appear to have been concerned mainly with fen peat, and in spite of searches in the last ten years or more, none of their successful examples of afforestation have been found to be on poor peat, though they were sometimes marginal. It seems probable that where they overstepped the margin the plantations were not successful, though survivors may have remained alive.

Hence foresters have had good reason to believe that it was impossible to grow trees on poor peat successfully. James Brown (1861) remarked that "Moss (i.e. peat) land, even after draining, is found of a dull and inert character and not apt to give life and energy to the growth of useful plants:" and Boyd, as lately as 1918, after experience both at Corrour and at Inverliever in the west of Scotland, stated that no areas bearing *Scirpus,* (*Trichophorum*), *Sphagnum, Eriophorum* or *Narthecium* should be planted.

Turfing had been in use in Ireland in 1805, and on *Molinia* peats the Prussians and Belgians had developed a planting system based on turf planting and the use of phosphate, and this was adopted in Scotland at the beginning of this century (Stirling-Maxwell, 1907). The extension of these methods to poor peat commenced at Inchnacardoch forest in 1923 (Experiment No. 6), and in 1924 at the Lon Mor experimental area. This became an important centre for research on poor peat, while parallel experiments were carried out at Achnashellach, Glen Righ, Beddgelert and other forests. The results up to 1954 were published in Forestry Commission Bull. No. 24—Experiments in Tree Planting on Peat.

Choice of Species.

Many of the experiments were carried out with various species of spruce, because spruces are traditionally associated with wet sites, but they went repeatedly into check, and no suitable technique for raising any species of spruce was found. It is not difficult to grow Sitka spruce (*Picea sitchensis*) for a few years. When it slows up, application of compound N P K fertilizers may give remarkable effects, but we do not yet know how to do this efficiently. Only one plot has been brought to the crop stage, and in spite of applications of P, N, K and Mg, its growth is not continuing satisfactorily.

It is evident that pines are less demanding and easier to grow. Scots pine has been successful on sites that are climatically satisfactory for it, and mountain pine on exposed sites. But lodgepole pine (*Pinus contorta*) of many provenances grows best of all and is proving to be the most productive.

Many trials were made of numerous other species to find one specially suited to peat, but without great promise. More recently, Wood (1955) has emphasised that both *Pinus contorta* and *Tsuga heterophylla* are less demanding than the spruces in their native habitats, and recent experience in Britain is substantiating the conclusion that they are likely to be the most suitable trees to grow on peat. Search for an even more oligotrophic species than lodgepole pine has therefore been terminated. So has the attempt to grow other species by nursing with the pine, and clearly little is likely to be gained on peat by nursing to suppress heather, as on the more fertile Upland Heaths, also the problem is not basically one of providing shelter for a tender species. The larches, Japanese and hybrid, proved extremely sensitive to the absence of phosphate, but it is now becoming evident that, given adequate mineral phosphate, they have a lower requirement for nitrogen than Sitka spruce, the most successful species of spruce, so that, next to lodgepole pine and western hemlock, Japanese or preferably hybrid larch appear to be the most suitable species.

LON MOR EXPERIMENTAL AREA

Table

PRODUCTION DATA

Age	No. of trees/acre	Top Ht.	Mean Girth	Basal area	Volume (Estimated) Main Crop	Total	Periodic Ann. Increment		Mean Ann. Increment
		ft.	in.	sq. ft. q.g.	H. ft.	H. ft.	1953-55	1956-59	to 1959
Lodgepole pine		*Experiment 47 P.28*			(plots 3-6)				
31	770	37.8	17½	101.6	1,590	1,930	190	140	60
Lodgepole pine		*Experiment 52 P.29*			(2 replications)				
A.30	930	40.1	14½	82.2	1,460	1,680	170	130	60
B.30	1,050	36.8	14	81.7	1,280	1,500	140	110	50
Scots pine		*Experiment 19 P.26*			(plot 10)				
33	790	30	16	88.3	950	1,010	80	70	30

Expt. 47. Drained at 8 ft. and turfed. 6.3 cwt. G.M.P. per acre.

Expt. 52. A. Intensive draining, 12 ft. spacing, deepened, 5 cwt./acre phosphate.

B. Moderate draining, 18 ft. spacing, undeepened, 3½ cwt./acre phosphate.

Expt. 19. Groups of shallow turves. About 6 cwt. basic slag per acre.

Only if the necessity for heavy and repeated fertilization is accepted, and a reliable system of doing it worked out, might it be desirable to determine the kinds and amounts of fertilizers necessary to grow Sitka spruce, with a view to comparing the production of spruce and pine in cubic feet of timber per ton of fertilizer, on a cost basis.

In the past, lack of knowledge about the timber quality of lodgepole pine and the attempt to use it as a nurse for other species has resulted in the establishment of many mixed crops in which the nursed species is proving a failure. This results in the effective spacing of the pine nurse being much greater than normal, so that the trees grow coarse and branchy. Especially is this the case with the most vigorous provenances of coastal lodgepole pine, so that an attempt is now being made to establish pure crops of both coarse vigorous and finer less vigorous provenances of pine with a view to the determination of the productive potential of lodgepole pine under normal forest conditions.

Fertilization.

Problems of nutrient supply have already been dealt with in earlier papers, but there are some practical points about the application of fertilizers which require mention. It seems likely that repeated applications will be necessary, and if that proves to be the case, it is not improbable that aerial application may come to be normal practice. But at present, applications of phosphate at the start can now be done with a considerable reduction in cost by a machine attached to the plough—a hopper fitted with an archimedean screw and agitator feeding ground mineral phosphate through a hose pipe into the vegetation layer between ground surface and plough ridge as the ridge turns over and upside down.

The efficacy of machine application has been tested by simulated hand applications in 1952, and as the results from a stream of G.M.P. under the plough ridge have proved satisfactory, the machine has been developed by the South Scotland Conservancy and Messrs. Clark of Parkgate. This means that we are reverting to the old practice of putting the fertilizer under the turf. Problems of how and where to put the fertilizer round the plant after planting, and also of damage to plants by application of fertilizer too soon after planting are thus eliminated.

Perhaps the chief objection to placing the fertilizer in a strip under the ridge is thought to lie in the danger that it might accentuate root development along that line. It was long ago noted that tree roots tended to exploit the turf before spreading out into the peat, and that with ploughing there is a serious danger that roots might be concentrated in a line along the plough ridge and furrow (Zehetmayr, 1954). Excavations in 9 year old small lodgepole pine and in the oldest (16 year) lodgepole pine planted on Cuthbertson ploughing have confirmed that this does in fact happen, though roots have also been found to cross shallow furrows filling up with litter. Though phosphate stimulates the growth of the root system greatly, there is no evidence to suggest that applying it in any particular position affects the direction of root development.

The use of basic slag was superseded by ground mineral phosphate in the war-time when high quality basic slag was unavailable; and as the P (or P_2O_5) content of the G.M.P. is greater, and the total weight of material to be applied less, it has retained its place. In some areas a change has been made to superphosphate or triple superphosphate, which has reduced the weight of material to be applied. There is no doubt that on a short-term view the critical factor is the amount of P, and that the form in which it is applied is less important. But on the long-term view the non-phosphatic content of the fertilizer may be of importance, either the Ca, trace or other elements, and in the absence of proof on this matter, many foresters still continue to use G.M.P.

Ground Preparation.

The modern method of ground preparation on poor peat, as described by Zehetmayr (*ibid,* p. 29) consists of two turf ridges from a single-furrow double-mouldboard plough alternating with deep single-furrow plough drains. Alternatively continuous double-mouldboard ploughing crossed at intervals by single-furrow plough drains was suggested. However, it has been found in practice that the early growth of trees is generally faster on the deep ridges produced by an S.F. plough than on the wide, shallow ridges produced by a D.M.B. plough, and it is easier to use only one kind of plough on a bog, with the result that continuous S.F. ploughing has often been carried out in practice. Under the former system the drains are spaced at approximately 17 ft. whereas in the latter the deep S.F. drains are at approximately 5 ft. to 6 ft. intervals. Clearly in this case not all the furrows are expected to continue as permanent drains, and the question of ultimate drain spacing is left undetermined.

As already mentioned, there is evidence that the roots tend to follow the line of the ridges, and that though they will cross furrows which fill up, they are unlikely to cross permanent drains. In fact such roots would be a source of future trouble if they were allowed to cross. Thus it appears that maximum early growth resulting from draining, the application of phosphate and the subsequent rapid mineralization of nitrogen is obtained with deep closely-spaced drains, but maximum stability of the future crop is likely to be obtained with widely-spaced drains, between which complete cultivation is desirable to allow roots to spread horizontally in all directions.

In depth roots will go down to a level approximating to that of the bottom of the drains and sometimes lower. The precise level is a matter about which we have little knowledge and it obviously depends on the range of influence of drains (according to their depth and spacing) on

the water-level in the peat between them. No doubt this depends to a great extent on the rainfall, both annual and in its distribution over the year, and also on the characteristics of the peat itself. In Norway the depth at which the water lies in the growing season is measured but in Britain the level in winter is thought to be critical in determining rooting depth. Finally, though the trees may be limited by the actual water level when they are young, as the crop matures and transpiration increases the trees may themselves determine, to some extent, the level of the water. Tree species apparently differ in their capacity to root deeply and there is evidence that small lodgepole pine may be able to root below the level of the drain depth, whereas Scots pine does not root so deeply (Binns, 1959).

It appears to be possible for a tree crop on a bog to suffer from drought, at any rate in a dry season. (See Forestry Commission Annual Reports 1955-56 to 1958-59). Overdraining may be expected to lead to a reduction in the nitrogen supply, and if severe, perhaps to irreversible changes in the peat. Though regulation of water level by blocking drains might be valuable, ceasing to cut drains which are not really necessary would be better.

Thus, there is a case for keeping the drains as wide apart as possible as is consonant with the successful establishment of the crop, and it will be better if drain-spacing is determined for the needs of growth and stability when the trees are tall, rather than for quick establisment in youth.

The functions of drainage and cultivation need separate consideration. Drainage may be considered as the removal of water from the mass of the peat by gravity, and although it is known that the effect of a drain in a mass of peat is limited at first, it may extend in time. Cultivation may be considered as the superficial breaking down of the peat to allow of aeration, the mobilization of nutrients, penetration of tree roots and inversion and suppression of the pre-existent vegetation. It is thought that complete cultivation should be reconsidered in the light of developments in modern machinery, in spite of the fact that as recorded by Zehetmayr (*ibid.* p. 30) it proved a failure in 1945. However, it may be that as at present the product of the double-mouldboard plough will have to be accepted in place of complete cultivation.

The problem then is how to drain away the moisture released either by the complete or the double-mouldboard ploughing in the early stages and from the site as a whole later on when the double-mouldboard ploughing becomes blocked by litter and tree roots. It is suggested that this should be done by means of a secondary draining system cut by the S.F. plough (either normal Cuthbertson or deep-going pattern) working at a suitable gradient into which the D.M.B. furrows or equivalent shallow drains between bands of complete cultivation would discharge. There is some evidence that the secondary draining system should work on a gradient of about $\frac{1}{2}°$ or 1 :120. The spacing of these drains should be adequate to remove surplus water later on when the tree crop is transpiring freely in times of maximum rainfall, conversely it may be found desirable to restrict the flow during dry periods. No trees would be planted on the ridges beside the drains which would be kept clear so as not to hinder drain cleaning. Access rides or roads would normally lie on one side of these drains.

The secondary draining system would discharge into an arterial draining system, which on blanket bog normally exists in the form of streams or gullies, though the latter may need to be opened by ploughing. On raised or valley bog, the main drainage system must needs be artificial and may often have to follow the line of maximum gradient, often much less than 1 : 120. These main drains must be large deep ditches, and hitherto they have not been constructed in forest practice in Britain. Such deep ditches are however common where bogs are being drained for agriculture, and they are also the basis of forestry practice in Northern Europe and Russia.

Steele (1826) gave a good description of such draining in the west of Scotland. His drains were 8 ft. wide at the top, 2½ ft. wide at the bottom and 4½ ft. deep, apparently spaced at about 8 to 10 chains. Between the drains, strips of complete cultivation 18 to 21 ft. broad were divided by secondary drains 2 ft. wide. The depth of these were "regulated to dry the moor enough but not too much."

In short, it appears that although we have developed a method of ground preparation which ensures the rapid establishment of a tree crop, we are by no means satisfied that it is the best method in the long run. In matters of draining, as well as cultivation, nutrition and choice of species, we have evidently a great deal to learn before we can claim to have solved the problem of maintaining productive forests on deep poor peat.

General Practice.

In general practice, on the basis of the results obtained to date, afforestation of poor peat mosses is going ahead on a small scale. As a rule only bogs contained within areas of better ground are planted and sometimes fertilizer is applied at a specially high rate (e.g. 3 cwt. G.M.P. per acre). Attempts to raise mixtures of species are now less frequent and lodgepole pine either pure or with a small admixture of other species, possibly Japanese or hybrid larch or *Tsuga* rather than Sitka spruce, is planted.

In order to gain more information than can be obtained from small trials, several trial forests are being set up in the North of Scotland where blanket bog is the prevailing formation. These will be managed by the local staff and not by the Research Branch, and they will be used to apply the latest experimental results under normal conditions of management with a view to determining the possibilities and value of forestry on poor peat.

References.

Binns, W. O., 1959. The physical and chemical properties of deep peat in relation to afforestation. (Thesis, University of Aberdeen).

Boyd, John, 1918. *Afforestation.* W. & R. Chambers, Edinburgh, p. 89.

Brown, James, 1861. *The Forester.* 3rd edn. Edinburgh, p. 539.

Steele, A., 1826. *The natural and agricultural history of peat-moss or turf-bog.* Edinburgh, p. 45-7.

Stirling-Maxwell, Sir John, 1907. The planting of high moorlands. *Trans. Roy. Scot. Arbor. Soc.* **20.** (1-7).

Wood, R. F., 1955. Studies of North-west American forests in relation to silviculture in Great Britain. *Bull. For. Comm.*, Lond. **25.**

Zehetmayr, J. W. L., 1954. Experiments in tree planting on peat. *Bull. For. Comm.*, Lond. **22.**

Society's Activities

Illustrated Lecture in Dublin

AN illustrated lecture delivered by Dr. Mooney on the "Vegetation of Ethiopia", was held in the Shelbourne Hotel, Dublin on the 9th December, 1961.

With excellent slides he described the different vegetation belts, ranging from semi-desert to rain forest.

The main types he outlined, in a country which consists of a low-lying coastal plain to the east and a high plateau to the west, were semi-desert, savanna, evergreen scrub and bamboo in the low lands changing to evergreen montane forest and high level bamboo as altitude increased, and followed at still higher elevations by Afro-alpine vegetation. Also described were the rain forest, gallery forest and sand dune belts, which are indigenous to Ethiopia.

Among the many intersting plant species mentioned were junipers, African box and eucalypts, members of the evergreen scrub vegetation; *Podocarpus,* pencil cedar, African olive, giant lobelia, *Erica arborea* (giant heath), of the evergreen montane forest and giant groundsel and the more familiar *Deschampsia, Festuca* and *Poa* species of the Afro-alpine vegetation belt. Tree ferns, palms, mangroves, blue gum and *Salix* species were mentioned with regard to the rain and gallery forests.

Dr. Mooney also referred to the potentialities of bamboo for paper manufacture, and the valuable commercial timbers to be found in the rain forests.

The President, Professor Clear, brought the evening to a close by complimenting the speaker on his interesting lecture and proposing a vote of thanks.

G.J.G.

Illustrated Lecture in Sligo

A meeting of the Society of Irish Foresters took place in Sligo on the 3rd February, 1962. To a packed house in the Imperial Hotel, Mr. O. V. Mooney gave a lecture with slides. The title of his talk was "Austrian Recollections". The material for the lecture was gathered by Mr. Mooney, when he and Mr. S. M. O'Sullivan were delegates for this country at the 13th Annual Congress of the International Union of Forest Research Organisation at Vienna. Delegates from 39 nations attended the Congress.

The tour, starting in Vienna, covered a large and representative area of the country. We were shown many aspects of forestry in Austria, where timber and its by-products are a major industry.

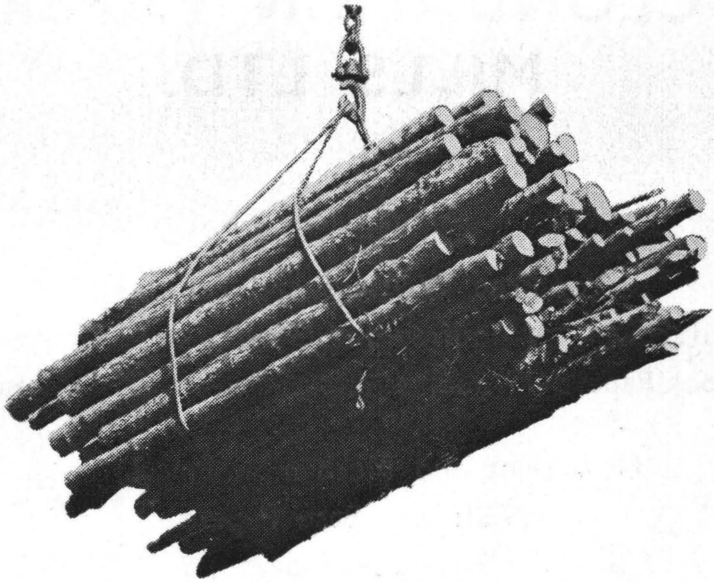
Forestry not only brings wealth to the state, but it also provides a livelihood, in conjunction with agriculture, for thousands of farmers and small holders. Small privately-owned forests are, in fact, the largest area under timber in the country, at 52% of the total.

We were shown the problems of afforestation in the Pannonian Lowlands, a large expanse of flat unbroken plain with very alkaline soils that militate against efforts to establish a forest crop. We saw slides of the Vienna Woods, situated on the heights and valley slopes of a ridge of low mountains just outside Vienna. Here, we were told, the main emphasis was on selection high forest. Oak and beech in mixture with *Abies alba, Picea abies* and *Larix europaea* form the selection. Prime stems for veneer was the ultimate aim.

We were shown many aspects of farm forestry in the Tyrol and other areas. Over the years many of these farms had degenerated to a sorry state. This, we were told, was primarily due to poor access to the farms and consequent lack of development. A form of shifting cultivation, often practised, was also blamed for soil deterioration. These and other problems of the hill farm-forest were demonstrated and also some methods that had been adopted to try and improve matters.

Many questions followed the lecture and finally the Vice-President, Mr. McNamara, thanked the speaker and closed the meeting.

M.J.S.



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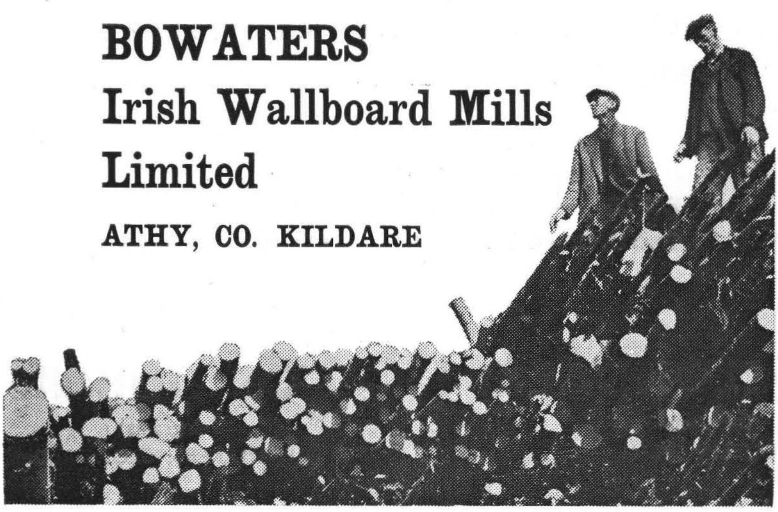

The Earlsfort Press Ltd., 85 Harcourt Street, Dublin.